UPDATING FLOOD ANNUAL MAXIMA IN SOUTHERN ITALY

AGGIORNAMENTO DELLE PORTATE AL COLMO DI PIENA IN ITALIA MERIDIONALE

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Abstract esteso

Negli ultimi anni, numerose ricerche hanno evidenziato una crescente preoccupazione riguardo agli effetti che i cambiamenti climatici hanno sul ciclo idrologico e sugli estremi idrologici. In particolare, le analisi statistiche su serie idrologiche lunghe oppure su dati modellati mostrano tendenze contrastanti in diverse aree d'Europa. In aggiunta, l'assenza di osservazioni continue e le significative alterazioni subìte da alcuni bacini idrografici rendono complesse le valutazioni sugli effetti indotti dai cambiamenti climatici. Tali criticità sono particolarmente sentite nel Sud Italia dove il monitoraggio idrometrico è spesso discontinuo, raramente esistono scale di deflusso aggiornate e i territori hanno subito importanti trasformazioni antropiche. Il presente lavoro si pone l'obbiettivo di aggiornare le misure di portata al colmo di piena in Italia meridionale nel periodo 1920-2021 utilizzando misurazioni dirette ed indirette. I numerosi dati di portata al colmo mancanti sono stati ricostruiti mediante scale di deflusso di piena appositamente definite ovvero utilizzando le portate giornaliere per ricavare le portate di piena equivalenti attraverso la funzione empirica di Fuller. Le serie ottenute sono state, poi, analizzate mediante il test non parametrico di Mann-Kendall al fine di rilevare possibili tendenze. I risultati del presente studio forniscono delle indicazioni preliminari sulle tendenze delle piene negli ultimi cinquant'anni nel Sud Italia superando i limiti legati alle disponibilità di dati misurati.

Abstract

Recent studies have highlighted concerns about the impact of climate change on the hydrological cycle and extremes. Analysis of long hydrological series or modeled data in Europe has revealed conflicting trends. The lack of continuous observations and significant alterations in some watersheds pose challenges for quantifying the effects of climate change, particularly in Southern Italy. The objective of this study is to update flood time-series in Southern Italy from 1920 to 2021 using direct and indirect measurements. Missing data were reconstructed using specific flood rating curves or daily flow rates to estimate equivalent flood peaks. The resulting series were analyzed using the nonparametric Mann-Kendall test to provide a preliminary description on flood trends in Southern Italy over the past 50 years.

1. Introduction

Flood studies in Southern Italy have long been hindered by chronic limitations in data availability. The existing data is often discontinuous and inadequate, particularly in the past four decades. This lack of comprehensive data has significantly impeded efforts to update flood studies and has restricted our ability to gain insights into flood trends. This limitation has been highlighted in previous research, such as the study by Blöschl et al. (2017) that identified a negative trend in flood time-series in Southern Italy based on available data.

Until now, many environmental authorities and agencies continue to rely on flood studies conducted as part of the VAPI project (Valutazione delle Piene in Italia), which utilized flood data from the

period between 1920 and 1980 (see, e.g., Versace et al., 1989; Cao et al., 1991; Copertino and Fiorentino, 1992; Cannarozzo et al., 1993; Rossi and Villani, 1995; Claps and Fiorentino, 1998). However, since the completion of the VAPI project, our ability to advance our understanding of flood processes has been limited by the lack of knowledge regarding recent discharge measurements in most rivers. Similar challenges have been encountered in the analysis of rainfall maxima, although the availability of a large number of rainfall gauges has helped address issues related to data discontinuity and missing information. For instance, Avino et al. (2021, 2022) undertook the task of reconstructing the time series of rainfall maxima in Southern Italy, enabling a comprehensive examination of rainfall patterns and trends. Their study revealed positive trends in short-duration rainfall events, indicating an increase in their intensity and/or frequency. Considering the ongoing anthropic transformation of river basins, these rainfall changes have the potential to impact flood statistics.
Exploiting previous experiences in data reconstruction in rainfall time-series, we explored the possibility to fill the existing gaps in order to update flood statistics, which are still very limited in Southern Italy. With this aim, the work integrates reconstruction methods, statistical methods, and hydraulic modelling to reconstruct the hydrological time-series of peak flood discharges in the period 1920-2021. Although the reconstruction was feasible for only a limited number of cross-sections, it successfully facilitated the development of a consolidated database of floods. This database offers a comprehensive overview of flood dynamics in Southern Italy, providing valuable insights into the patterns and characteristics of these events. Despite the constraints, the reconstruction effort has significantly enhanced our understanding of flood dynamics in the region.

1. Methodology

1.1 Database

In Italy, the hydrological monitoring has been performed by National Hydrographic and Mareographic Service (SIMN) for several years. In 2002, the entire monitoring network were transferred to regions with a Prime Ministerial Decree of the 24/07/2002. Therefore, its management was assigned in most of the cases to the Regional Department of Civil Protection (or to Regional Agencies) which focused mainly on water level measurements. This produced a critical discontinuity in most of the time series of floods.
In order to maximize the value of available information on floods, we reconstructed the fragmented information on floods using different sources such as: Publication n. 17, Hydrological Yearbooks, and water level observations obtained from the Regional Department of Civil Protection. More specifically, the hydrological dataset was extracted from:

- Publication n. 17 (Ministero LL.PP., 1935-1980) was used to extract the maximum daily and flood peaks for the period 1935-1980;
- The Hydrological Yearbooks (Part II) was used to extract the annual maximum values of the average daily discharges, the flow rating curves of the year, as well as information about the hydrometric stations (such as, the stage at zero flow, the basin area, the location of the stations) since 1918-1994;
- Between 1995 and 2021, the Regional Department of Civil Protection primarily provided water level measurements, with the exception of the Puglia Region, which also provided discharge measurements.

The amount of information available differ from one region to the other. In Puglia Region, the Civil Protection has kept publishing the Hydrological Yearbooks until 2012, providing continuous time-series of peak flood discharge. In Campania, Calabria, and Basilicata Regions, instead, flood records are available until 1980 from the Publication n.17. Therefore, no flood peak measurements are available for the most recent years. Therefore, the most recent data have been reconstructed by using

indirect measurements (e.g., water level measurements) for all stations where it was possible to reconstruct the Flood Rating Curves (FRCs).
The database includes 42 hydrometric stations of the SIMN monitoring network in Campania, Lazio, Puglia, Calabria and Basilicata Regions. These stations have been selected after a preliminary screening of the information availability and measurements continuity. In fact, historical monitoring cross-sections have been preserved only in limited cases that include the present selection. The characteristics of the stations are listed below in Table 1.

Table 1 – Main characteristics of the hydrometric stations investigated in the present study
Tab. 1 – *Caratteristiche delle stazioni idrometriche analizzate nel presente lavoro.*

River	Station	Region	Mean Annual Rainfall (mm/year)	Area (km^2)	Monitoring Period	Number of years of observation (R_0)
Alento	Casalvelino	Campania	1279	280	1961-1980	18
Calore Irpino	Apice	Campania	1121	533	1933-1973	39
Calore Irpino	Montella	Campania	1431	123	1931-1978	40
Calore Irpino	Solopaca	Campania	1105	2966	1965-1980	15
Sele	Contursi	Campania	1338	329	1932-1979	32
Sele	Albanella	Campania	1215	3235	1929-1980	45
Sele	Scafa di Persano	Campania	1281	2396	1929-1941	13
Tammaro	Pago Veiano	Campania	1087	557	1958-1976	18
Tammaro	Paduli	Campania	1010	675	1954-1970	16
Volturno	Amorosi	Campania	1371	2015	1931-1980	42
Volturno	Cancello Arnone	Campania	1179	5558	1925-1970	31
Volturno	Ponte Annibale	Campania	1177	5442	1915-1942	16
Garigliano	Ponte Sant'Ambrogio	Lazio	1393	3500	1929-1942	12
Garigliano	Suio (San Castrese)	Lazio	1384	4763	1933-1942	10
Liri	Sora	Lazio	1124	1272	1929-1976	42
Liri	Isola Liri	Lazio	1173	1410	1929-1962	26
Sacco	Ceccano	Lazio	1270	923	1959-1980	19
Ofanto	S. Samuele di Cafiero	Puglia	724	2716	1929-2020	81
Ofanto	Cairano	Puglia	1031	272	1963-1994	30
Atella	P.te sotto Atella	Puglia	837	158	1934-2020	71
Ofanto	Monteverde	Puglia	902	1028	1956-2020	60
Ofanto	Rocchetta S. Antonio	Puglia	844	1120	1926-1952	22
Arcidiaconata	P.te Vecchio Rapolla	Puglia	772	124	1952-2020	56
Lapilloso	P.te SS 168	Puglia	706	29.5	1973-2012	31
Venosa	P.te Ferroviario	Puglia	649	201	1973-2020	35
Venosa	P.te S. Angelo	Puglia	666	261	1929-1971	34
Carapelle	Carapelle	Puglia	602	720	1935-1980	36
Carapelle	P.te Vecchio Ordona	Puglia	605	506	1986-2020	35
Cervaro	Incoronata	Puglia	685	657	1928-2020	80
Celone	S. Vincenzo	Puglia	716	86	1967-2012	36
Celone	P.te Foggia-S. Severo	Puglia	653	256	1935-2015	62
Vulgano	P.te Troia Lucera	Puglia	697	94	1965-2020	56
Salsola	Casanova	Puglia	676	43.1	1965-2020	50
Casanova	P.te Lucera-Motta	Puglia	657	52.3	1965-2020	46
Salsola	P.te Foggia -S. Severo	Puglia	681	463	1933-2020	66
Triolo	P.te Lucera-Torremaggiore (1)	Puglia	625	54	1943-2020	33
Canale S.Maria	P.te Lucera-Torremaggiore (2)	Puglia	610	59	1948-2020	43
Bradano	S.S. 106	Basilicata	672	2743	1933-2020	19
Sinni	Episcopia-Pizzutello	Basilicata	1583	233	1925-2020	27
Lao	Piè di Borgo	Calabria	1569	279	1927-1975	24
Ancinale	Razzona	Calabria	1716	116	1927-1984	50
Coscile	Camerata	Calabria	1249	303	1928-1978	29

2. Reconstruction Methods

Flood reconstruction exploited two methods: 1) the use of Flood Rating Curves (FRCs) applied on the recent water levels measurements and 2) the empirical reconstruction based on daily mean discharge measurements.

Flow rating curves (FRCs) are critical for discharge estimations (Chow, 1959; Fenton and Keller, 2001; Kumar, 2011; Manfreda et al., 2018). They are generally derived with annual surveys or alternatively using hydraulic simulations. Both procedures require topographic survey of the cross sections, which may change over the years). Moreover, it is difficult to quantify the roughness coefficients in the riverbed (Bartolini et al., 2016)

Given difficulties associated with the description of the FRCs especially for low flows and given that the main channel may change dynamically one year after the other, it is challenging to reconstruct FRC without discharge observations. Nevertheless, changes of the cross-section geometry caused by ordinary discharges would have a negligible influence on higher water level and discharge values (Claps et al., 2010).

When daily annual maxima discharges are available, it is possible to derive flood peaks with the empirical method proposed by Fuller (1914):

$$Q_{max} = Q_{med} \cdot (1 + 2.66 \cdot A^{-0.3}) \tag{1}$$

where: Q_{max} is the flood peak; Q_{med} is the mean daily discharge; A is the river basin area in km^2. More details about this kind of approaches are discussed in Taguas et al. (2008).

The function chosen for the calibration of FRCs was the one proposed by Herschy (1985):

$$Q = a \cdot (h - h_0)^b \tag{2}$$

where: Q is the discharge; h is the water level; a and b are coefficients to be calibrated; h_0 represents the stage at zero flow (datum correction).

The parameters of the FRCs were obtained by interpolating the flood peak values and the maximum water level extracted from the Hydrological Yearbooks. In particular, the maximum water level values were derived using the flow rating curves reported in the Hydrological Yearbooks (part II, sec. C). The flow rating curves adopted in the Hydrological Yearbooks are:

$$Q = d_1 + c_1 \cdot (h - l_0) \tag{3}$$

$$Q = c_2 \cdot (h - l_0)^{3/2} \tag{4}$$

where: c_1, d_1 and c_2 are calibration coefficients; l_0 represents the stage at zero flow.

Therefore, for each year and station, the annual flow rating curves were collected. It is worth to mention that the formulation is not always available but is has been interpolated using the pairs of values reported in a specific year.

By using the obtained curves, the annual flood peaks were transformed into the annual maximum water level. In order to test the reliability of the derived model, the calibrated flow rating curves were compared to the numerical FRCs obtained using hydraulic simulations by means of the software HEC-RAS (Brunner, 2002). The reconstruction error was evaluated using two different error indices: the Root Mean Square Error (*RMSE*) and the Mean Absolute Percentage Error (*MAPE*):

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n_e}(Q_{st,i} - Q_{oss,i})^2}{n_e}} \tag{5}$$

$$MAPE = \frac{1}{n_e}\sum_{i=1}^{n_e}\left|\frac{Q_{oss,i} - Q_{st,i}}{Q_{oss,i}}\right| \cdot 100 \tag{6}$$

where: $Q_{oss,i}$ represents the value of the annual maximum of peak flood discharge relative to the i-th year; $Q_{st,i}$ represents the value of the annual maximum of peak flood discharge, estimated with the FRC, relative to the i-th year; n_e represents the number of years.

3. Statistical Analysis

The next step was the statistical analysis of the historical and reconstructed data in order to test the reliability of the reconstruction techniques and verify the trend of the flood time-series after the reconstruction of recent flood events.
The Kolmogorov-Smirnov statistical tests (in the two-sample version) and the Mann-Kendall trend test were performed to investigate the similarity between the reconstructed samples and the historical one. If the reconstructed sample belong to the same probability distribution of the historical one, the complete time-series of discharges can be used to check the presence of significant trends.
The non-parametric estimate of the trend slope, called Sen's slope (Sen, 1968) was calculated. In detail, the trend slope is defined as the median of the slopes β_j:

$$\beta_j = \frac{Q_i - Q_k}{i - k} \tag{7}$$

where: Q_i are the annual maxima of discharges at time i or k with $i > k$ and $j = 1, ..., W$, and W is the total number of pairs of discharge observations.
Positive values indicate an upward trend, while negative values indicate that there is a negative trend in the time-series. The advantage of this method is represented by the fact that the test is not affected by outliers and its value defined the magnitude of the detected trend.

4. Results

One of the relevant outcomes of the present research is represented by the definition of FRC, whose accuracy has been obtained comparing these functions with the outcomes of a hydraulic simulations. Parameters of the FRCs obtained within the present study are given in Table 2, together with the determination coefficient (R^2). In addition, the errors associated to the use of the two reconstruction methods have been defined using contemporary instantaneous flood peaks and daily discharge measured in each station. The errors associated to each station are also given in Table 2, where the values of the RMSE (for both the reconstructed approaches: Fuller and FRC methods) and the MAPE are given. For most of the stations, the results are extremely encouraging with some exception which may be due to the displacement of the monitoring stations and changes of the stage at zero flow not reported in the Hydrological Yearbooks, and the changes in the cross-section geometry caused by exceptional flood events.
In order to provide a description of the main outcomes of the study, an example of application to the station of Cancello Arnone on the Volturno river will be discussed more in details. The validation of the FRCs have been carried out with numerical simulations performed using a 5-meters DEM as input for geometry description and a satellite landcover data for the definition of surface roughness (e.g., Manning coefficient in the main channel at Cancello Arnone was set equal to 0.03). The comparison between the simulation and the FRC reconstructed from pairs of flood measurements extracted from the past can be observed in Figure 1. The graph provides an example applied to the station of Cancello Arnone, where it can be noticed that the two functions have a similar behaviour. The reconstruction procedure allowed obtaining homogeneous and continuous flood time-series. The characteristics of the reconstruction, regarding the Cancello Arnone station, are shown in Figure 2. Each reconstructed time-series is made by the three data samples, which are:

- R_0: historical floods collected from Publication No 17 (1920-1980);
- R_1: sample of floods reconstructed using the Fuller method (1980-1994);
- R_2: sample of floods reconstructed with the calibrated FRCs (1995-2021).

Table 2 - Parameters of the flood rating curves defined according to Eq. 2 and rror indices related to the two reconstruction methods (FRC and Fuller's method)

Tab. 2 - *Parametri della scala di deflusso di piena secondo l'espressione in Eq. 2 e Indici di errore relativi ai due metodi di ricostruzione (FRC e metodo di Fuller)*

Station	E[Q] (m³/s)	Flood Rating Curve				MAPE – FRC (-)	RMSE - FRC (m³/s)	RMSE - Fuller (m³/s)
		a	*b*	h_0	R^2			
Cancello Arnone	1115	17.37	2.3	0.054	0.81	0.08	111	110
Ponte Annibale	1422	33.05	2	0.046	0.74	0.15	265	-
Amorosi	651	35.55	2.18	0	0.7	0.2	151	103
Contursi	229	52.69	1.41	0.98	0.69	0.25	104	108
Scafa di Persano	872	62.62	2.08	0	0.92	0.09	82	236
Albanella	1225	4.44	2.87	0	0.84	0.18	281	451
Montella	52	7.86	1.87	0	0.57	0.17	16	18
Apice	333	129.23	1.18	0.9	0.79	0.28	89	135
Solopaca	995	15.15	2.2	0	0.97	0.1	95	323
Casalvelino	261	12.65	1.79	0	0.91	0.08	23	105
Pago Veiano	196	62.94	1.83	0	0.58	0.3	60	66
Paduli	201	12.7	2.44	0	0.73	0.45	69	-
Sora	169	68.72	1.4	0.49	0.95	0.1	30	44
Isola Liri	175	80.21	1.47	0.05	0.77	0.22	68	-
Ceccano	263	9.4	2.45	1.22	0.77	0.07	50	-
P.te Sant'Ambrogio	912	67.84	1.57	0	0.76	0.06	75	-
Suio (San Castrese)	909	0.02	1.41	0	0.71	0.14	104	-
S.S. 106	506	1.83	3.35	0	0.59	0.47	323	288
Episcopia-Pizzutello	238	36.25	1.45	0	0.76	0.19	68	107
Pie di Borgo	233	54.35	1.66	0	0.7	0.26	69	-
Razzona	76	12.11	2.08	0	0.69	0.36	29	-
Camerata	74	12.84	2.71	0.19	0.75	0.24	21	-

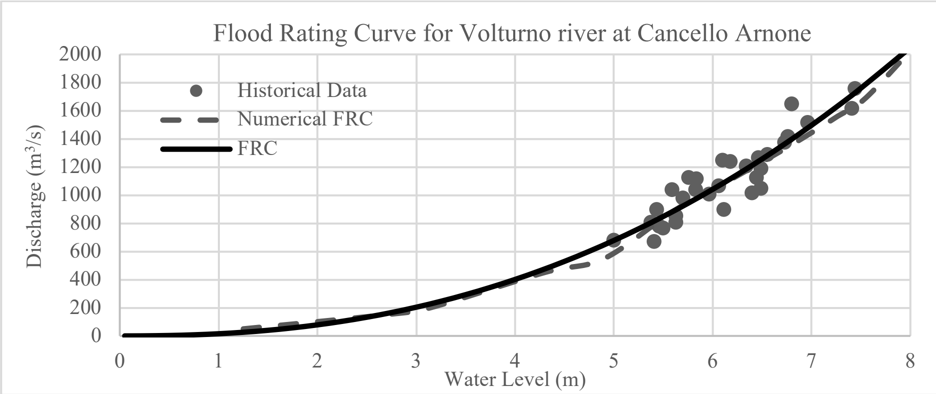

Figure 1 - Graphical comparison between measured data, FRC (continuous line) calibrated on historical data and numerical FRC obtained with HEC-RAS

Fig. 1 - *Confronto tra le scale di deflusso di piena derivate e simulate con modello idraulico e i dati misurati*

The implemented approaches successfully reconstructed time-series of floods in an area with limited information. The reliability of the reconstruction methods was assessed using the Two-Sample Kolmogorov-Smirnov (KS) test, which indicated that the reconstructed data samples exhibited the same probability distribution as the historical data in 50% of the stations (see Table 3). In these cases, the initial observed dataset and the reconstructed database are statistically homogeneous.

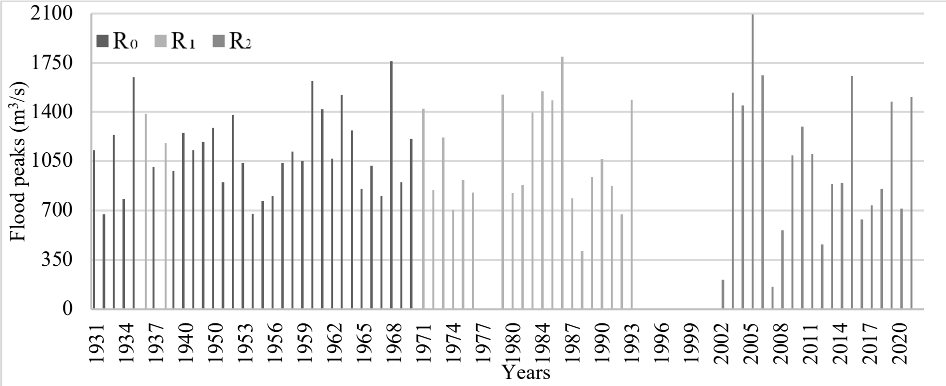

Figure 2 - Time-series of flood peaks for the Cancello Arnone station (Volturno river) reconstructed by means of Fuller method (sample R_1) and FRC approach (R_2)

Fig. 2 - *Serie storica delle portate al colmo di piena della stazione di Cancello Arnone (fiume Volturno) ricostruita con metodo Fuller (campione R_1) e approccio FRC (R_2)*

Table 3 - Number of historical flood observations (R_0), floods reconstructed with Fuller's method (R_1) and the FRC (R_2). In addition, the results of the Two-Sample Kolmogorov-Smirnov test (H-KS) applied on the reconstructed samples compared with the original ones, the Mann-Kendall test (H-MK) and the Sen's slope (b) estimate applied on the complete reconstructed time-series are reported

Tab. 3 – *Osservazioni di portata al colmo (R_0), dati ricostruiti con il metodo di Fuller (R_1) e dati ricostruiti con FRC (R_2). Sono inoltre riportati i risultati del test di Kolmogorov-Smirnov (H-KS) eseguito confrontando i dati ricostruiti e le serie originale, del test di Mann-Kendall (H-MK) e della stima della Sen's slope (b) applicati alle serie completa*

**significance α at 5%*

Station	Num. R_0	Num. R_1	Num. R_2	TOT	Reference Period	H-KS (R_0-R_2) (α = 5%)* Null hypothesis	H-KS (R_0-R_1) (α = 5%)* Null hypothesis	H-MK (α = 5%)*	*b*
Cancello Arnone	31	22	20	73	1925-2021	Accepted	Accepted	No trend	-1.00
Ponte Annibale	43	0	20	63	1915-2021	Accepted	-	No trend	2.72
Amorosi	41	10	27	78	1931-2021	Rejected	Rejected	Trend	-3.45
Contursi	32	14	27	73	1932-2021	Accepted	Rejected	No trend	-0.89
Scafa di Persano	13	4	27	44	1929-2021	Rejected	Accepted	Trend	14.07
Albanella	41	16	27	84	1929-2021	Accepted	Accepted	No trend	2.98
Montella	45	14	24	83	1931-2021	Rejected	Accepted	Trend	-0.18
Apice	38	0	27	65	1933-2021	Rejected	-	Trend	-3.02
Solopaca	15	8	27	50	1965-2021	Rejected	Accepted	Trend	-13.73
Casalvelino	18	16	17	51	1961-2021	Rejected	Rejected	Trend	-5.19
Pago Veiano	18	6	14	38	1958-2021	Rejected	Accepted	Trend	7.38
Paduli	16	0	27	43	1954-2021	Accepted	-	No trend	0.00
Sora	41	10	26	77	1929-2021	Accepted	Accepted	No trend	-0.51
Isola Liri	25	0	18	43	1929-2021	Rejected	-	Trend	28.84
Ceccano	19	0	27	46	1959-2021	Rejected	-	Trend	-10.21
P.te Sant'Ambrogio	12	0	20	32	1929-2021	Accepted	-	No trend	-4.37
S.S. 106	19	15	22	56	1933-2021	Accepted	-	Trend	18.02
Episcopia-Pizzutello	27	21	20	68	1925-2021	Rejected	-	No trend	-0.84
Piè di Borgo	24	2	6	32	1927-2020	Accepted	-	No trend	-0.89
Razzona	50	6	6	62	1927-2020	Accepted	-	No trend	0.02
Camerata	29	1	6	36	1928-2020	Rejected	-	Trend	1.80

The reconstruction procedure (detailed for the Cancello Arnone section) has been applied for all the considered stations for the Basilicata, Calabria and Campania Regions. In fact, in the recorded dataset less than 50% of the series has a length of more than 20 years in the analysed period (1920-2021). The total number of available data was 597, while number of floods increased to 1195 after the reconstruction. The main characteristics of the reconstruction are reported in Table 3.
Then, the trend analysis was carried out on the reconstructed series by means of the Mann-Kendall (MK) tests. The MK test detected the presence of a decreasing statistically significant trends in several stations (see also Table 3). It is worthy to underline that seven stations among the homogeneous time series (according to the KS-test) display a negative trend and four a positive one.
In the case of the Puglia Region, there was no need for the reconstruction procedure as all the analyzed stations had continuous data, as indicated in Table 4. Therefore, only the Mann-Kendall (MK) test was applied. Most of the stations in this region did not exhibit a statistically significant trend. However, in cases where a trend was detected, it tended to be decreasing, except for the Lapilloso river.
The results of the MK test are summarized in Figure 3, which provides an overview of the stations and their associated trends. This spatial representation allows for the identification of localized clusters of stations characterized by either an increasing or decreasing trend in flood peaks.

Table 4 - The results of the Mann-Kendall test (H-MK) and the Sen's Slope (b) estimate
Tab. 4 - *I risultati del test di Mann-Kendall (H-MK) e la stima Sen's Slope (b)*

Station	Region	Num. R_0	Reference Period	H-MK	*b*
S.Samuele di Cafiero	Puglia	81	1929-2020	Si trend	-6.00
Cairano	Puglia	30	1963-1994	Si trend	-5.95
P.te sotto Atella	Puglia	71	1934-2020	No trend	0.29
Monteverde	Puglia	60	1956-2020	Si trend	-7.07
Rocchetta S.Antonio	Puglia	22	1926-1952	No trend	18.40
P.te Vecchio Rapolla	Puglia	56	1952-2020	No trend	-0.20
P.te SS 168	Puglia	31	1973-2012	Si trend	0.44
P.te Ferroviario	Puglia	35	1973-2020	No trend	0.27
P.te S.Angelo	Puglia	34	1929-1971	No trend	0.52
Carapelle	Puglia	36	1935-1980	No trend	-2.29
P.te Vecchio Ordona	Puglia	35	1986-2020	No trend	0.46
Incoronata	Puglia	80	1928-2020	No trend	-1.22
S.Vincenzo	Puglia	36	1967-2012	No trend	-0.49
P.te Foggia-S.Severo	Puglia	62	1935-2015	Si trend	-0.87
P.te Troia Lucera	Puglia	56	1965-2020	Si trend	-2.69
Casanova	Puglia	50	1965-2020	Si trend	-1.63
P.te Lucera-Motta	Puglia	46	1965-2020	No trend	-0.44
P.te Foggia -S.Severo	Puglia	66	1933-2020	No trend	0.61
P.te Lucera-Torremaggiore (1)	Puglia	33	1943-2020	No trend	-0.87
P.te Lucera-Torremaggiore (2)	Puglia	43	1948-2020	No trend	0.18

5. Final Discussion

In this study, we examined flood processes in Southern Italy, an area that has been overlooked for nearly three decades due to data limitations. To overcome this challenge, we reconstructed the time-series of peak flood discharges, effectively doubling the amount of available flood data.
The initial phase of the study involved the implementation of novel methodologies for data reconstruction utilizing flood rating curves (FRC). This straightforward yet highly effective procedure resulted in the creation of FRCs, which can serve as a crucial resource for Civil Protection agencies. These FRCs not only facilitate data reconstruction but also play a vital role in verifying hydraulic risk

and conducting hydraulic modelling of watercourses. They provide an essential tool to enhance the understanding and management of flood-related concerns.

The new dataset, composed by three groups of data (R_0, R_1, R_2), allowed to update flood statistics. Through the analyses carried out, it became evident that there is a considerable heterogeneity in the dynamics of floods, with a noteworthy number of stations exhibiting negative trends. However, it is important to note that a negative trend does not necessarily indicate a reduction of hazards. Recent time series also exhibit greater variability compared to the past, which could potentially impact flood severity. Thus, it is essential to consider the potential implications of increased variability alongside the observed negative trends.

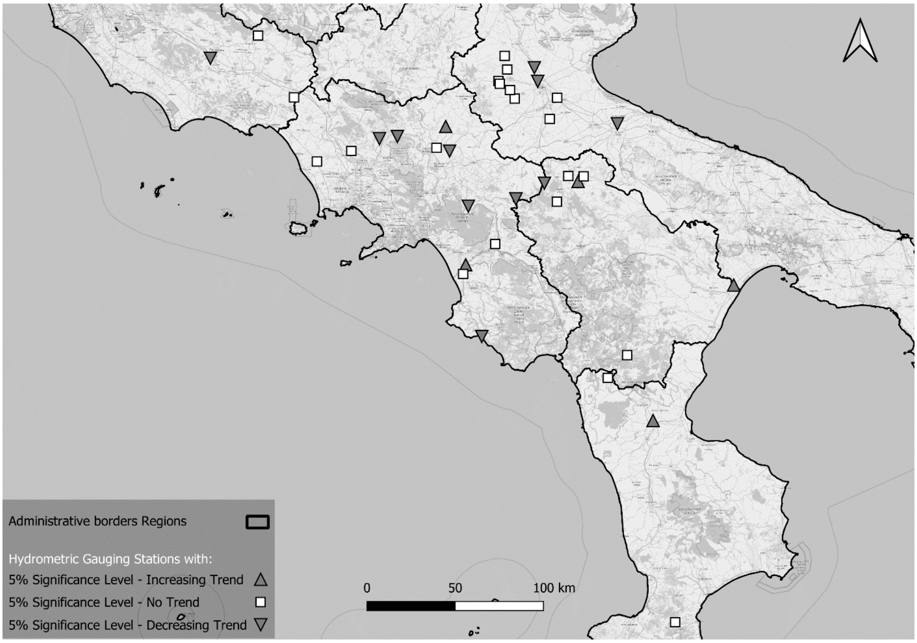

Figure 3 - Maps of the station where a trend is detected with the Mann-Kendall test at 5% significance level

Fig. 3 - *Mappe delle stazioni in cui è stato rilevato un trend con il test di Mann-Kendall al livello di significatività del 5%*

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