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TECHNOLOGIES FOR INTEGRATED RIVER BASIN MANAGEMENT

TECNICHE PER LA DIFESA DEL SUOLO E DALL'INQUINAMENTO

A cura di

GIUSEPPE FREGA & FRANCESCO MACCHIONE

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Technologies for Integrated River Basin Management

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HYDRO-MORPHIC ANALYSIS OF URBAN BASINS CHANGES AND HYDROLOGICAL RESPONSE ASSESSMENT: THE CASE STUDY OF THE CITY OF MATERA

LETTURA IDRO-MORFICA DELLE TRASFORMAZIONI OPERATE NEI BACINI URBANI E VALUTAZIONE DELLA RISPOSTA IDROLOGICA: IL CASO STUDIO DELLA CITTÀ DI MATERA

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ABSTRACT ESTESO

La lettura dell'evoluzione delle città è cruciale al fine di tracciare una visione idrologica dei territori e della loro sostenibilità in quanto le morfologie e la loro interrelazione con gli aspetti urbanistici e architettonici regolano i processi idrologici che concorrono alla formazione del deflusso a partire dalle precipitazioni meteoriche. Il presente lavoro ha assunto un approccio metodologico che adotta l'analisi idromorfica delle trasformazioni operate nei bacini urbani e la valutazione della risposta idrologica applicato alla città di Matera (Italia), dove l'edificato del suo centro storico (Sassi) si è evoluto come un complesso ecosistema urbano che intreccia il tessuto abitativo e le infrastrutture idriche di raccolta, stoccaggio e drenaggio. Negli ultimi anni, invece, si è assistito ad una significativa trasformazione della città che ha causato frequenti eventi di inondazione dovuti ad eventi estremi di precipitazione. Infatti, i cambiamenti profondi in termini idromorfici dei Sassi e delle zone a monte di essi hanno provocato alterazioni morfologiche (urbanizzazioni delle colline e del piano), modifiche dei reticoli idrografici (coperture dei Grabiglioni) e modifiche locali delle capacità di intercettazione (abbandono delle cisterne), oltre ad alterazioni superficiali conseguenti alle opere di urbanizzazione e alle infrastrutture stradali. Il presente studio si è proposto di esaminare gli impatti a scala di bacino di queste trasformazioni analizzando, nel tempo, le variazioni subite dai deflussi superficiali in conseguenza di differenti assetti urbanistici attraverso (i) la lettura delle componenti morfologiche del territorio (al fine di individuare le situazioni di criticità idrologica) e mediante (ii) l'utilizzo di modelli di simulazione idrologica e idraulica per stimare quantitativamente e in modo distribuito la risposta idrologica del bacino e la vulnerabilità del territorio. In particolare, lo studio ha condotto delle simulazioni idrodinamiche adottando diversi modelli bidimensionali e cioè FLORA-2D e LISFLOOD-FP. I risultati ottenuti con i diversi schemi di calcolo appaiono coerenti con le osservazioni dirette di eventi passati ottenute da immagini/video e tendono a convergere all'aumentare della tolleranza (differenza dei tiranti idraulici). FLORA-2D risulta più adatto a scopi di pianificazione poiché, a differenza di LISFLOOD-FP, consente la variazione spaziale della permeabilità delle diverse aree assegnando ietogrammi differenziati della pioggia efficace. Quindi, si è scelto FLORA-2D per quantificare le criticità e la variazione dei deflussi in scenari di urbanizzazione relativi all'anno 1954 (urbanizzato concentrato nei Sassi e nel centro) e 2019 (espansione urbana e impermeabilizzazione, soprattutto nella parte di monte). Le analisi hanno individuato le aree più soggette a fenomeni alluvionali ed evidenziato legami tra le parti di monte e di valle del bacino urbano, osservando incrementi significativi delle portate nella rete stradale e nelle aree più a valle anche laddove non sono stati operati aumenti dell'urbanizzazione (aree già sature). Tale visione assegna a tutti gli elementi un ruolo strategico-funzionale per l'equilibrio complessivo che supera canoni estetici o di vincolo, come ad esempio le aree verdi o periferiche avrebbe potuto assume il ruolo di protezione delle parti di valle, sovvertendo il ruolo ricreativo o di marginalizzazione a cui sono tipicamente relegate. La metodologia proposta può leggere le aree urbane e interpretarne l'evoluzione partendo da una visione idrologica per proteggere i territori dai rischi idraulici e incrementare la sostenibilità dello sviluppo dell'ambiente costruito, valutando in modo rigoroso e consapevole gli impatti di interventi passati e futuri.

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ABSTRACT
The evolution of cities is important for tracing a hydrological vision of the territories and their sustainability as urban morphologies and uses regulate the rainfall-runoff processes. The analysis of water fluxes in urban areas under different conditions assess the hydrological response, the hydro-morphic features and their interrelation with urban, architectural or administrative characteristics. This study presents an approach for hydro-morphic analysis of urban basins changes and hydrological response assessment applied to the city of Matera (Italy). Matera - especially the Sassi - represents an ideal case study: in its history it evolved as a complex urban ecosystem of dwellings and water infrastructures for collection, storage, and drainage, whereas in recent years the city transformation led to frequent urban pluvial flood events. The study adopted for hydrodynamic simulations different two-dimensional models: an adapted version of FLORA-2D and LISFLOOD-FP with three numerical schemes (Acceleration, Flow-Limited and Roe). The study included the estimation of hydraulic hazard for extreme precipitation in urban areas with the FLORA-2D model, the evaluation and the comparison of the characteristics and performance of the hydrodynamic models. FLORA-2D results were consistent with flood events observations. LISFLOOD-FP with the Acceleration scheme provided results similar to FLORA-2D and required shorter simulation times. The LISFLOOD-FP schemes tended to converge with FLORA-2D with greater depth tolerance thresholds, so they can offer useful alternatives for some cases. For large areas, the Flow-Limited scheme could be preferred because of its reduced computational times. FLORA-2D appears the most suitable for planning purposes as it allows permeability spatial variations by using differentiated effective rainfall hyetograph whereas LISFLOOD-FP input hyetograph can variate only over time. The choice of simulation model will depend on the characteristics of the study (purposes, area of interest, data available, desired computational time). In light of this, FLORA-2D was used to evaluate the hydrological response thus the hydrological impacts of urban basin changes by calculating the hydraulic invariance index. The analysis of two urbanisation scenarios (1954 and 2019) allowed to identify the urban areas more prone to flooding phenomena, coinciding with road network and downstream areas. The proposed methodology can be used effectively to read the urban areas and interpret their evolution to protect the territories from water-related risks and to increase sustainability of built environment development, evaluating the hydrological impacts of past or future interventions.

1. Introduction

Understanding the morphological evolution of cities is important not only for historical knowledge but also for tracing a hydrological vision of territories to recognize and evaluate the impacts and sustainability of urbanization and other transformations of the natural landscape. Urban morphologies regulate the rainfall-runoff processes, so the alterations of hydrologic regimes over time at urban scale can describe the changes and evolution of the considered basins. Analysing the water fluxes in urban areas, starting from their natural condition (absence of urbanization), it is possible to identify their fundamental hydro-morphic characteristics (extension, permeability, slope, etc.), morphological relationships and their interrelation with urban, architectural or administrative characteristics.

The urbanization transformations that affect directly or indirectly the conformation of the urban basin and the stream network (thus influencing the surface flow dynamics and the hydrological response) involve physical transformations of the basin characteristics: shape (perimeter, area, slope), permeability, stream patterns. We can identify three main categories of transformations: 1) Areal modifications: affect the basin conformation, modifying its geometry or permeability; 2) Linear modifications: affect the stream network morphology within the basin; 3) Punctual modifications: affect locally the stream network, modifying circumscribed areas ("points") within the basin.

This study presents an approach to analyse the surface water flows within a portion of the territory to assess the efficiency of the urban forms and the hydrological response over time. The methodology was applied to urban basins in the city of Matera (Basilicata, Italy).

Hydro-morphic analysis of urban basins changes and hydrological response assessment can be used as diagnostic tools for water-related risk protection, sustainability and urban livability or as support tools for infrastructure and urban planning, nature-based solutions and development policies. In this sense, such studies help to build more resilient cities with a hydrological processes sensitive approach, addressing the United Nations Sustainable Development Goals: *#6 Ensure availability and sustainable management of water and sanitation for all, #9 Build resilient infrastructure, promote sustainable industrialization and foster innovation, #11 Make cities and human settlements inclusive, safe, resilient* *and sustainable, #12 Ensure sustainable consumption and production patterns, #13 Take urgent action to combat climate change and its impacts* and *#15 Sustainably manage forests, combat desertification, halt and reverse land degradation, halt biodiversity loss.*

2. Material and Methods

2.1 The case study: the city of Matera

The Matera municipal area is located in the East of Basilicata region in Southern Italy, covering about 390 km², bordering the Apulian municipalities of Altamura, Gravina in Puglia, Santeramo in Colle, Ginosa and Laterza, and the Lucanian municipalities of Montescaglioso, Miglionico and Grottole. It is placed at the border between Murge plateau and Bradanica pit, presenting the characteristics of both formations. The north-western part has a flatter conformation, with gentle hilly slopes, while the rest presents the typical characteristics of inland areas with river depressions delimited by modest reliefs.

Matera urban area (60.459 inhabitants) occupies a hilly area at about 400 m above sea level. It has an elongated and discontinuous shape that straddles the hills and interacts with the two watercourses to the east and west (Gravina di Matera and Gravina di Picciano streams) which, in the southern part of the territory - further downstream from the San Giuliano reservoir - flow into the Bradano river, which then continues its course until the Gulf of Taranto. The urbanised area includes several nuclei that arose in different eras: the original nucleus of the Sassi Barisano and Caveoso, the Piano, the consolidated city, the rural villages of La Martella and Venusio, and the areas of industrial expansion.

Water played an important role in driving urban evolution of Matera as testified by historical systems for water collection, storage, drainage (Ermini et al., 2010; Laureano, 2012; Manfreda et al., 2016) that evolved across successive urban ecosystems via adaptations over the centuries.

The first nucleus of the built-up area of Matera (the Civita) was built on a rocky spur jutting out with steep walls into the Gravina. This spur rises at the confluence of the Jesce stream. To the east it overlooks the Gravina torrent, with a difference in height of about 100 m., while to the north and south it is flanked by two torrential incisions called Grabiglioni. The morphological conditions and the presence of the calcarenite bank favoured the formation of the two rocky villages of the Sassi.

The first settlements developed as dwellings excavated (sub-horizontal caves) and partially built using the blocks of calcarenite excavated, creating a structure of overlapping steps for water collection. As time went on, the morphology evolved along with water infrastructures as a complex system of dwellings, neighbourhoods, hanging gardens, stratified terraces and streets. Collection, storage and consumption systems ensured the regulation of surface and sub-surface waters by combining the principles of capture, distillation and condensation. In this way, an integrated system of canals and storage cisterns guaranteed the protection of the dwellings from surface runoff and, at the same time, the supply of precious water resources for the subsistence of the settlement.

Next to the Civita, the Sasso Barisano and the Sasso Caveoso developed around the two deep incisions (Grabiglioni), adopting residential structures made up of superimposed terraces.

In their progressive integration with the Civita, which can be considered fully realised between the 15th and 16th centuries, the Sassi gradually shaped as a city functionally organised according to the site orography. Until the 17th century, Matera was significantly characterised by the two-way relationship between the Sassi and the Piano. In the 17th century the first significant expansion of the town took place beyond the Sassi, while in the following two centuries the physical and social separation between the two parts of the town became increasingly accentuated. The Piano became the seat of ecclesiastical and governmental structures and the residence of the bourgeois and aristocratic classes, whereas the Sassi saw the beginning of their decline, which became more marked in the 20th century, with the rapid demographic growth of peasant population that was increasingly marginalised with the regard to the political and administrative life of the city.

At the beginning of the 21st century, after the visit of Prime Minister Zanardelli, special measures were established in favour of the Basilicata province and Law 140 of 1904 was approved, with which the Ministry of Public Works and the Civil Engineers drew up a plan for the rehabilitation of Matera. The plan, by intervening in the Sassi Barisano and Caveoso, provided for:

- clearance and demolition of the unhealthiest areas, construction of new districts in more suitable locations and relocation of the resident population;

- covering and lining of the open-air rain and wastewater canals Barisano and Caveoso to transform them into sewage collectors, building access roads to the Sassi and extending the road network to the upper part of the city;

These interventions (carried out in subsequent years, 1915: covering of the Barisano and 1927: covering of the Caveoso) improved the accessibility of the two districts but significantly altered the dynamics of the surface flows of the basins in which the Sassi are included.

The post-World War II period determined a new demographic context and additional housing needs. Levi brought to national attention the dwelling issues of the Sassi. The leader of the Italian Communist Party Togliatti visited Matera in 1948 and defined the unhealthy environments as "national shame". A few years later, De Gasperi, founder of the Christian Democratic Party and first Prime Minister of the Italian Republic, declared that evacuating and resettling Materan peasants was a national priority.

The anthropological, sociological, and urban debate stimulated the government to implement a rehousing program for Matera's cave dwellers in 1952. As a result, the Sassi were gradually emptied and the population was rehoused. A process of socio-economic and urban planning regeneration, the Risanamento, led to new districts and purpose-built rural villages designed by prestigious exponents of contemporary Italian Neorealist Rationalism current.

Sassi restoration began in 1980s. In 1993, UNESCO granted The Sassi and the Park of the Rupestrian Churches of Matera World Heritage status. The city was a European Capital of Culture in 2019.

Nowadays the city suffers from recurrent urban flooding triggered by intense rainfall, which demonstrate the change in the contemporary water-soil-urbanization balance: the ancient infrastructures don't serve their original function of water regime regulation, e.g. the Grabiglioni were closed (Figure 1) with the arrival of the sewerage system, becoming the access routes to the Sassi.

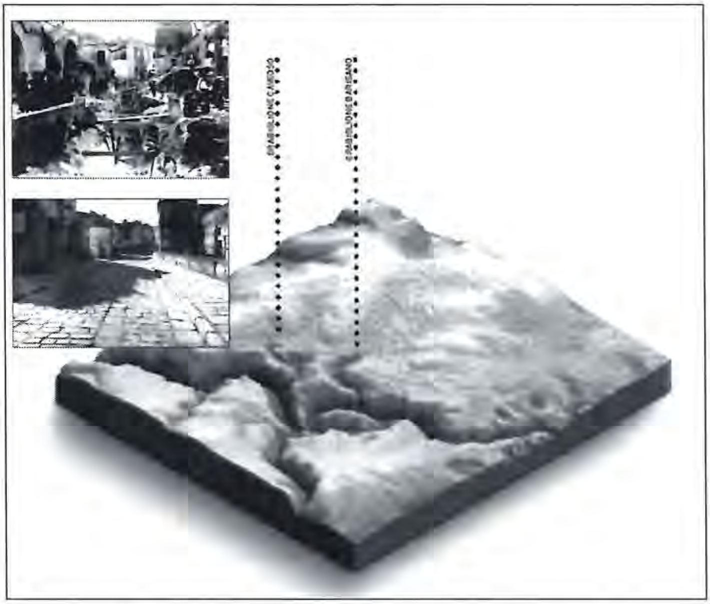

Figure 1 - 3D representation of The Sassi and Grabiglioni morphology and hystorical pictures *of Gabriglione and its closure*

Fig. 1 - *Rappresentazione tridimensionale della morfologia dei Sassi e dei Grabiglioni: e fotografie storiche del Gabriglione e della sua tombatura*

Thus, Matera - especially the Sassi - can be considered as an ideal case study to investigate the dynamics between urban sub-basins and meteoric water through hydro-morphic analysis and hydrological response assessment to understand past evolution and define future interventions.

2.2 *Methodology*

The present work aims to analyse the urban area of Matera from a hydrological point of view; thus, it was subdivided it into hydrographic basins – hydrological units not coinciding with urban planning units - as the hydraulic hazard doesn't impact on a single point but affects all elements that make up the whole study area. The representation by urban basins allows to read the territory by understanding the patterns of relationship between the contexts examined, their urban development and connections through the flow paths of precipitation.

Over the last few years, Matera has experienced a significant increase of vulnerability as a consequence of its hydro-morphic transformations (Figure 2) and has been affected by intense rainfall events that have caused significant inconvenience to the population and various damages.

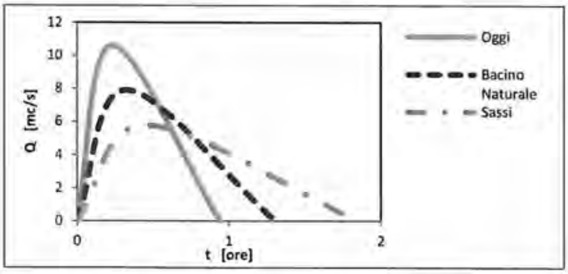

Figure 2 - Barisano Grabiglione runoff hydrograph comparison for different urbanization scenarios: natural basin, urbanization of Sassi, urbanization of areas upstream of the Sassi (current situation)
Fig. 2 - *Idrogrammi di piena del Grabiglione del Barisano per diversi scenari di urbanizzazione: bacino naturale, urbanizzazione dei Sassi, urbanizzazione a monte dei Sassi (situazione a oggi)*

Simulations with a two-dimensional hydraulic model are important in urban areas whenever the return period of precipitation exceeds the design time of the drainage system. In fact, urban drainage systems often fail during heavy rainfall events for several reasons, such as: original design return periods not particularly high (e.g. Tr=10 years); addition of new drainage capacity to the network without an overall adaptation strategy; increase of flow rates due to the soil impermeabilization (e.g. as a consequence of increasing urbanization, changes in land uses, etc.) or due to more intense precipitation events stemming from climate change. In all cases of hydraulic overload of the drainage networks, a two-dimensional hydrodynamic model allows to evaluate and map the critical flood characteristics: extent of the floodable areas, water depths, and velocities.

The most recent calamitous event occurred on 12 November 2019, when water and mud penetrated the houses, flooding the lower floors and interrupting traffic in several places. Not having insitu measurement data we adopted the two-dimensional hydrodynamic models FLORA-2D (Cantisani et al., 2014) and LISFLOOD-FP (Bates, 2010) for hydrodynamic simulations. The results of the simulations were compared to evaluate different operational procedures and tools for flood management for purposes of forecasting and warning as well as territorial planning support.

The FLORA-2D model, which use a simplification of the shallow water equations where the convective terms are assumed negligible, was originally developed to simulate flood propagation across floodplains considering the spatio-temporal variation of roughness according to vegetation characteristics. It was adapted to the case of urban pluvial flood by including the possibility of receiving as input effective rainfall hyetographs that vary spatially with the type of land cover.

The LISFLOOD-FP model includes numerical schemes that simulate the flood propagation using simplifications of the shallow water equations differing by the terms considered, so its application can adapt to the data available and the purposes of the study (e.g. desired time of execution). In Matera case study we tested three numerical schemes: Acceleration (shallow water terms included: friction and water slopes, local acceleration; terms assumed negligible: convective acceleration); Flow-Limited (shallow water terms included: friction and water slopes; terms assumed negligible: local and convective acceleration); Roe (shallow water terms included: all).

Matera urban area was divided into five sample hydrographic basins. The delineated watersheds were used as masks to clip a 5 m resolution digital terrain model (DTM), publicly available on the cartographic portal of the Region Basilicata (RSDI), into the basin areas.

For a more realistic representation of the anthropogenic elements that have altered the hydrological and hydraulic response of the historic centre of the city of Matera (the Sassi), characterized by a very high density of dwellings, the DTM has been upscaled from 5 to 2 m resolution with details retrieved from the Regional Technical Map. On the basis of the soil permeability derived from land use, the areas pertaining to the hydrographic basins considered have been divided into three types with different Manning coefficient: the attributed values were 0.11 $s/m^{1/3}$ for pervious areas, 0.06 $s/m^{1/3}$ for semi-pervious areas and 0.05 $s/m^{1/3}$ for impervious areas. The different soil absorption coefficient Curve Number (CN) assigned were respectively 74, 86 and 98. Buildings and road footprints were classified as impervious areas, while sports, parking and pedestrian areas were classified as semi-pervious areas; all land use categories not included in the previous classification were considered pervious. For simplicity and for the sake of safety, considering the short duration of the peak flow in urban areas (e.g. of the order of tens of minutes), together with the steep slopes and the limited capacity of the sewer network, the contribution of the sewer network to drain and the ability of the buildings to absorb water volumes was assumed to be negligible. The design rainfall to input in the FLORA-2D model was computed using different Chicago hyetographs of gross rainfall for different return periods (2, 5, 10, 15, 20, 25, 30, and 50 years), the corresponding hyetograph of effective rainfall were subsequently obtained for the different CN values relating to the different permeability characteristics. In the LISFLOOD-FP model, unlike the FLORA-2D model, it is not possible to insert a different hyetograph for each land cover type, so it was used a single hyetograph averaged over the entire study area according to the permeability characteristics.

The various simulations were evaluated through a cell-by-cell comparison: each cell with significant inundation depth obtained from the FLORA-2D model was compared with its corresponding cells with water depths obtained from the numerical schemes of the LISFLOOD-FP. The idea is to verify whether all the simulations identified coinciding critical points, since the FLORA-2D model has proven to be effective for inundation depth and extent estimation in several studies, e.g. for the Bradano river mouth case (Scarpino et al., 2018). Hence, the differences in terms of maximum water depths between the maps produced by the LISFLOOD-FP model calculation schemes and those by the FLORA-2D were calculated for the basins of interest and for three reference return periods (5, 20 and 50 years). The statistical test was carried out as a binary classification case, considering as positive class the values falling within pre-set intervals.

3. Results

The effects of precipitation events - in terms of water depth, speed and flow rates - obtained from the FLORA-2D model locate the highest flood hazard points in correspondence of the streams that convey the waters towards the basin outlet and of the circumscribed low-lying areas. Such results are consistent with the direct observations from photographs and videos of flood events showing worst-hit areas. The correspondence between the areas most affected and/or damaged by flooding and the highest hazard areas identified by the model allow us to assume the FLORA-2D results as a ground-truthing for evaluating the performances of LISFLOOD-FP model. Figure 3 shows an excerpt of the results obtained from the simulation of the event of 12 November 2019.

The LISFLOOD-FP model showed different results in terms of maximum water depths and velocities, depending on the numerical scheme used. The degree of similarity between the results of the LISFLOOD-FP numerical schemes (i.e. Acceleration, Flow-Limited and Roe scheme) and the FLORA-2D model varies according to the return period of the rainfall and the maximum water height difference considered significant. However, the localization of the highest hazard areas is comparable to the localization obtained from the FLORA-2D model. In order to analyse the compatibility between the results of the different numerical schemes of the LISFLOOD-FP model and the FLORA-2D model, histograms were produced showing the percentage of cells for which the water depth difference is less than a threshold value, indicated in the abscissa (Figure 4).

It is apparent from the results that the tool choice depends strongly on the purposes of the analysis and the specific case. For example, for civil protection purposes in flat areas, we can assume that the flow velocity is close to zero so that the urban flood hazard for an individual of average height can be assessed by relating the water height alone to the body parts reached: in this case the tolerable uncertainties on the water height are greater than in cases where the water velocities are not negligible and can aggravate the hazard, generating loss of stability due to phenomena of dragging or overturning (Russo et al., 2013).

Figure 3 - Extreme rainfall event simulation: Envelope of maximum water depths obtained from the FLORA-2D model (event of 12 November 2019), situation of Piazza Vittorio Veneto and images related to the event considered in the same area

Fig. 3 - *Inviluppo dei massimi tiranti della simulazione mediante FLORA-2D di un evento di precipitazione estrema comparabile con l'evento del 12 novembre 2019, situazione di Piazza Vittorio Veneto e immagini relative all'evento considerato nella stessa area*

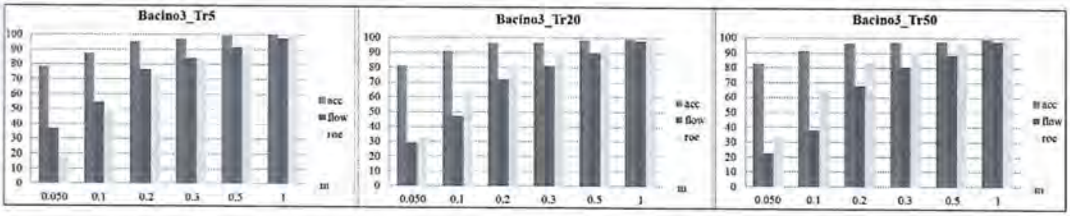

Figure 4 - Models comparison: Histograms referring to one of the urban basins for return periods of 5, 20 and 50 years

Fig. 4 - *Confronto dei modelli. Istogrammi relativi ad uno dei bacino urbani per tempi di ritorno pari a 5, 20 e 50 anni*

By balancing accuracy and calculation time, LISFLOOD-FP model with the Acceleration scheme can represent a good alternative to the FLORA-2D model, as it provides similar results and requires shorter simulation times. The three numerical schemes of LISFLOOD-FP gradually tend to converge with FLORA-2D with increasing of the tolerance considered, so all of them can offer useful alternatives for some cases. However, when analysing large areas, the Flow-Limited numerical scheme could be preferred as its use considerably reduces the computational times.

The FLORA-2D model, on the other hand, appears more suitable for territorial planning purposes, for example to evaluate the impacts of new edifications, as it allows to take into account the spatial variation of the permeability of the different areas, using differentiated effective rainfall hyetograph whereas LISFLOOD-FP input hyetograph can variate only over time and be spatially constant.

In light of this, FLORA-2D model was also used to calculate the hydrological response of the territory to evaluate the hydrological impacts of urban basin changes by calculating the hydraulic invariance index (Pappalardo et al., 2016) with the equation (1) as shown in Figure 5.

$$\text{Hydraulic Invariance Index, } Idx = \frac{Q_{post}}{Q_{prev}} - 1 \tag{1}$$

The analysis of the two scenarios, respectively the current urban development (see Q_{post} in eq.1) and the urbanization at 1954 (see Q_{prev} in eq.1), i.e. mainly downstream in the "Sassi", allowed to identify the urban areas more prone to flooding phenomena and showed a widespread increase in the magnitude of the flows over the entire study area, with more extreme values in correspondence of the road network, squares and downstream areas.

Figure 5 - Results of hydraulic modelling: 1954 and 2019 urbanisation scenarios and hydraulic invariance index
Fig. 5 - *Risultati della modellazione idraulica su scenari di urbanizzazione del 1954 e 2019 e indice di invarianza idraulica*

4. Conclusions and future work

The proposed methodology can be used effectively to read the urban areas and interpret their evolution using a hydrological approach to protect the territories from water-related risks and to increase sustainability of built environment development. The method can be useful to assess and select the flood mitigation measures in cities with important historic urban centre and landscape value such as Matera city. Aiming at finding potential measures with both flood mitigation and historic preservation, further studies are being developed using a multi-criteria analysis. Such analysis takes into account various flood mitigation measures and evaluates the best performing measure to reduce certain physical flood characteristics (i.e. maximum inundation depth, maximum flow velocity, and the maximum value of their product), using hydrodynamic modelling. This method could further be refined by making the urban basin characterization more accurate, specifying the surface type in several categories, or by simulating a larger number of rainfall events.

In future investigations, it might be useful to combine an alternative model that takes into account the effect of drainage systems on the flow dynamics with FLORA-2D to evaluate the effectivity of flood mitigation measures that involve the improvement of drainage systems.

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