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Hydromorphic analysis of urban areas transformations: the case study of the Matera city

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Abstract. The paper analyzes the urban context of Matera city, adopting an approach based on the concept of watershed, interpreted in its dynamic meaning. This approach exceeds the classical urban planning analysis by focusing on the interaction between the morphological characteristics of the territory, the land uses and their human-made changes and the consequent hydrological response and surface runoff. The morphological description combined with the classic urban representation that looks at the types of intervention implemented (permeable, impervious, green, land uses) drive into the understanding of the urban and territorial transformation processes responses. Furthermore the urban evolution analysis for different time period can provide a time-based interpretation of the transformations impacts providing useful information for future planning of the entire area of Matera.

1. Introduction

1.1. Background

Urban growth continues to occur across large spatial scales, in case of entire cities being constructed in short times (e.g. Binhai New Area, China[1]. But urban development occurs also at local scales [2][3]. Kongjian Yu, founder of the Turenscape studio and professor at Peking University, recognizes that soil infrastructure is the main cause of the water resources impacts that contemporary cities are facing today [4].

The expansion of urban space results in an increase of impervious areas amount and artificial drainage networks that can cause dramatic changes in the magnitude, pathways (shapes, slopes, roughness) and timing of runoff at individual buildings level as well as at larger developments scale [5][6][7]. The modification of urban land leads to shorter times of concentration and reduced recession times, since infiltration is reduced, resulting in increased pounding or surface runoff [8][9].

The world is undergoing drastic urbanization. In 2020, it is estimated around 4.4 billion of people lives in cities, and this number is expected to reach 6.7 billion by 2050 [10]. The rapid urbanization process inevitably leads to an increase in impervious surfaces and in drainage pipelines producing a significantly change in hydrological processes [11][12]. This modification in time and space of impervious surfaces in urbanized areas, due to urban growth, could dramatically increase the possible flood risk.

According to the European Environment Agency [13], almost 1.500 floods have occurred in Europe since 1980, and more than half of them occurred after 2000. In Europe, the Expected Annual Damage (EAD) from river flooding is about € 6.4 billion, while the Expected Annual Population (EAP) exposed to floods is around 195.000 people [14].

The increase in urban flood risks and in serious flood losses are more troubling due the more frequent extraordinary weather phenomena (such as extreme precipitation events, typhoons, and storm surge), affected by the contribute of the uninterrupted global warming [15]. Indeed a large number of studies show that climate change is leading to an increase in both the frequency and intensity of hydrometeorological extremes [16][17] [18][19] [20][21].

Hence serious urban floods are projected to occur more frequently in cities in the future due to continued global climate changes and accelerated urbanization.

In urbanized areas the presence of widespread impervious surfaces alters the dynamics of infiltration and results in contrasting impacts on baseflow behaviour at a range of scales [7], increases in overall runoff volumes [22][23], reduces in runoff lag time [24][25], increases in flood return periods [26][27][28], and elevates in peak discharges during storm events [24][25][29]. Determining the impacts of urban areas on in-stream ecological communities has been the focus of many excellent detailed reviews [30][31][7] in which stormwater was viewed as an hazard in urban areas despite the presence of a complex network of drainage infrastructure able to collect surface water and transport it away from the urban area.

Whilst extensive networks of urban drainage systems remain a pragmatic component of managing urban water, increasingly small and medium scale strategies are being implemented by local and national authorities, enabling individual houses and businesses to capture water and use it for greywater applications [32].

A shift toward sustainable urban drainage in urban planning policies is incorporating consideration of aqueous environments and ecosystem habitats managing at a range of spatial scales [33] stormwater (at source) and reducing the adverse impacts urban runoff can have on surrounding environments.

Impervious areas are of critical importance [34] in how urban areas translate rainfall to runoff, where the most part contribute to a rapid stormwater runoff into adjacent channels, resulting in high flood risk [35][36]. Eshtawi et al. [35] identified that a 1% increase in impervious/urbanized area yielded up to a 100% increase in runoff.

Note that it is not just the surface type that establishes its hydrologic behavior, but the nature of connection of areas with different degree of permeability: the runoff produced by impervious zones that passes over pervious land can rapidly increase the rate of saturation and result in quick attenuation of flows; the saturation derived flows that are adjacent to impervious areas have pathways of low resistance that can facilitate rapid transfer of large volumes of water. The role of these zones on overall water balance is uncertain and may have a significant impact on small-scale local flood risk [37].

1.2. Motivations and objectives

In a natural basin, the behavior of runoff flows resulting from a rainfall event, are strictly dependent by the shape, the size, the slope of the territory, by the permeability of the soil and by the characteristics of the hydrographic network that conveys the flows through the basin, to the outlet. These characteristics are affected by the uman-indiced transformation made over time within the basin and, consequently, they produce effects on surface runoff flows.

By extending the latter concept to urbanized areas [38], it is possible to introduce, even in the urban context, the basin schematization in which, however, the classic natural morphologies are replaced by the forms induced by urbanization as well as the natural hydrographic network by road or other infrastructures.

In this way, the dynamic interpretation of a region offers the opportunity to evaluate the urbanization effects on natural components and on the overall territorial sustainability.

By estimating the surface runoff flows related to the different situations, it is possible to evaluate the effects resulting from these modifications and, therefore, to estimate a quantitative indicator of the changes efficiency.

The changes that can affect a basin are the consequence of physical transformations that can be schematically described as:

- areal changes, which affect the conformation of the basin, modifying its geometry (area, perimeter, length, slope) or even its physical characteristics such as permeability;
- linear changes, which mainly affect the morphology of the flow pathways inside the basin, by varying the routes followed by the surface runoff (length, slope);
- punctual changes, which affect only locally in well-circumscribed portions of the basin and directly affecting the flows;

all these transformations, on the basis of their location, extent and type, can be able to produce (more or less) significant effects on the dynamics of runoff flows development and, therefore, on the hydrological response of the basin.

By evaluating the runoff related to a certain event scenario and territorial configuration, it is possible to quantitatively characterize the hydrological response strictly correlated to the morphology analyzed and any modification will result in alterations of the response that we could therefore define as hydromorphic [38].

The representation by basins allows to overcome the urban fragmentation by interpreting the territory on the basis of the morphological characteristics that govern fundamental relationships between different parts of the basin on the basis of the dynamics of their respective surface runoff which also measure the influence that each area have on the others.

2. Methodology and its application to Matera case study

The hydrological modelling of the phenomenon of surface runoff flows development can be performed using the well known and widely used Rational Method [39][40]:

$$Q = \varphi \; i_{tc} \; S \tag{1}$$

which allows to evaluate the maximum runoff Q in the watershed outlet, as a product of: the runoff coefficient φ, the intensity of precipitation i_{tc} related to the time of concentration t_c of the basin and the surface of the basin S.

Ultimately, the equation (1) allows to express in a synthetic way the hydrological efficiency of a certain urban or territorial morphology considered, through the parameters cited (φ, t_c, i_{tc}, S) and therefore, it is well suited to interpret and summarize any changes that may affect the various urban basins. In fact, the changes in the shape, dimensions or characteristics of a basin affect the parameters φ and S, instead the changes in the water flow pathways affect the parameter t_c, and the local changes directly alter the discharge Q. Therefore the estimate of the peak runoff Q, allows to measure the effects of any morphological change in the basin. Furthermore, through the i_{tc} parameter, it is possible to take into account the effects induced by climate change.

By processing the urban DTM map of the city of Matera in a GIS environment, the urban area was divided into 21 different sub-basins (Figure 1).

For each sub-basin, the main characteristics (shape, size, slope, network of main flow path) corresponding to different urbanization evolution scenarios were evaluated and the values of the overall runoff coefficients, corresponding to each time, were obtained for each of the basins considered (Table 1) assuming the values of φ equal, respectively, to 0.8 for impervious surfaces and 0.2 for pervious surfaces.

The highest values of φ are found for the basin named GM2, GM3 and GM4 in the Table 1. GM4 that corresponds to the Sassi districts and neighboring areas have reached very high levels of urbanization increase during its time evolution (+60%, 70%).

Table 1. Matera sub-basins characteristics (i.e. total basin area, impermeable and permeable surfaces, and Q) during the 3 urbanization scenarios (1954, 1973, 2016)

Bacini		1954			1973			2016			coeff deflusso		
		TOT AREA [Km²]	Sup Imp	Sup Perm	TOT AREA [Km²]	Sup Imp	Sup Perm	TOT AREA [Km²]	Sup Imp	Sup Perm	1954	1973	2016
T. Gravina di Matera	GM1	2,8	0,03	2,75	2,8	0,08	2,70	2,8	0,46	2,32	0,2	0,22	0,30
	GM2	0,7	0,19	0,47	0,7	0,37	0,28	0,7	0,42	0,24	0,4	0,54	0,58
	GM3	1,2	0,41	0,80	1,2	0,68	0,53	1,2	0,86	0,35	0,4	0,54	0,63
	GM4	0,2	0,07	0,10	0,2	0,09	0,09	0,2	0,11	0,07	0,4	0,50	0,58
	GM5	0,1	0,00	0,06	0,1	0,01	0,06	0,1	0,02	0,04	0,2	0,26	0,38
	GM6	0,2	0,05	0,16	0,2	0,10	0,12	0,2	0,13	0,09	0,4	0,46	0,55
	GM7	0,3	0,03	0,29	0,3	0,04	0,28	0,3	0,07	0,25	0,3	0,27	0,34
	GM8	1,9	0,10	1,79	1,7	0,48	1,21	1,7	0,76	0,92	0,2	0,37	0,47
	GM9	6,9	0,06	6,86	6,9	0,12	6,80	6,9	0,50	6,42	0,2	0,21	0,24
	Tot. GM	14,2	0,96	13,29	14,0	1,97	12,07	14,0	3,33	10,71			
T. Gravina di Picciano	GP1	7,2	0,03	7,12	7,2	0,07	7,08	7,2	0,22	6,93	0,2	0,21	0,22
	GP2	0,7	0,01	0,69	0,7	0,02	0,68	0,7	0,11	0,59	0,2	0,22	0,30
	GP3	0,4	0,00	0,43	0,4	0,01	0,42	0,4	0,20	0,23	0,2	0,22	0,48
	GP4	0,5	0,02	0,48	0,5	0,03	0,47	0,5	0,08	0,41	0,2	0,23	0,30
	GP5	2,0	0,00	1,96	1,5	0,03	1,47	1,5	0,81	0,69	0,2	0,21	0,52
	GP6	0,4	0,00	0,42	0,4	0,00	0,42	0,4	0,17	0,25	0,2	0,20	0,44
	GP7	1,0	0,02	0,98	0,4	0,01	0,43	0,4	0,18	0,25	0,2	0,21	0,45
	GP8	4,2	0,06	4,10	5,4	0,32	5,07	5,4	1,12	4,26	0,2	0,24	0,33
	GP9	3,6	0,01	3,58	3,6	0,06	3,53	3,6	0,06	3,53	0,2	0,21	0,21
	GP10	1,0	0,00	1,00	1,0	0,01	0,99	1,0	0,02	0,98	0,2	0,21	0,21
	GP11	1,4	0,00	1,42	1,4	0,03	1,40	1,4	0,04	1,39	0,2	0,21	0,22
	GP12	6,3	0,07	6,26	6,3	0,17	6,16	6,3	0,42	5,90	0,2	0,22	0,24
	Tot. GP	28,7	0,22	28,44	28,9	0,76	28,11	28,9	3,45	25,42			
Tot. MT		42,9	1,2	41,7	42,9	2,7	40,2	42,9	6,8	36,1			

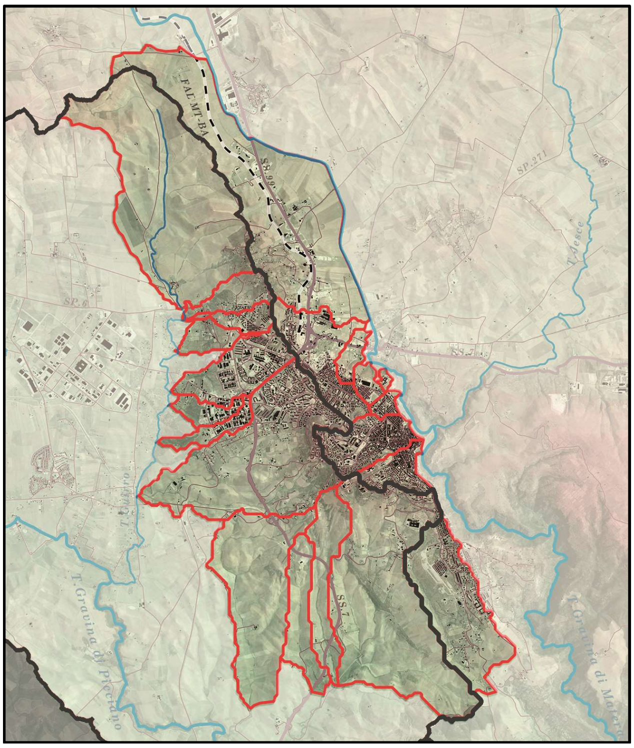


Figure 1. Matera Urban sub-basin

From 1954 to 2016 all the basins denote an increase in the impervious areas which correspond to an increase in the runoff coefficients φ.

The increases in φ relative to the different basins are included between 2% and 160%, with the highest values for the western basins and for the 2016 urbanization scenario.

The time of concentration t_c is related to the same morphological characteristics and it is defined as the maximum time interval taken by the precipitation particle fallen on the basin at the hydraulically farthest point, to reach the watershed outlet. The t_c can be expressed, depending on the morphological characteristics of the watershed, through the equation (2) of Kirpich [39][40]:

$$t_c = 0.000325\, L^{0.77}\, j_v^{-0.385} \tag{2}$$

where L is length of the main flow path in meters and j_v is the average main channel slope.

It is therefore evident that, under the same climatic conditions (Intensity Duration Frequency curve), the intensity of precipitation that characterizes the most critical situation of a given basin (maximum surface runoff), depends on the basin's time of concentration which, in turn, varies according to the morphology of the watershed (parameters L and j_v).

Table 2. Urban catchement time of concentration

Bacini		Superficie bacino			Lunghezza bacino			Pendenza media bacino			Pendenza media asta			tempo di corrivazione $0.15+0.000325*(L^{0.77})/(j_v^{0.385})$			i_{tc} $i_{tc} = 50.42\ t^{0.239}$		
		1954 [Km²]	1973 [Km²]	2016 [Km²]	1954 [m]	1973 [m]	2016 [m]	1954	1973	2016	1954	1973	2016	1954	1973	2016	1954	1973	2016
T. Gravina di Matera	GM1	2,78	2,78	2,78	4075	4024	4024	0,13	0,13	0,13	0,05	0,05	0,05	0,78	0,78	0,78	61	61	61
	GM2	0,66	0,66	0,66	1467	1464	1464	0,22	0,22	0,22	0,12	0,12	0,12	0,35	0,35	0,35	111	112	112
	GM3	1,21	1,21	1,21	2115	2115	2112	0,17	0,17	0,17	0,07	0,07	0,07	0,47	0,47	0,47	89	89	89
	GM4	0,18	0,18	0,18	675	725	725	0,18	0,18	0,18	0,19	0,17	0,17	0,24	0,25	0,25	148	144	144
	GM5	0,06	0,06	0,06	414	414	414	0,20	0,20	0,20	0,17	0,17	0,17	0,22	0,22	0,22	162	162	162
	GM6	0,22	0,22	0,22	575	593	593	0,12	0,12	0,12	0,14	0,14	0,14	0,24	0,25	0,25	148	147	147
	GM7	0,32	0,32	0,32	1018	1018	1018	0,18	0,18	0,18	0,08	0,08	0,08	0,33	0,33	0,33	118	118	118
	GM8	1,90	1,69	1,69	2630	2976	2976	0,13	0,13	0,13	0,05	0,04	0,04	0,59	0,68	0,68	75	67	67
	GM9	6,92	6,92	6,92	6077	6077	6077	0,10	0,10	0,10	0,02	0,02	0,02	1,37	1,37	1,37	40	40	40
T. Gravina di Picciano	GP1	7,15	7,15	7,15	5400	5400	5400	0,12	0,12	0,12	0,03	0,03	0,03	1,60	1,60	1,60	35	35	35
	GP2	0,70	0,70	0,70	1632	1632	1632	0,19	0,19	0,19	0,12	0,12	0,12	0,37	0,37	0,37	108	108	108
	GP3	0,43	0,43	0,43	1543	1543	1543	0,18	0,18	0,18	0,13	0,13	0,13	0,35	0,35	0,35	111	111	111
	GP4	0,50	0,50	0,50	1682	1682	1682	0,15	0,15	0,15	0,09	0,09	0,09	0,40	0,40	0,40	101	101	101
	GP5	1,96	1,50	1,51	3531	2365	2413	0,13	0,14	0,14	0,06	0,09	0,08	0,67	0,48	0,49	69	88	87
	GP6	0,42	0,42	0,42	1380	1380	1266	0,14	0,14	0,14	0,09	0,09	0,10	0,37	0,37	0,35	108	108	113
	GP7	1,00	0,44	0,44	3099	1862	1766	0,13	0,12	0,12	0,08	0,08	0,08	0,57	0,44	0,42	77	94	97
	GP8	4,16	5,39	5,39	3775	5888	5904	0,17	0,16	0,16	0,07	0,05	0,04	0,66	1,01	1,01	69	50	50
	GP9	3,59	3,59	3,59	4916	4916	4916	0,16	0,16	0,16	0,05	0,05	0,05	0,88	0,88	0,88	56	56	56
	GP10	1,00	1,00	1,00	3149	3149	3149	0,19	0,19	0,19	0,06	0,06	0,06	0,63	0,63	0,63	72	72	72
	GP11	1,43	1,43	1,43	3754	3754	3754	0,24	0,24	0,24	0,08	0,08	0,08	0,63	0,63	0,63	72	72	72
	GP12	6,33	6,33	6,33	4202	4202	4202	0,17	0,17	0,17	0,07	0,07	0,07	0,69	0,69	0,69	67	67	67

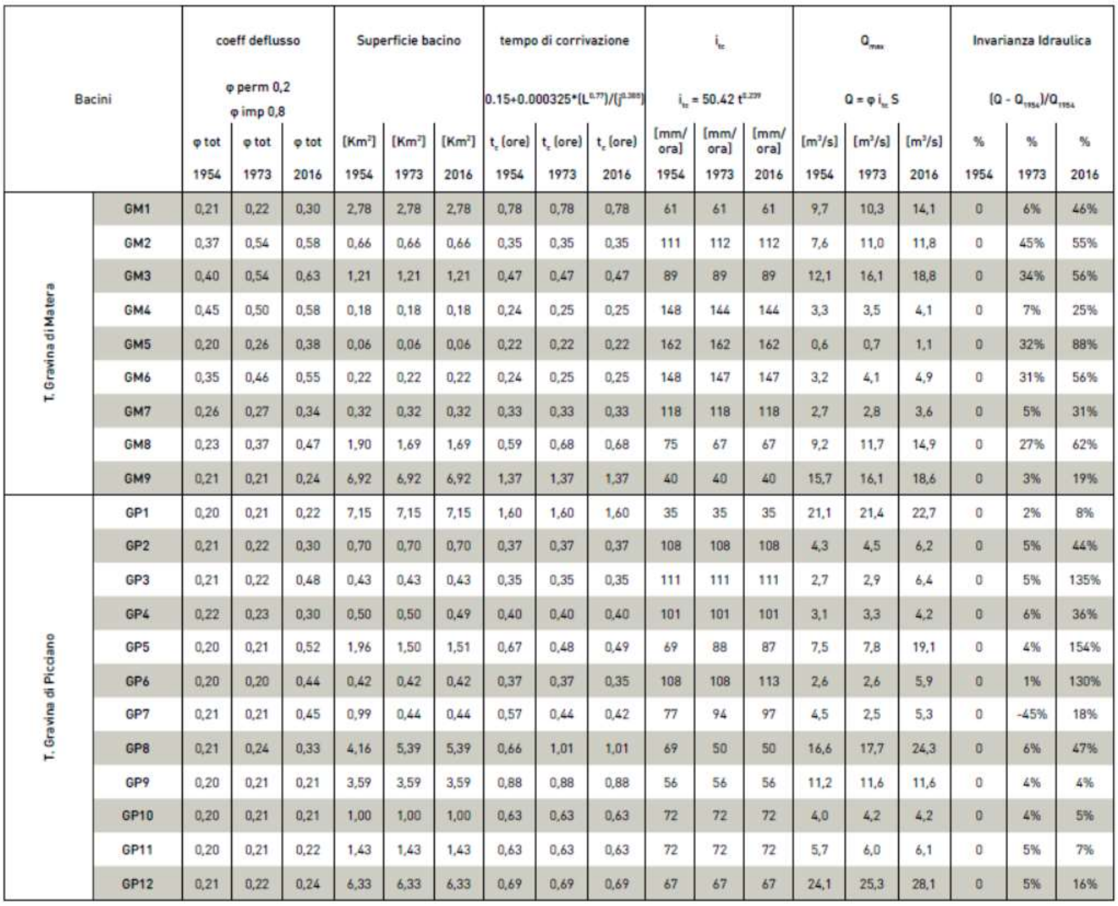
In the case of the urban sub-basins in which is divided the Matera city (Table 2) we obtain that:

- all the eastern side basins and the most part of those on the western side have t_c that are almost constant over time;
- the GP5 and GP7 basins show a reduction in t_c due to the drastic reduction of their surfaces due to the expansion of the main road SS-7;
- the GP8 basin, due to the extension of the SS-7, during the time evolution has incorporated portions of the adjacent GP5 and GP7 basins and consequently has increased its surface area and has increased t_c;
- the GM8 basin, following the urbanization interventions that have affected it, has changed its characteristics (shape and size) and shows an increase in t_c.

Therefore, the morphological transformations induced by urbanization, by modifying the morphological parameters (L and j_v), modify the t_c which, in turn, influences the estimate of the corresponding intensity of precipitation i_{tc}, critical for the basin under study.

The hydromorphic response of each basin is summarized in the value of the peak runoff discharge Q following a predefined precipitation event (IDF curve) through equation (1) obtaining the values shown in Table 3.

Table 3. Urban catchements' peak runoff discharge and hydraulic invariance index



Bacini		coeff deflusso			Superficie bacino			tempo di corrivazione			i_{tc}			Q_{max}			Invarianza Idraulica		
		φ perm 0,2 φ imp 0,8						$0.15+0.000325*(L^{0.77})/(j^{0.385})$			$i_{tc} = 50.42\ t^{0.239}$			$Q = \varphi\ i_{tc}\ S$			$(Q - Q_{1954})/Q_{1954}$		
		φ tot	φ tot	φ tot	[Km²]	[Km²]	[Km²]	t_c (ore)	t_c (ore)	t_c (ore)	[mm/ora]	[mm/ora]	[mm/ora]	[m³/s]	[m³/s]	[m³/s]	%	%	%
		1954	1973	2016	1954	1973	2016	1954	1973	2016	1954	1973	2016	1954	1973	2016	1954	1973	2016
T. Gravina di Matera	GM1	0,21	0,22	0,30	2,78	2,78	2,78	0,78	0,78	0,78	61	61	61	9,7	10,3	14,1	0	6%	46%
	GM2	0,37	0,54	0,58	0,66	0,66	0,66	0,35	0,35	0,35	111	112	112	7,6	11,0	11,8	0	45%	55%
	GM3	0,40	0,54	0,63	1,21	1,21	1,21	0,47	0,47	0,47	89	89	89	12,1	16,1	18,8	0	34%	56%
	GM4	0,45	0,50	0,58	0,18	0,18	0,18	0,24	0,25	0,25	148	144	144	3,3	3,5	4,1	0	7%	25%
	GM5	0,20	0,26	0,38	0,06	0,06	0,06	0,22	0,22	0,22	162	162	162	0,6	0,7	1,1	0	32%	88%
	GM6	0,35	0,46	0,55	0,22	0,22	0,22	0,24	0,25	0,25	148	147	147	3,2	4,1	4,9	0	31%	56%
	GM7	0,26	0,27	0,34	0,32	0,32	0,32	0,33	0,33	0,33	118	118	118	2,7	2,8	3,6	0	5%	31%
	GM8	0,23	0,37	0,47	1,90	1,69	1,69	0,59	0,68	0,68	75	67	67	9,2	11,7	14,9	0	27%	62%
	GM9	0,21	0,21	0,24	6,92	6,92	6,92	1,37	1,37	1,37	40	40	40	15,7	16,1	18,6	0	3%	19%
T. Gravina di Picciano	GP1	0,20	0,21	0,22	7,15	7,15	7,15	1,60	1,60	1,60	35	35	35	21,1	21,4	22,7	0	2%	8%
	GP2	0,21	0,22	0,30	0,70	0,70	0,70	0,37	0,37	0,37	108	108	108	4,3	4,5	6,2	0	5%	44%
	GP3	0,21	0,22	0,48	0,43	0,43	0,43	0,35	0,35	0,35	111	111	111	2,7	2,9	6,4	0	5%	135%
	GP4	0,22	0,23	0,30	0,50	0,50	0,49	0,40	0,40	0,40	101	101	101	3,1	3,3	4,2	0	6%	36%
	GP5	0,20	0,21	0,52	1,96	1,50	1,51	0,67	0,48	0,49	69	88	87	7,5	7,8	19,1	0	4%	154%
	GP6	0,20	0,20	0,44	0,42	0,42	0,42	0,37	0,37	0,35	108	108	113	2,6	2,6	5,9	0	1%	130%
	GP7	0,21	0,21	0,45	0,99	0,44	0,44	0,57	0,44	0,42	77	94	97	4,5	2,5	5,3	0	-45%	18%
	GP8	0,21	0,24	0,33	4,16	5,39	5,39	0,66	1,01	1,01	69	50	50	16,6	17,7	24,3	0	6%	47%
	GP9	0,20	0,21	0,21	3,59	3,59	3,59	0,88	0,88	0,88	56	56	56	11,2	11,6	11,6	0	4%	4%
	GP10	0,20	0,21	0,21	1,00	1,00	1,00	0,63	0,63	0,63	72	72	72	4,0	4,2	4,2	0	4%	5%
	GP11	0,20	0,21	0,22	1,43	1,43	1,43	0,63	0,63	0,63	72	72	72	5,7	6,0	6,1	0	5%	7%
	GP12	0,21	0,22	0,24	6,33	6,33	6,33	0,69	0,69	0,69	67	67	67	24,1	25,3	28,1	0	5%	16%

Note that in the more recent scenarios all the basins show ever increasing values of the Q, denoting a generalized increase in the criticality of the areas analyzed. Therefore, in all cases, the urban transformations have led to a worsening of the pre-existing situations in terms of flood hazard.

The effects of the transformations, for all the basins analyzed, resulted in a reduction of the surface permeability, accompanied by modest variations in the time of concentration, leading to an increase in the estimated peak runoff characterized by a value of included between 10% and 150% for the Gravina di Picciano basin (and sub-basins) a value of between 30% and 40% for the Gravina di Matera basin and sub-basins.

The basins in which the Sassi are splitted, despite its limited extension, develop the greatest surface runoff, above all, due to their high imperviouness which has increased over time with the transformations carried out in the upstream areas (Macamarda hill and Lanera and Pini districts) that, during the last (analyzed) fifty years, have produced an increase of more than 30% in critical outflows.

The GM1 and GM9 basins, respectively in the south and north part of the town, are almost permeable, but have significant extensions and, therefore, produce substantial runoffs. In these areas, designed to incorporate future urbanizations, the project hypotheses of inducing transformations, that can alter the hydromorphic balances of the areas, should be carefully evaluated since they could generate further and conspicuous increases in the maximum runoff resulting from rainfall events of a certain importance and widespread local criticalities on the receiving water bodies.

3. Results and discussion

Each of the basins considered, although belonging to the same urban context and often to the same neighborhood, has undergone transformations over time that have influenced its hydrological response in a different way. In fact, the transformations consequent to the urbanization interventions producing superficial, linear or punctual modifications, determine alterations of the superficial permeability, of the runoff paths or of the runoff times and therefore modify the fundamental parameters that influence the peak discharge related to rainfall events.

The Q relating to each basin are therefore able to synthesize the combined effects of the rainfall and of the hydrological response of the basin itself, condensing an efficient indicator of the state of the basin into a single parameter.

The value of the peak runoff Q relative to each basin and to each period of urbanization development considered (scenarios), allows to characterize the types of modifications that have been produced, correlating the causes and effects of the changes that have occurred in the different areas.

The comparison between the situations relating to the various scenarios can be expressed even more effectively by assuming as the reference scenario that relating to 1954 and calculating the following index:

$$INV = (Q_t - Q_{1954}) / Q_{1954} \tag{3}$$

in which, Q_t is the value of the maximum runoff Q relating to the scenario at time t and Q_{1954} is the value of Q relating to the year 1954, taken as a reference.

The Hydraulic Invariance Indicator (INV) index [41], expresses the ratio between the increase in the maximum runoff of a t time of urbanization evolution, compared to the reference value of 1954, and the same reference value. Therefore the equation (3) would like to quantify, trough a dimensionless index (not distorted by local scale factors), the alteration of the maximum runoff of urbanized areas during different urbanization scenarios.

INV assumes null values, if Q remains unchanged over time, positive values, if Q increases and negative values, if the maximum runoff decreases.

The INV index, obtained for the different basins with reference to the two scenarios of 1973 and 2016 (Table 3), allows to summarize in a single indicator the effects of the transformations carried out in the different periods and allows comparisons between the different situations observed and between the different scenarios, providing interesting discussion prompts:

- Until 1973, the basins of the western slope show weak transformations that result in negligible impacts, with the exception of the GP7 basin which denotes a reduction in the maximum runoff, where INV equal to -45%, is mainly due to the reduction of the basin surface consequent to the realization of the extension of the SS 7.
- In the same period, the basins on the eastern side show a general increase in the INV indicator, very contained for the more peripheral basins and more pronounced for the more central ones which in that period underwent the greatest transformations; among all should be emphasized the values of 45% and 34%, corresponding to the basins of the Sassi, in which the urbanization of the upstream portions of the basins have been implemented, with non-negligible effects.
- In the subsequent period (2016), the expansion of urbanization and the transformation of natural areas into impermeable areas, involves a conspicuous increase in the hydraulic response of the territories with INV indices that reach even very high values (130% the GP6, 135% GP3, 154% GP5), especially in the basins in which urban expansion was most extensive (new Aquarium districts, PAIP area).

- Even the GP7 basin, which in the previous period had shown a reduction in the INV index, undergoes a significant increase in impacts in the subsequent period, mainly attributable to the widespread urbanization that affected the area.

The only situations that are still stable, even if affected by outflows of a certain importance, are those relating to the GP1, GP9, GP10 and GP11 basins which, being more peripheral, have not yet been affected by transformations of a certain importance.

4. Conclusions

The analysis of the case study of Matera city in Basilicata (Italy) implemented by the hydomorphic methodology allow to evaluate the peak runoff related to each individual area of the urban context, in different scenarios.

The map of runoff extended to an urban context allows a synthetic assessment of the natural response of each sub-basin, permitting to localize the areas potentially most exposed to phenomena of a certain importance and to understand the influence of any changes made in the basin.

Through the concept of urban watershed, interpreted in its dynamic meaning, varying the downstream outlet respect to which the basin itself is defined, it is possible to adapt the sensitivity of the analyzes to the different approximation scales required by the particular contexts analyzed. This allows multi-scale analyses, but based on the same fundamental hydraulic parameter that govern the hydraulic motion and, therefore, this can ensure the full homogeneity of the results produced, which can be compared with each other, or with different sample situations, in order to obtain useful indications of the consequent impacts.

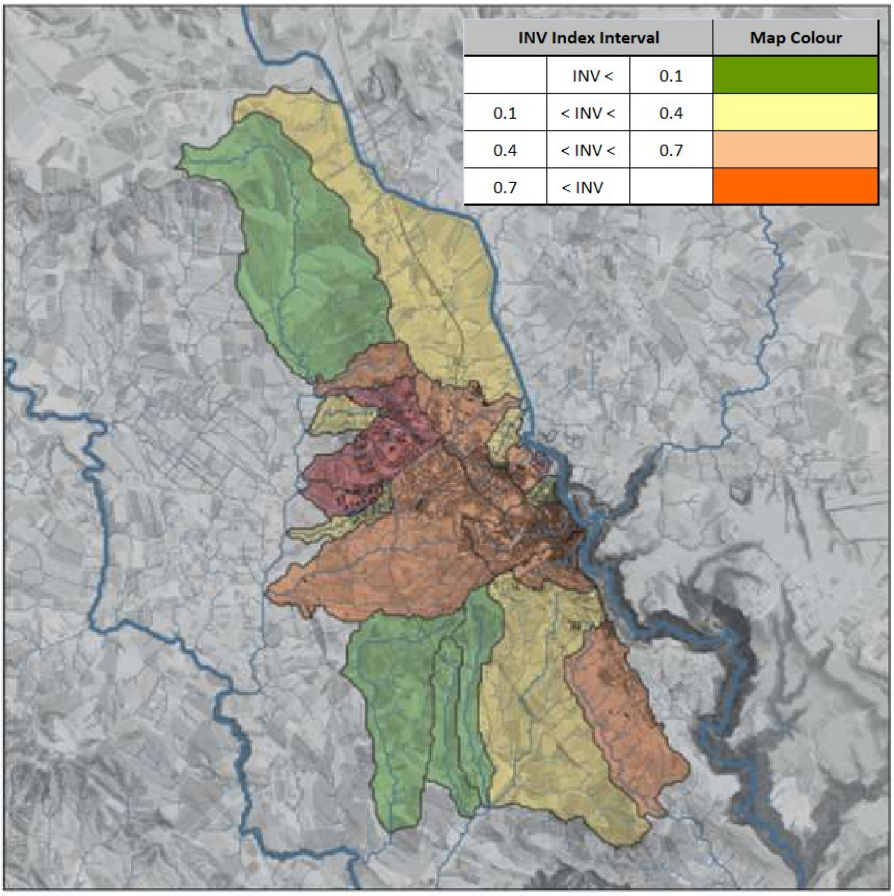


Figure 2. Map of the INV index for each basin

In fact any different territorial portions could be analyzed in connection with the other areas related by the dynamics of the surface runoff, thus highlighting the reciprocal influences between any different areas.

The declination of the role attributed to the different areas: upper-mountain, intermediate-hillside and lower-valley, helps to highlight the relationships between the different urbanized and non-urbanized places, ensures an effective reading of the hydromorphic complexities involved in urban transformation processes and allows to evaluate the adaptation capacity of a territory, basing on the morphological shape that influences the dynamics of the surface outflows.

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