

Notes on the Performances of Morphological Descriptors for the Evaluation of Flood Susceptibility in Apulian Ephemeral Streams

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Abstract. Different tools and models are nowadays available for the identification of flood-prone areas. The application of these approaches is strongly influenced by the availability of site-specific hydrological information. As an example, a combined scheme of hydrological and hydraulic models for the definition of flood events is reliable when there are lots of hydrological and hydraulic information, which makes it difficult to be exploited in ungauged catchment. In this context, DTM-based geomorphological methods are able to provide a rapid identification of a flood susceptibility where the availability of data directly observed in situ is limited. In this study we investigated ability and performances of two morphological descriptors in defining flood exposure with respect to accuracy of morphological information in the context of ephemeral streams located in Puglia region (Southern Italy). Results showed an influence of data resolution on descriptors performances, providing an additional contribution to the investigations carried out in similar areas during last years.

Keywords: Morphological descriptors · DTM-based approach · Flood-prone areas

1 Introduction

Floods are one of the most important natural phenomena, which have the potential to cause deaths and widespread damages to the environment. These effects are especially observed where rivers have been cut off from their natural area of inundation and confined to main channels, in order to enable the urban expansion. In the last few years this kind of floods are becoming highly frequent and produce strong damaging consequences with particular reference to high vulnerably territories like shallow karst ephemeral/episodic streams known as *lame*, typical of Puglia region (southern Italy), where the combination of physical characteristics of river basins and intense and irregularly distributed rain can generate flash floods.

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A high infiltration capacity is ensured by the limestone of the Murgia, with the consequence of the absence of a significant drainage networks for long period, except for several natural incisions; this is the reason why, during extreme rainfall events, lame are typically unprepared to deal with these natural phenomena generating awful effects. This is what happened in lama Balice on days 16th, 17th, 18th of June 2014 [1].

This kind of consequences can be exacerbated by the increased flood risk caused by climate change effects (e.g., [2–4]). In particular, future changes in floods and environmental related risks are expected to be conducted by a combination of potential changes in climate, catchment conditions and vulnerability of the territory and assets (e.g., [5–9]). Interpretation of changes is the focus of the new Panta Rhei decade of the International Association of Hydrological Sciences (IAHS) [10]. On the other hand, the increasing of urbanization and soil sealing has led to the growth of impermeable surfaces (e.g., [11–13]) causing the reduction of soil infiltration capacity and consequently the increasing effects of the short-duration highly intense rainfall. In this context, according to the recent European legislation on flood risk protection (Flood Directive 2007/60/EC), European programs of scientific research (as Horizon 2020) and scientific community are looking for new techniques able to provide a rapid identification of a flood susceptibility.

Different tools and models are nowadays available for the identification of flood-prone areas (e.g., [14–17]). Some of them essentially consists in using a combined scheme of hydrological and hydraulic models [18–20] for the definition of flood events but are not always applicable because they are reliable when there are lots of hydrological and hydraulic information. In addition, in ungauged catchment the use of these methodologies become difficult due to their parameterization (e.g., [21–23]), leading to the need of looking for alternative source of data and insights (e.g., [24, 25]).

This is the reason why, in areas with limited availability of data, is important the preliminary detecting of flood susceptibility, to avoid expensive analyses that could take a significant employment of resources. In the last few decades methodologies for the identification of flood prone areas to monitor the spatio-temporal evolution of terrestrial phenomena have been developed (e.g., [26–28]) thanks to the availability of new technologies for remote surface elevation observation; in particular global positioning system [GPS], synthetic aperture radar [SAR] interferometry, airborne laser altimetry technology LiDAR (e.g., [29]) can provide reliable information on flood susceptibility [30, 31] considering the increasing availability of high resolution topographical maps developed by Digital Terrain Models [DTMs] (e.g., [32]), and their capacity to give lots of information on morphology and earth surface's characteristic.

Although these methodologies are useful for the investigation of prone areas to flood inundation, mono- and two-dimensional hydraulic numerical models approach is necessary in order to calibrate their information to reference flood maps.

In the proposed work, the DTM-based hydrogeomorphic methods application integrated with the use of Remote Sensing techniques for the derivation of high resolution topographical maps were developed on a case study of an ephemeral stream network known as Lama Balice located in the Puglia region (southern Italy), with the purpose of comparing the inundated areas for three design events characterized by return periods (T) of 30, 200 and 500 years in the context of the evaluation of best performing spatial

resolution (considering 2 m × 2 m, 8 m × 8 m and 30 m × 30 m grid cells) of DTM topographical maps.

2 Case Study and Data

Lama Balice is an ephemeral stream located in Puglia region (Southern Italy), mainly flowing in the municipal areas of Bitonto and Bari, oriented in a SW-NE direction. According to Iacobellis et al. [1], its catchment originates in the territories of Ruvo di Puglia and Corato and the main channel proceeds its path running down to the Adriatic Sea. Lama Balice represents one of the most significant karst ephemeral streams of metropolitan area of Bari, with a length of the main channel of about 20 km, average slope equal to 4.84% and maximum altitude of 635 m.a.s.l [33].

Lama Balice has always been a place of strategic importance for local population and wildlife, because its role of crossroad between the hinterland and the coast [34]. It provided shelters and water, even in arid conditions, since Neolithic period: different lithium finds were found near cities of Bari Palese, Bari San Paolo and Bitonto, supporting the historical importance of these stream networks. In these areas, there are some evidences about prehistoric villages; in fact, its karst cliffs, easily excavated, allowed a protection from cold winds. This is why is part of a protected area of a Regional Natural Park (see Fig. 1).

Due to the social, archeological and naturalistic importance, in the area of lama Balice a natural park was established since 2007, whose extension is about 500 ha and is characterized by a Mediterranean, thermophilic and xerophilic vegetation. Furthermore, the karstification allowed water to penetrate in some limestones fractures, attack rocks and create caverns and passages, where it is possible to appreciate the so-called stalagmites and stalactites. It is estimated that in the park there are six natural caves at least, two sink holes and a thousand of natural shelter in which stalactites and stalagmites hide [34].

One of the last events occurred in June 2014, with an intensity peak in the afternoon of day 17th when more than 100 mm of cumulative rain were recorded [1]. As a consequence, Lama Balice has reactivated itself causing several problems in terms of the effect of ungovernable and chaotic anthropogenic impact, that, associated with incorrect planning, result in catastrophic events [35].

In the proposed research, the Remote Sensing techniques were used for the derivation of high resolution topographical maps, useful for the application of the DTM-based hydrogeomorphic approaches on a case study of Lama Balice; in particular the DTM map with 2 m × 2 m resolution was obtained using the new technologies for the measurement of surface elevation (i.e. Light Detection And Ranging – LiDAR); instead the 8 m × 8 m and 30 m × 30 m DTM topographical maps were extracted from the official regional technical base map of Puglia region, called CTR.

3 Methodologies

As recalled in the Introduction, methodologies applied into this paper relies on the use of geomorphic descriptors computed at catchment scale, coupled with the method of

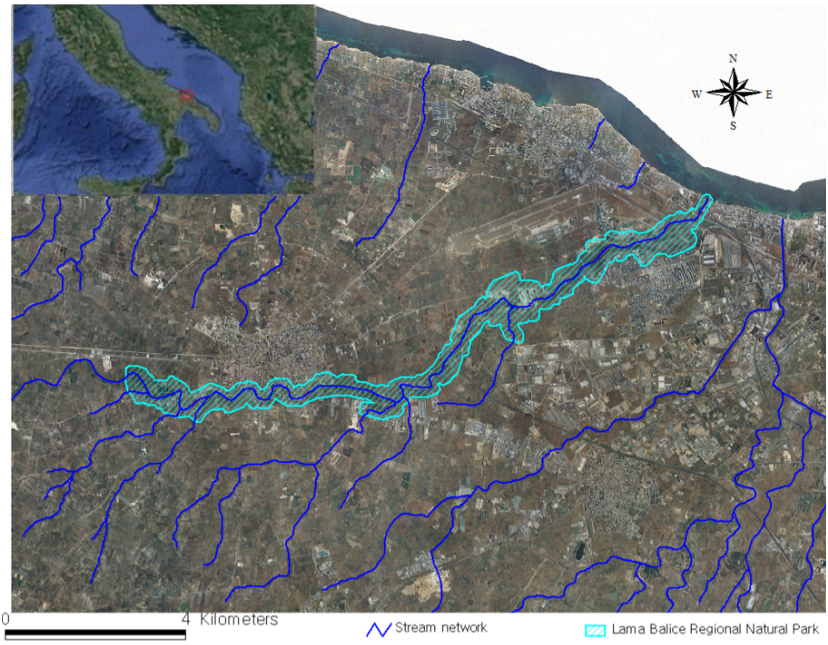


Fig. 1. Development of the stream network of Lama Balice (in blue) (Color figure online).

linear binary classifiers and the Receiver Operating Characteristics (ROC) curves. In this paragraph these approaches are summarizing and described in their main features.

3.1 Morphological Descriptors of Basin

Following results of studies carried out on similar areas (e.g., [33, 36]), we exploited properties of the following descriptors:

- *elevation to the nearest stream*, H [m]: this index is defined as the elevation difference between a point on the catchment and the hydrologically connected point on the drainage network;
- *Geomorphic Flood Index* (GFI), $\ln(h_r/H)$: this descriptor is evaluated as the natural logarithm of the ratio between h_r and H, where h_r is an intrinsic cell quantity that can be defined as:

$$h_r \cong bA_r^n$$

where A_r is, for the selected cell, the upslope contributing area related to that hydrologically connected on the stream network, while b and n were respectively set equal to 10^{-2} and 0.3.

3.2 Linear Binary Classifiers Method and ROC Curves

In order to exploit studies carried out in the previous decades with the same methodologies (e.g., [37]) and on similar case studies located in Puglia region (e.g., [33, 36]), the ability of these indices in the evaluation of flood-prone areas has been tested using the linear binary classifiers method. This allowed us to obtain uniform measures for comparing main findings of our study with those reported in literature.

In order to apply this method, reference and descriptors maps have to be transformed into binary ones, where value 1 is devoted to inundated cells and 0 to others. Then, a transformation is performed for geomorphic indices by scaling each map between -1 and 1 and applying a mobile threshold with a step of 0.001. Cell is therefore classified as inundated or not according to the physical meaning of the index. Comparison between so-obtained maps is carried out by identifying each cell as:

- TP (*True Positive*): when the classifier correctly identifies a flooded element reported on the reference map;
- FP (*False Positive*): when the cell is inundated for the classifier, but the flood reference map doesn't identify it as an element of a flooded area;
- TN (*True Negative*): when the classifier correctly identifies a not flooded element;
- FN (*False Negative*): when the cell is not inundated for the classifier, but the flood reference map identifies it as an element of a flooded area.

By this point the *true positive rate* r_{tp} and *false positive rate* r_{fp} are defined:

$$r_{tp} = \frac{TP}{TP + FN}$$

$$r_{fp} = \frac{FP}{FP + TN}$$

and the best performing threshold is measured by minimizing the following objective function:

$$OB = r_{fp} + \left(1 - r_{tp}\right)$$

Above-mentioned rates can be exploited also for deriving two performance measures, namely the Receiver Operating Characteristics (ROC) curves and the Area Under Curve (AUC), evaluated for each ROC line [37].

4 Results and Discussion

Results of the calibration steps for the case study are illustrated with respect to metrics described in Sect. 3, and summarized accordingly:

– Figure 2 a visual comparison between reference and descriptor maps for a 30-years return period event is shown;

– in Table 1 numerical outputs of linear binary classifiers method are reported, together to AUC values;
– in Fig. 3 ROC curves for H and GFI descriptors evaluated for a 30-year return period event are illustrated.

Table 1. Results of the calibration procedure for morphological descriptors for investigated return periods

Return period	Descriptor	Resolution (m)	τ	r_{fp}	r_{tp}	*min(ob)*	AUC
30 years	H	2	−0.791	0.047	0.975	0.071	0.987
		8	−0.855	0.091	0.907	0.184	0.955
		30	−0.595	0.250	0.900	0.349	0.898
	GFI	2	−0.479	0.058	0.856	0.202	0.949
		8	−0.492	0.092	0.890	0.202	0.946
		30	−0.310	0.266	0.900	0.365	0.876
200 years	H	2	−0.753	0.051	0.975	0.077	0.989
		8	−0.824	0.105	0.909	0.196	0.955
		30	−0.392	0.310	0.947	0.363	0.903
	GFI	2	−0.491	0.057	0.819	0.237	0.933
		8	−0.564	0.133	0.907	0.226	0.946
		30	−0.310	0.258	0.874	0.383	0.882
500 years	H	2	−0.753	0.044	0.967	0.077	0.990
		8	−0.824	0.105	0.892	0.213	0.951
		30	−0.392	0.310	0.942	0.367	0.895
	GFI	2	−0.493	0.053	0.815	0.238	0.931
		8	−0.561	0.131	0.888	0.243	0.941
		30	−0.505	0.334	0.942	0.392	0.874

The visual analysis of the flooded areas obtained by applying the calibration procedure described is illustrated in Fig. 2 for the GFI index for the event with a return time of 30 years. It is possible to appreciate the effects of the related resolution of the digital terrain model on the distribution of the flooded areas, which faithfully follow the reference ones up to the intersection with the railway network, beyond which is less evident the ability of the descriptors in interpreting the phenomenology of the formation of flooded areas.

Results reported in Table 1 show a general tendency of both geomorphological descriptors to increase their performances in passing from a resolution of 30 m × 30 m to one of 2 m × 2 m. Moreover, this behavior does not seem to be affected by the return

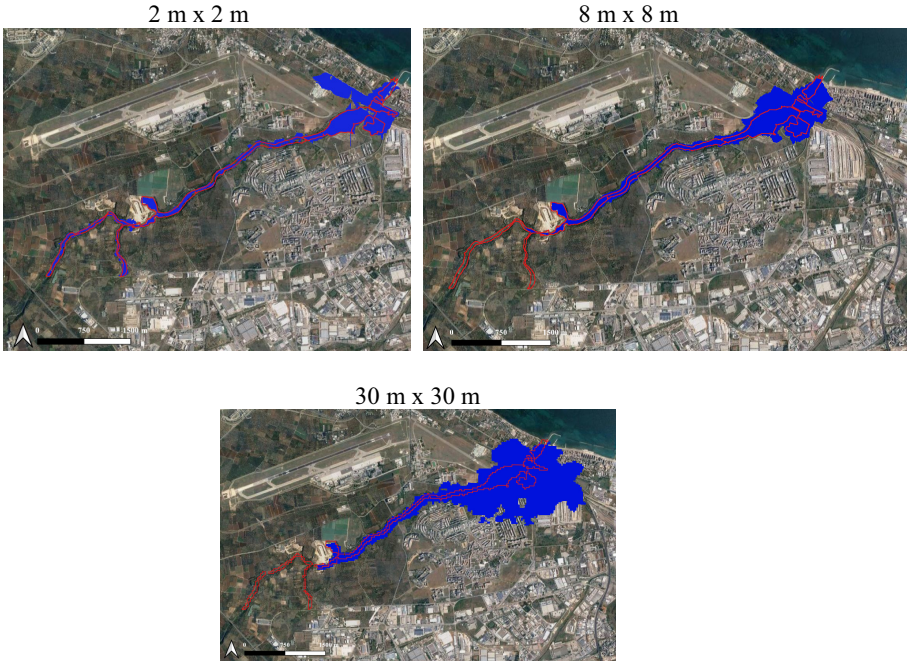


Fig. 2. High hydraulic hazard is represented by using the descriptor GFI for a 30-year return period event. In blue is represented flooded area obtained with the calibration procedure, while red line represents borders of reference map (Color figure online).

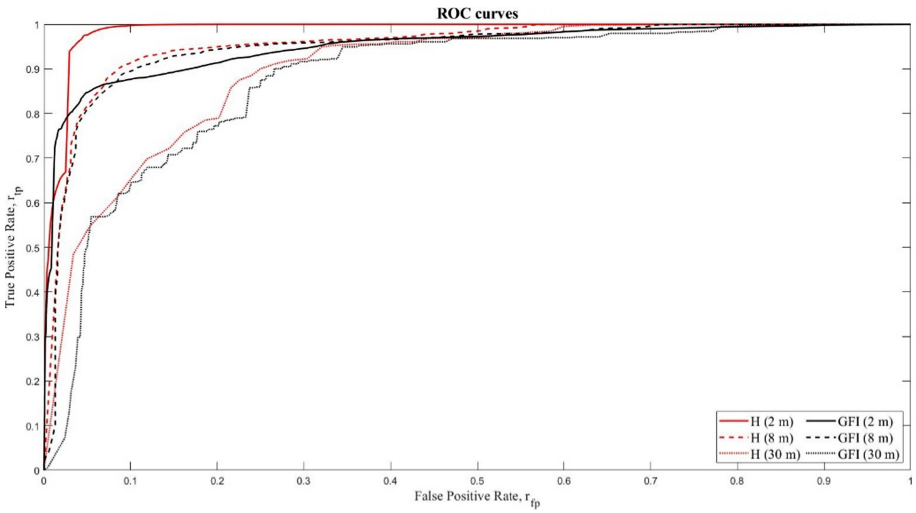


Fig. 3. Comparison of ROC curves for H and GFI descriptors evaluated for a 30-year return period event.

period of the simulated event, in accordance with what already observed by Gioia et al. [33].

The descriptor H is the one that presents the best results. Numerical evidence of this can be found in Table 1. In fact, with reference to the resolution of 2 m × 2 m and the three investigated return periods, it can be noted that the objective function assumes a minimum value of 0.071, with a maximum rate of true positives equal to 0.975. These are excellent performances, which are also reflected in the AUC values, which are close to 0.990. At the other resolutions, on the other hand, a progressive loss of performance is observed, due to the lower accuracy in the reproduction of the real flooded surface.

These results and considerations can also be extended to the GFI, albeit with lower performance over the entire study area. In any case, the results are still good, and reflect, in absolute values, what already emerged in previous studies conducted in similar areas [33, 36].

A visual inspection of these results can be obtained by the analysis of Fig. 3, where ROC curves for H and GFI descriptors evaluated for a 30-year return period event are reported.

The illustrated results confirm good performances of investigated descriptors in interpreting the flood susceptibility of the areas conterminous to those of the Lama Balice. This seems to reflect the effect of the singular morphology of these karst structures. The effect of the resolution of the digital terrain model is confirmed to be an important element for the accuracy of the results, to the detriment, however, of the computational effort. In fact, in passing from the resolution of 2 m × 2 m to the others, the number of cells of the raster greatly decreased, decreasing the time necessary for the completion of the algorithms. This seems to suggest the possibility of adopting an intermediate resolution for a preliminary rough mapping to be carried out on larger areas, reserving more detailed analyzes for particular cases.

5 Conclusions

Taking advantage of the case study of lama Balice, the morphological descriptors of basin and the linear binary classifiers method were applied in order to compare the results for different DTM resolution.

Aim of this study was to provide a further research contribution carried out on karst ephemeral streams conducted in last years, trying to provide technical insights for supporting further analyses in similar areas, characterized by a common nature and hydrological phenomenology. This paper can be considered as a starting point for setting up a hierarchical approach aimed at mapping flood-prone areas in these areas, supporting decision-makers and local authorities in a sustainable management of these territories.

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