Climate and Soil Controls on Flood Frequency

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Abstract: - The flood frequency estimation in ungauged basins is an important field that requires the development of innovative statistical tools aimed to improve the available techniques for risk assessment. This research is aimed to better understand and classify the hydrological processes underlying the flood generation exploiting the theoretical model of Iacobellis and Fiorentino [8]. The present paper is oriented to investigate the variables responsible of flood generation, analyzing the effects of climatic and physiographic basin features on the main variables of the theoretical flood probability distributions. Investigations are focused on the scaling relationships between estimates of flood distribution variables and physical features of 33 gauged basins in a wide area of Southern Italy. Results provide interesting information for the research of an analytical derivation of a flood frequency distribution whose parameters are directly correlated to climate and geomorphologic characteristics.

Key-Words: - Floods, Climate-soil-vegetation interaction, Geomorphoclimatic derivation, Probability distribution of floods.

1 Introduction

The analysis of hydrological extremes represents a critical issue for scientific research and technical practice. The reduction of uncertainty in estimating the return period of floods is one of the main challenges for hydrologists and one of the major needs for flood risk prediction and mitigation. In the latest years, the research is oriented to investigate on the physical description of the processes influencing the flood generation in order to define reliable models for floods prediction. In particular, great efforts have been given to the development of flood frequency distribution able to exploit information on the precipitation frequency, vegetation coverage, soil permeability, etc. in order to improve the performances of models for flood prediction in ungauged basins.

A wide literature is oriented to review the available statistical methods for flood peaks estimation. It seems that methods, which renounce to the contribution provided by a full description of physically based phenomena, have achieved their evolutionary limit. These methods, including the regional analysis, make use of statistical procedures which essentially exploit the hydrometric and pluviometric information leaving only a marginal role to other significant data (climate, soil and vegetation).

Therefore, the main purpose of this research is to provide a deeper knowledge of the physical mechanisms involved in the flood generation process with particular regard to their effect on the frequency of floods, enhancing the role of physical basin characteristics within the estimation procedures.

Moreover, the need of improving the application of models for flood prediction to ungauged basins is producing an effort toward a harmonization of models in terms of comparison, classification, identification of hydroclimatic areas and of space-time characteristic scales of application (e.g., [5], [11]).

In this field, it is crucial to investigate on the key variables responsible of flood generation process with the aim to analyse and classify their behaviour for different climatic and geologic environments.

This paper explores the influence of climatic and geomorphologic factors on theoretical flood probability distribution by means of the model proposed by [8] (hereafter called IF model).

In fact, theoretically derived distributions of floods provide a powerful tool based on the probability distribution of rainfall, the absorption processes and the flood routing with the aim to draw the hydrological dynamics of extreme events. In the latest twenty years, many researchers (e.g., [2],[8],[7]) have developed several models based on the original idea of Eagleson [3].

Although theoretically derived distributions may be considered not ready for practical engineering application, they appear to be one of the most promising tools to improve our knowledge on physical processes controlling the flood generation mechanisms. In fact the theoretically derived distributions may be defined adopting a physically based scheme that needs of a strong physical support regarding climatic, geopedologic and morphologic characteristics.

Iacobellis and Fiorentino [8] introduced a theoretical model for the probability distribution of annual maxima of floods, which aims to highlight the stochastic and deterministic factors influencing the flood generation. The model adopts a limited set of physically based parameters accounting for both the geomorphoclimatic features of basins and the random spatial distribution of rainfall.

The model is applied over a wide range of natural basins with different climate, vegetation coverage, soil structure and permeability. Investigated basins belong to Southern Italian Regions of Puglia and Basilicata and Calabria.

2 Theoretical framework

The probability function of peak streamflow can be derived, either in an analytical or synthetic way, from the probability density function of rainfall, by using the functional relationships provided by the basin's hydrologic response.

The theoretical model [8] is based on the following assumptions: (i) the peak flood Q_p can always be represented as the product of two random variates, namely the average runoff per unit area u_a and the peak contributing area a; (ii) the marginal distribution of u_a can be related, at a first order approximation, to that of the rainfall depth occurring in a duration equal to a characteristic response time τ_a of the contributing part of the basin; (iii) τ_a can be supposed to scale with a according to a power law.

Consequently, the probability density function of Q_p can be found as the integral, over the total basin area A (≥a), of that of a times the density function of u_a given a. In particular, it is suggested that u_a can be expressed as a fraction of the excess (net) rainfall, which is simply assumed as the exceedance of total rainfall above a threshold depending on basin adsorption, then:

$$Q_P = \xi\,(i_{a,\tau} - f_a)\, a + q_o \tag{1}$$

where ξ is a constant routing factor, $i_{a,t}$ is the areal rainfall intensity in the duration equal to the lag-time τ_a within the source area a, f_a is the average water loss rate, within the same duration τ_a and area a, q_o is the base flow estimate [8].

The time-space behaviour of the model parameters is controlled by the observed geomorphological power-type relationship. For instance, the mean areal rainfall intensity $E[i_{a,\tau}]$ is usually found to scale with a according to a power law:

$$E\left[i_{a,\tau}\right] = i_1\ a^{-\varepsilon} \quad \text{with} \quad i_1 = E\left[i_A\right]A^{\varepsilon} \tag{2}$$

where i_1 is rainfall intensity referred to the unit area.

Also, in the model the threshold responsible for runoff generation, f_a, (also responsible of the yield of flood events) is in general supposed to scale with the basin area a through a relationship of the type:

$$f_a = f_1\, a^{-\varepsilon'} \quad \text{with} \quad f_1 = f_A\, A^{\varepsilon'} \tag{3}$$

in which f_A represents the average water loss rate when the entire basin contributes to the flood peak, f_1 is water loss in the unit area and ε' is a parameter whose value depends on the average behaviour of hydrological losses in time and space. Indeed, τ_A, $E[i_A]$, f_A, ν, ε and ε' are characteristic features of the basin.

In the proposed model it was assumed that a and u_a are gamma and Weibull distributed respectively.

The average areal water loss f_A may be related to the ratio between the average annual rates of rainfall and flood events, respectively Λ_p and Λ_q, by means of the equation proposed by [6]:

$$f_A = \frac{E\left[i_A\right]}{\Gamma(1+1/k)}\left[\log\left(\frac{\Lambda_p}{\Lambda_q}\right)\right]^{1/k} \tag{4}$$

where k is the exponent of the Weibull distribution of rainfall intensity and equals unity when the variate $i_{a,\tau}$ is exponentially distributed, Γ(·) is the gamma function.

Since u_a and a are supposed to be stochastic dependent variables, the cumulative distribution function of peak streamflow (base process) is derived integrating the joint density function $g(u_a, a)$ over the region $R(q)$ where the peak streamflow is smaller than q depending on u_a and a.

The cdf (cumulative density function) of the annual maximum values of Q_p is obtained, under the hypothesis that flood occurrence is of Poisson type.

Thus, [8] derived an analytical formulation of probability distribution function of the annual maximum values of Q_p with parameters directly correlated to climatic and geomorphologic characteristics:

$$F_{Q_p}(q_p) = \exp\left\{-\Lambda_q \int_0^A \left[\left(\frac{1}{\alpha\Gamma(\beta)}\left(\frac{a}{\alpha}\right)^{\beta-1}\exp\left(-\frac{a}{\alpha}\right) + \delta(a-A)P_A\right) \exp\left(-\frac{\left((q_p-q_o)/(\xi a) + f_1 a^{-\varepsilon'}\right)^k - \left(f_1 a^{-\varepsilon'}\right)^k}{\left(i_1 a^{-\varepsilon}/\Gamma(1+1/k)\right)^k}\right)\right] da\right\} \tag{5}$$

where α and β are position and shape parameters respectively of the probability density function of a and P_A is the finite discrete probability of the total contributing area.

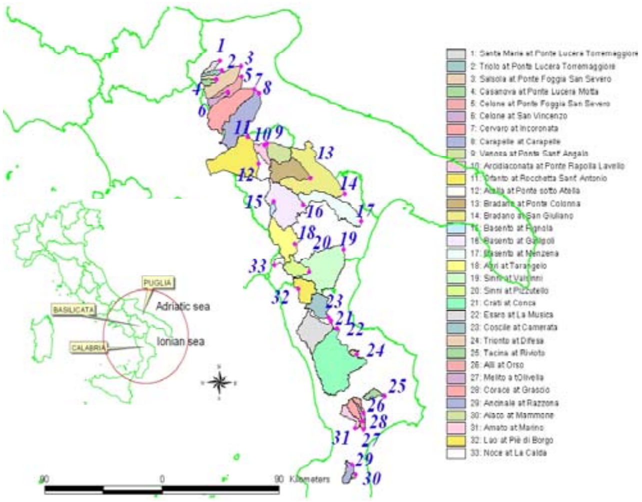


Fig. 1. Puglia, Basilicata and Calabria regions and river basins at the gauging stations considered herein.

3 Climatic, geologic and morphologic features of the investigated zones

The investigated area includes 33 gauged basins of three administrative Regions, namely, Basilicata, Calabria and Puglia, in Southern Italy with area ranging from 40 to 1650 km^2. These regions are quite heterogeneous for climatic, geologic and land use characteristics.

The climate displays drastic changes inside the study area, due to the existing morphological differences. The north-eastern sector (Puglia) is characterized by low hills or flat lands with a hot-dry Mediterranean climate (semiarid or dry sub-humid).

As one proceeds to the West-Southern sector (Basilicata and Calabria), climate becomes more cold and humid.

The annual average rainfall depth goes from a minimum of about 600 mm/year observed in Puglia and a maximum up to 1800 mm in Basilicata and Calabria. Rainfall is distributed quite irregularly over the year, with the highest average shown in the October-March semester, almost twice the amount of the April-September period. July is the least rainy month, while the highest varies from October to January.

The climatic characteristics are well interpreted by the climatic index [12]:

$$I = \frac{h - E_p}{E_p} \tag{6}$$

with h mean annual rainfall depth and E_p mean annual potential evapotranspiration.

The land cover is consistent with climatic features and morphology of the study area. Arid and semi-arid zones are characterized by scarce vegetation, which gradually turns into sub-humid Mediterranean vegetation (Macchia Mediterranea) and pasture land, to finally reach the mountain forest in humid and hyper-humid areas.

The different lithological units that constitute the investigated regions show different type and degree of permeability. Within the examined area, sediments and rocks permeable for primary permeability, rocks permeable because of fissuring, sediments and rocks permeable for primary and secondary permeability can be distinguished.

The system also shows communicating cracks like bedding joints, faults, and intense circulation of groundwater.

On the investigated zone a permeability index ψ (see fig. 2) was calculated:

$$\psi = \psi_h + 0.9\,\psi_m \tag{7}$$

where ψ_h and ψ_m are the fraction of the total area with outcrops belonging respectively to the highly permeable lithoid complexes and lithoid complexes with medium permeability.

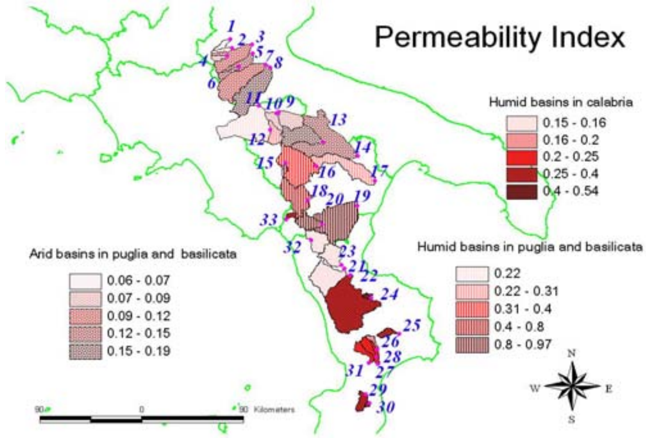


Fig. 2. Mapping permeability index in basins of Puglia, Basilicata and Calabria.

4 Analysis on the hydrological variables involved in theoretical model

4.1 The lag time

The time-space behaviour of the hydrological variables involved in the flood generation is mainly controlled by the variability of the contributing area.

In particular, the basin lag-time τ_A respects the geomorphological power-type relationship with basin area A. With regard to the Puglia and Basilicata regions, [6] found the relationship:

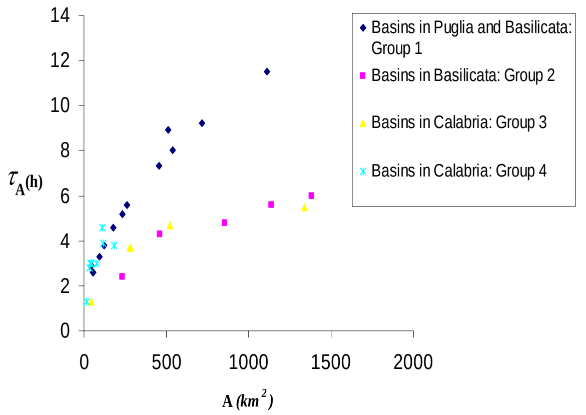
$$\tau_A = \tau_1\, A^{\nu} \tag{8}$$

where τ_A is the lag-time of the basin and ν is a parameter that assumes values close to 0.5.

The main features of the basins considered in the present study are given in table 1.

In particular, basins belonging to Puglia (1 through 12 in tab.1) and to the North-Western Basilicata (15 and 18) can be grouped (Group 1) to give $\tau_1 = 0.39$ [$h{\cdot}km^{-2\nu}$] and $\nu = 0.48$ ($R^2 = 0.97$), while the others belonging to Basilicata region (Group 2) are characterized by $\tau_1 = 0.19$ [$h{\cdot}km^{-2\nu}$] and $\nu = 0.48$ ($R^2 = 0.94$).

Claps et al. [1] analyzed the flood series of 13 basins in the Calabria region (figure 1) with lengths ranging between 15 and 49 years. Basin areas A and lag-times τ_A were taken from [1]. In particular, assuming $\nu = 0.50$, τ_1 is equal to 0.18 [$h{\cdot}km^{-2\nu}$] for basins 21, 22, 23, 32, 33 (Group 3) very close to the one observed in Basilicata. For the other basins (Group 4) $\tau_1 = 0.36$ [$h{\cdot}km^{-2\nu}$] assumes a value very close to the one observed in Puglia (see fig.3).



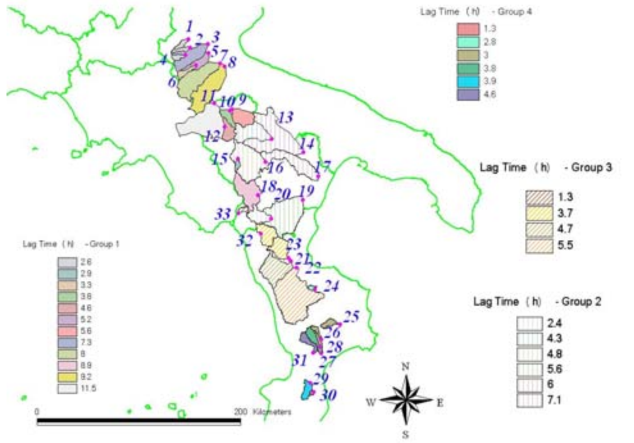


Fig. 3. Basin lag-time τ_A as a function of the basin area A and map of the basin lag-time τ_A on investigated regions.

n.	Basins	I	A (km²)	$E[i_A]$ (mm/h)	f_A (mm/h)	ε	ε'	τ_A (h)
1	Santa Maria at Ponte Lucera Torremaggiore	-0.28	58	1.99	6.48	0.39	0.5	2.6
2	Triolo at Ponte Lucera Torremaggiore	-0.25	56	2.88	8.67	0.39	0.5	2.6
3	Salsola at Ponte Foggia San Severo	-0.27	455	0.80	1.89	0.39	0.5	7.3
4	Casanova at Ponte Lucera Motta	-0.14	57	2.04	5.62	0.39	0.5	2.6
5	Celone at Ponte Foggia San Severo	-0.24	233	1.05	2.09	0.39	0.5	5.2
6	Celone at San Vincenzo	-0.06	92	1.63	3.41	0.39	0.5	3.3
7	Cervaro at Incoronata	-0.19	539	0.78	1.80	0.39	0.5	8
8	Carapelle at Carapelle	-0.23	715	0.71	1.19	0.39	0.5	9.2
9	Venosa at Ponte Sant'Angelo	-0.17	263	1.02	2.64	0.39	0.5	5.6
10	Arcidiaconata at Ponte Rapolla Lavello	-0.04	124	1.40	3.67	0.39	0.5	3.8
11	Ofanto at Rocchetta Sant'Antonio	0.16	1111	0.77	1.13	0.39	0.5	11.5
12	Atella at Ponte sotto Atella	0.17	176	1.58	1.76	0.39	0.5	4.6
13	Bradano at Ponte Colonna	-0.08	462	1.44	2.36	0.33	0.5	4.3
14	Bradano at San Giuliano	-0.17	1657	1.06	2.17	0.33	0.5	7.1
15	Basento at Pignola	0.7	42	2.16	0.07	0.39	0	2.9
16	Basento at Gallipoli	0.28	853	1.26	0.97	0.33	0	4.8
17	Basento at Menzena	0.08	1382	1.16	1.21	0.33	0.5	6
18	Agri at Tarangelo	0.47	511	1.03	0.14	0.39	0	8.9
19	Sinni at Valsinni	0.57	1140	1.54	0.07	0.33	0	5.6
20	Sinni at Pizzutello	1.26	232	2.32	0.03	0.33	0	2.4
21	Crati a Conca	0.61	1339	1.60	1.40	0.28	0	5.5
22	Esaro a La Musica	0.77	520	1.80	3.50	0.28	0	4.7
23	Coscile a Camerata	0.65	285	2.40	4.50	0.28	0	3.7
24	Trionto a Difesa	0.90	32	4.10	1.00	0.28	0	2.8
25	Tacina A Rivioto	1.43	79	6.70	3.20	0.32	0	3
26	Alli A Orso	1.26	46	4.30	5.80	0.28	0	3
27	Melito a Olivella	0.72	41	4.10	4.50	0.28	0	3
28	Corace a Grascio	0.90	182	2.90	3.40	0.28	0	3.8
29	Ancinale a Razzona	1.34	116	6.40	4.40	0.32	0	3.9
30	Alaco a Mammone	1.66	15	12.10	7.40	0.32	0	1.3
31	Amato a Marino	0.86	113	2.50	2.60	0.28	0	4.6
32	Lao a Piè di Borgo	1.16	280	2.20	3.90	0.28	0	3.7
33	Noce a La Calda	1.58	42.5	4.20	2.90	0.28	0	1.3

Table 1. Investigated river basins and their main hydrological features.

4.2 The space-time average of rainfall intensity

Exploiting the relationship between the averages of annual maxima and the base process, the expected value of the space-time averaged of rainfall intensity, with regard to the total area of the basin, occurring in the duration τ_A may be evaluated by means of:

$$E[i_A] = \frac{p_1 \tau_A^{n-1}\left[1-\exp\left(-1.1\tau_A^{0.25}\right)+\exp\left(-1.1\tau_A^{0.25}-0.004A\right)\right]}{\Lambda_p S_{\Lambda_p}} \qquad (9)$$

in which the *U.S. Weather Bureau* areal reduction factor is used (see [3]). $\Lambda_q S_{\Lambda q}$ is a factor that allows to elapse from the mean of the base process to the mean of maxima. p_1 and n are the parameters of the at-site intensity-duration frequency curve (idf) referred to the expected value of the annual maximum rainfall intensity in the duration τ_A.

Thus, with regard to equation (2) described in previous section, we can get regional estimated values of parameters i_1 and ε. In particular for Puglia and Basilicata regions, with reference to the same two groups of basins already recognized as homogeneous, with respect to the lag time-area relationship, [6] got i_1 = 10 [$mm\ h^{-1}\ km^{-2\varepsilon}$], ε = 0.39 (Group 1) and i_1 = 13 [$mm\ h^{-1}\ km^{-2\varepsilon}$], ε = 0.33 (Group 2) respectively.

For Calabria region, basins belonging to the Tyrrhenian and Central zones (from 21 to 24, from 26 to 28, from 31 to 33 table 1) follow (e.g. [1]) the power relationships in equation (2) with parameters i_1 = 11.5 [$mm\ h^{-1}\ km^{-2\varepsilon}$] and ε = 0.28, while basins of the Ionian Zone (25, 29 and 30 table 1) are characterized by higher rainfall intensities with i_1 = 28.8 [$mm\ h^{-1}\ km^{-2\varepsilon}$] and ε = 0.32 ($R^2$ = 0.98).

It is worth noting that (see fig. 4) excluding basins belonging to Ionian zones of Calabria, the investigated basins maintain the same behaviour with respect to the space-time averaged intensity of the rainfall.

4.3 The average space-time infiltration intensity

The variable f_a represents the threshold responsible for the difference between mean annual number of flood events and mean annual number of rainfall events. The average water loss rate, f_A, when the entire basin contributes to the flood peak is supposed to scale with the basin area A through a relationship of the type:

$$f_A = f_1\, A^{-\varepsilon'} \qquad (10)$$

For each basin of area A, the characteristic value f_A of the total abstraction rate can be estimated by means of equation (4) where the water loss parameter f_A, is related to mean annual number of rainfall and flood events and the expected value of the space-time averaged of rainfall intensity measured during the storm in a duration τ_A, where τ_A is the lag time of the basin of surface area A.

Assuming the hypothesis of Weibull distribution of rainfall intensity and poissonian occurrence of events, the distribution of annual maxima turns out to be a Power Extreme Value (PEV) type.

A regional estimation based on a PEV-ML procedure was applied to the study area; regional values of k (e.g. [6]) were assumed equal to 0.8 in Puglia and Basilicata (resulting by regional analysis performed on the annual maxima rainfall series recorded at 178 gauging stations) and 0.53 (e.g. [1]) in Calabria (resulting by regional analysis performed on the annual maxima in 225 raingauge stations with record length not less than 20 years).

Using the values of E[i_A], Λ_p and Λ_q observed, we can obtain the estimates of f_A. Exploiting the classification based on the climatic index I, we look separately at results referring to dry and humid basins, evaluating equation with respect to basins belonging to climatically homogeneous regions.

The equation 10 shows the variability of f_A versus the area A for the studied basins. In particular in arid regions, where significant water losses are due to initial storage and soil moisturizing, the values of f_A for basins from arid to sub-humid (I < 0.3) are displayed in fig 5.

They show a remarkable scale relationship, as the log-linear regression furnishes f_1 = 37 [$mm\ h^{-1}\ km^{-2\varepsilon'}$] and ε'= 0.5 ($R^2$ = 0.76). On the other hand, see fig.6, f_A values relative to basins in Puglia, Basilicata and Calabria with positive climatic index are shown.

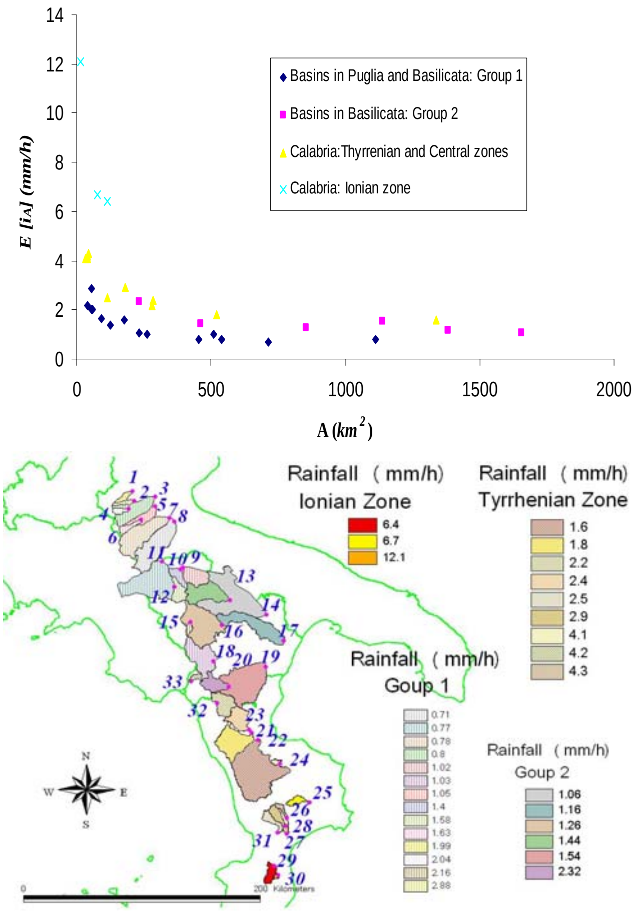


Fig. 4. Average space-time intensity of rainfall versus basin area A and the map of the same variable over Puglia, Basilicata and Calabria regions.

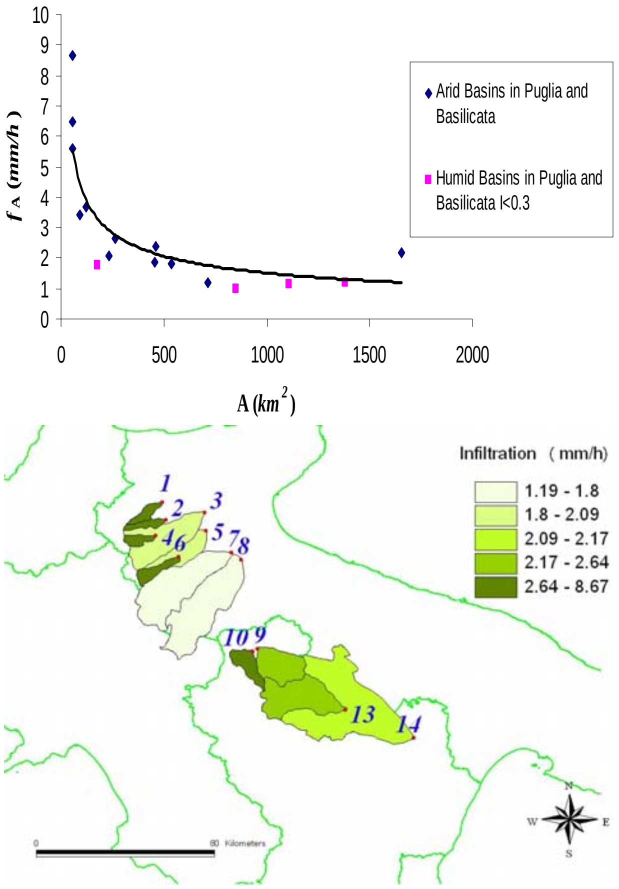


Fig. 5. Average space-time water loss intensity versus basin area A and the map of the same variable in arid basins of Puglia and Basilicata.

These values are quite low and do not show any dependence on area. With regard to them, one can obtain $f_1 = E[f_A] = 0.7$ [$mm\ h^{-1}$] and $f_1 = 3.7$ [$mm\ h^{-1}$] respectively and ε' = 0. In humid areas, where water losses during a flood event are mainly given by the infiltration rate at the saturation state, f_A is expected to be constant.

The analysis carried out in a recent study [4], regarding the use of a distributed model called DREAM [10] to simulate a large number of extreme events, gave similar results about the infiltration intensity as a function of the contributing area. In Calabria, f_A is almost constant (figure 6). In the figure, the horizontal line represents a typical behaviour of humid basins for which the water loss is not influenced from the area. Small basins are responsible of the observed deviation from this behaviour, for them the local heterogeneity may lead to consistent oscillations of the runoff threshold. The constant value represented by the horizontal line is quite higher respect to that observed in Basilicata over basins with similar climatic conditions.

Nevertheless such behaviour may be justified considering that in Calabria the distribution of rainfall maxima is characterized by a higher skewness and also the average of maxima is higher in the Jonian coast of Calabria. Furthermore basins in Calabria are characterized by higher mean permeability respect to basins in Basilicata.

While in fig 5 one can observe a scaling effect, this is not present in fig 6.

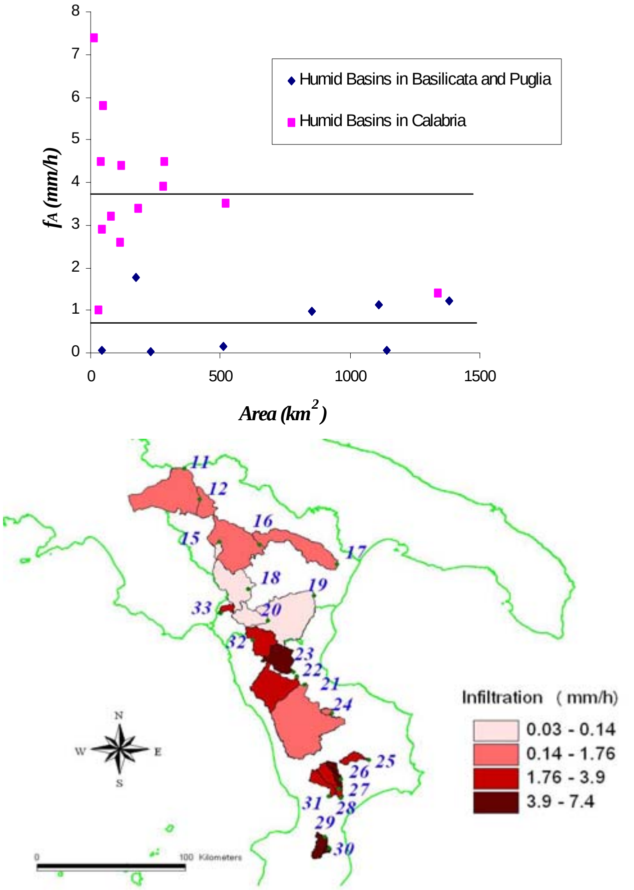


Fig. 6. Average space-time water loss intensity versus basin area A and the map of the same variable in Humid basins of Calabria and Basilicata.

4.4. The influence of physical factors on mean annual number of flood events

The influence of climate on the average annual number of flood peaks, Λ_q, is analyzed in this section with the aim to characterize the ratio, Λ_q/Λ_p, between mean annual number of flood and rainfall events, that influences the theoretical derived distribution of floods. 33 catchments in a wide area that comprises Basilicata, Puglia and Calabria (southern Italy) are considered with climates ranging from humid to semi-arid, evaluated by means of the climatic index I [12].

The values of Λ_q and Λ_p used here, are those estimated by [9] and [1] and are displayed in table 2.

A regional analysis of frequency distribution of floods was performed on these basins. Both Λ_q and the ratio Λ_q/Λ_p were found to be strongly related to I [9].

Looking at the relationship (4), it is interesting to note that the generation of flow peak (that controls the flood number ratio Λ_q/Λ_p) mainly depends on rainfall and infiltration variables; thus, being the slope of the scaling relationship (2) of areal rainfall intensity substantially homogeneous over the three

n.	Basins	I	A (km^2)	Λ_p	Λ_q	Λ_q/Λ_p
1	Santa Maria at Ponte Lucera Torremaggiore	-0.28	58	44.6	2.6	0.06
2	Triolo at Ponte Lucera Torremaggiore	-0.25	56	44.6	3.1	0.07
3	Salsola at Ponte Foggia San Severo	-0.27	455	44.6	5	0.11
4	Casanova at Ponte Lucera Motta	-0.14	57	44.6	3.7	0.08
5	Celone at Ponte Foggia San Severo	-0.24	233	44.6	6.6	0.15
6	Celone at San Vincenzo	-0.06	92	44.6	6.1	0.14
7	Cervaro at Incoronata	-0.19	539	44.6	5.2	0.12
8	Carapelle at Carapelle	-0.23	715	44.6	8.5	0.19
9	Venosa at Ponte Sant' Angelo	-0.17	263	44.6	4.2	0.09
10	Arcidiaconata at Ponte Rapolla Lavello	-0.04	124	44.6	4.1	0.09
11	Ofanto at Rocchetta Sant' Antonio	0.16	1111	21	4.7	0.22
12	Atella at Ponte sotto Atella	0.17	176	21	6.3	0.30
13	Bradano at Ponte Colonna	-0.08	462	21	4	0.19
14	Bradano at San Giuliano	-0.17	1657	21	2.9	0.14
15	Basento at Pignola	0.70	42	21	19.6	0.93
16	Basento at Gallipoli	0.28	853	21	8.5	0.40
17	Basento at Menzena	0.08	1382	21	6.6	0.31
18	Agri at Tarangelo	0.47	511	21	16.8	0.80
19	Sinni at Valsinni	0.57	1140	21	19.1	0.91
20	Sinni at Pizzutello	1.26	232	32	31	0.97
21	Crati a Conca	0.61	1339	20	7.5	0.38
22	Esaro a La Musica	0.77	520	20	3	0.15
23	Coscile a Camerata	0.65	285	20	3.2	0.16
24	Trionto a Difesa	0.90	32	20	10.7	0.54
25	Tacina A Rivioto	1.43	79	10	4	0.40
26	Alli A Orso	1.26	46	20	4	0.20
27	Melito a Olivella	0.72	41	20	4.8	0.24
28	Corace a Grascio	0.90	182	20	4.5	0.23
29	Ancinale a Razzona	1.34	116	10	3.3	0.33
30	Alaco a Mammone	1.66	15	10	3.5	0.35
31	Amato a Marino	0.86	113	20	5	0.25
32	Lao a Piè di Borgo	1.16	280	34	5.5	0.16
33	Noce a La Calda	1.58	42.5	34	13.7	0.40

Table 2. Characteristics of the investigated river stations: a look at relationship between Λ_q, Λ_p and climatic index.

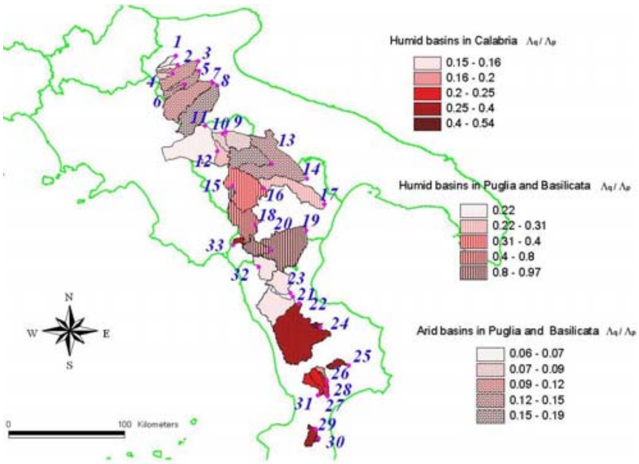


Fig. 7. Mapping mean annual number of flood and rainfall events ratio in basins of Puglia, Basilicata and Calabria.

regions, the different behaviour of the ratio Λ_q/Λ_p depends only by the scaling properties of the equations (3).

Therefore, with regard to the arid zones in Puglia and Basilicata, due to the significant tendency of f_A to decrease as the basin size increases, one may expect this ratio to increase at increasing A. Nevertheless, since f_A and $E[i_A]$ tend to scale with A by power laws with exponents not far from each other, this increase may be not very significant.

In comparison with the opposite case of humid basins of Puglia, Basilicata and Calabria regions, where f_A assumes a constant behavior with basin Area, one can note a tendency of the ratio Λ_q / Λ_p to decrease as A increases (see fig 7), and it can be noticed that, because of the high permeability, basins (see fig 2) belonging to the Calabria region, there is a lower capability to generate floods regarding the other humid river basins of the investigated zone.

4 Conclusion

The relationships between theoretical model variables and climatic, physical and geomorphological basin parameters directly measurable provides a contribution to the analysis of flood frequency for ungauged basins.

In this paper, geomorphological relationships between the main variables which govern the mechanism of flood formation in the theoretical model proposed by [8] (basin lag-time "τ_A", space-time average of rainfall intensity "$E[i_a]$", average space-time intensity of the infiltration "f_a", mean annual number of flood and rainfall events ratio "Λ_q/Λ_p") and climatic and physiographic basin parameters (climatic index "I" permeability index "ψ") are analyzed in 33 gauged basins belonging to a wide area of Southern Italy characterized by different climatic characteristics, in order to provide a valid tool to classify theoretical model characteristics for different climatic and geomorphologic environments.

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