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PAOLO BILLI [1,2]

DAILY MAXIMUM AND PEAK DISCHARGE OF RIVERS IN TUSCANY, ITALY

Abstract - P. BILLI, *Daily maximum and peak discharge of rivers in Tuscany, Italy.*

Flow discharge of many small rivers in Tuscany is not or no longer monitored though some of them have experienced devastating floods in the last decades. In the monitored rivers, average daily discharge data are available but for high flood risk assessment instantaneous peak discharge data are crucial. In small rivers, daily and peak discharge, recorded on the same day, typically do not coincide and the first is always smaller than the latter. Average daily discharge and the corresponding highest peak discharge ever recorded data of 43 rivers in Tuscany were used to investigate the possibility of predicting peak discharge from average daily discharge and catchment area. The results obtained indicate that first-hand predictions of high floods are significant and the equations derived are particularly useful for rivers with no flow data or past, short time series.

Key words - maximum discharge, peak discharge, unit peak discharge, flow data, Tuscany, Italy

Riassunto - P. BILLI, *Portata giornaliera e portata di picco dei fiumi in Toscana.*

In molti piccoli fiumi in Toscana non viene o non viene più misurata la portata liquida, sebbene alcuni di essi, negli ultimi decenni, siano stati interessati da devastanti alluvioni. Per i fiumi ove sono installati degli idrometri sono invece disponibili i dati di portata media giornalieri, ma per la stima di eventi estremi sono necessari i dati di portata di picco. Nei fiumi piccoli i valori di portata giornaliera e quella di picco registrate nello stesso giorno, tipicamente non coincidono e la prima è sempre inferiore alla seconda. Per questo studio sono stati utilizzati i dati di portata media giornaliera e quelli della portata di picco più alta mai verificatasi di 43 fiumi in Toscana. Questi dati sono stati analizzati allo scopo di verificare la possibilità di stimare le portate di picco partendo dai dati di portata media giornaliera e dall'area del bacino idrografico sotteso. I risultati ottenuti indicano che le stime delle portate di picco con lungo tempo di ritorno (30-50 anni) hanno un elevato grado di significatività statistica e le equazioni derivate sono particolarmente utili per quei fiumi che non hanno serie temporali di dati di portata o dove queste sono troppo brevi.

Parole chiave - portata massima, portata di picco, portata di picco unitaria, dati idrologici, Toscana

INTRODUCTION

In the last decades, in Italy, devastating floods have been more and more frequent (Faccini *et al.*, 2016; Silvestro *et al.*, 2016; Bentivenga *et al.*, 2020). In particular, flash floods have increased in number causing casualties and damage to properties and productive activities. Flash floods are generated by short and very intense (as much as 150 mm in one hour and 300 mm in three hours) rainstorms that, commonly, form over very small areas (Tarolli *et al.*, 2012; Vallebona *et al.*, 2015). It follows that flash floods predominantly occur and have catastrophic effects in small to medium rivers with catchment areas typically less than 1000 km^2, whereas they are uncommon in larger rivers and do not occur in big rivers such as the Po and the Tiber.

Climate change and the progressive expansion of urbanization are complementary factors that substantially contributed to increasing the frequency of flash floods and their disastrous effects. The acknowledgement of this situation and the need to mitigate the negative effects of flash floods implies a rethinking of the past land and river management with the involvement of the scientific community. The regional hydrological monitoring institutions are called to expand the current knowledge on the formation of flash floods through the enlargement of the river monitoring network and the availability of hydrological data. Among them, peak discharge data are crucial for the prediction of the flooding risk. Nevertheless, peak flow data are not reported in the national and regional hydrological archives, which include only the daily average discharge (Qd), which is commonly much smaller than peak discharge, especially in small rivers/catchments. Peak discharge data (Qp) are only reported occasionally in case of exceptionally high floods of the monitored rivers. Moreover, many small rivers, which are the most prone to flash flooding, are not monitored and no flow data is therefore available.

In the last decades, many hydrological models have been developed to assess peak discharge from rainfall data (e.g., Linsley *et al.*, 1988; Mosavi *et al.*, 2018). All these models, however, require a huge amount of data and validation of results, which is not always guaranteed for small, unmonitored fluvial systems lacking hydrological data time series to calibrate the efficiency of the selected model.

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In the Hydrological Annals of the Italian National Hydrographic Service, the value of the daily discharge derives from averaging three daily hydrograph readings at 6.00, 12.00 and 18.00 (Fig. 1). This method, also used in other countries, works well for large rivers whose flood wave develops slowly across a few days. In small Mediterranean catchments, if rainfall is very intense, floods grow to peak in a very short time (commonly less than an hour) and vanish shortly after the peak. Under these conditions, the three daily readings method is often unable to catch the highest flow peaks which, potentially, may translate into flooding risks downstream.

This problem is not new among hydrologists and in the scientific literature. Already in 1914, Fuller investigated the relationship between the daily average maximum and peak discharge for a few rivers in the western United States and proposed a direct relationship between the catchment area and the Qp/Qd ratio. In the following years, other authors (actually, very few) approached the problem of assessing peak discharge from daily discharge data (Ellis & McGray, 1966; Taguas *et al.*, 2008; Bartens & Haberlandt, 2021). These authors used regional or local scale data and found that annual rainfall, land use and watershed morphometric parameters, such as area, highest and lower elevation, etc., may have some influence on the Qp/Qd ratio. Nevertheless, they also concluded that the direct relation is the most efficient tool to determine the Qp/Qd ratio.

Canuti & Moisello (1988) investigated the Qp/Qd ratio using data from 19 rivers in Tuscany and considered a few morphometric parameters such as basin shape, drainage density, relief ratio, etc. (see their Table 1). These authors based their study on solid probabilistic methods and found a correlation between some morphometric parameters and the distribution of the Qp/Qd ratio, but they also concluded that, in any case, the distribution of Qp is a function of Qd distribution. Though one can agree that the watershed morphometric parameters may influence the development of the flood wave and hydrograph shape, the timings of the discharge values measured from the hydrograph are fixed and the relationship between the average daily discharge and peak discharge is probabilistic rather than deterministic. Even in the case of a hypothetic hydrograph, perfectly symmetrical with the peak at 12.00 hours, Qp will be always higher than Qd, which is the average of discharges recorded at 6.00 am, 12.00 and 6.00 pm. In the real world, hydrographs are not symmetrical (Fig. 1) for the known variability of the factors controlling overland flow and the runoff volume. In complex hydrographs, such as that of Fig. 2, the Qp/Qd ratio is largely influenced by other factors such as rainfall discontinuity or diachronous flood peaks of the tributaries joining the main river upstream of the gauging station.

Tuscany is a region particularly vulnerable to flash floods but, unfortunately, like many other Italian regions, peak discharge data are missing except for a few, outstanding long return time floods. Aiming at expanding the database of Canuti & Moisello (1988) in terms of flow gauges considered and time interval investigated, 43 Tuscan rivers with peak flow data were selected and their data were used to develop e simple correlation tool for peak discharge assessment to be used especially for small ungauged streams. Such a simple approach may be useful for a preliminary high flood risk assessment and for the definition of the most flood-prone areas with long return time flash floods.

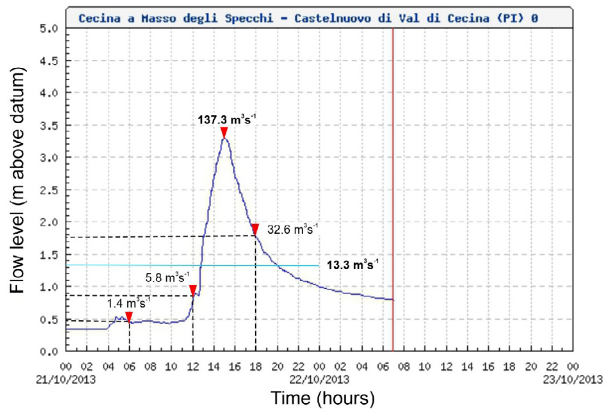

Figure 1. Example of a hydrograph with the flow level reading that will be then translated into discharge values by the rating curve. The dashed lines indicate the standard readings at 6.00, 12.00 and 18.00 hours. The solid line is the average flow level/discharge.

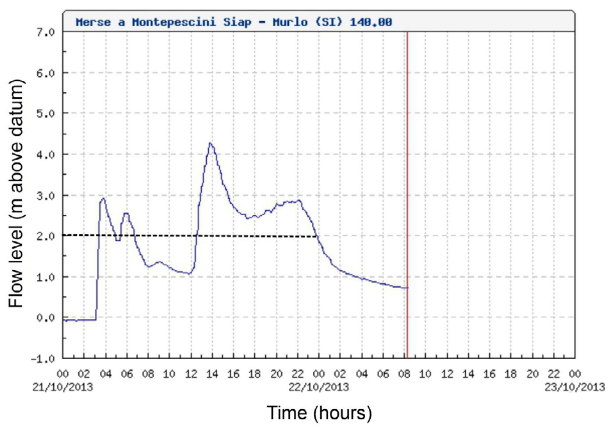

Figure 2. Example of a complex hydrograph. The dashed line is the average flow level. The rating curve of this gauging station is not available. Therefore, it was not possible to calculate the corresponding discharge.

Table 1. Database used in this study. Qd = average daily discharge; Qp = peak discharge; A = catchment area.

River @ gauging station	year	Qd	Qp	Qp/Qd	A
		m^3s^{-1}	m^3s^{-1}		km^2
Albegna @ Montemerano	1951	238	760	3.19	192
Albegna @ Marsiliana	2012	820	1645	2.01	537
Ambra @ Bucine	1996	50	103	2.05	170
Arno @ S.Giovanni alla Vena	1929	2060	2230	1.08	8186
Arno @ S.Giovanni alla Vena	1949	1575	2270	1.44	8186
Arno @ Stia	1940	50	138	2.77	62
Arno @ Stia	1966	148	312	2.11	62
Arno @ Subbiano	1934	401	770	1.92	738
Arno @ Subbiano	1960	379	873	2.30	738
Arno @ Subbiano	1966	1190	2250	1.89	738
Arno @ Nave Rosano	1934	1320	1780	1.35	4083
Bisenzio @ Carmignanello	1940	138	278	2.01	100
Bisenzio @ Gamberame	1966	165	302	1.83	150
Bisenzio @ S. Piero a Ponti	1996	257	409	1.59	146
Brana @ Burgianico	1951	7	68	9.33	13
Bruna @ Lepri	1960	86	460	5.36	229
Cecina @ P.te Monterufoli	1939	362	803	2.22	634
Cornia @ Frassine	1958	20.6	115	5.92	97
Cornia @ P.te Aurelia	1958	628	1170	1.86	356
Cornia @ P.te per Montioni	1992	142	505	3.56	195
Cornia @ P.te per Montioni	1996	75	551	7.37	195
Cornia @ P.te SS Aurelia	1958	628	1170	1.86	356
Elsa @ Castelfiorentino	1951	135	316	2.34	806
Elsa @ Castelfiorentino	1966	406	612	1.51	806
Farma @ P.te Torniella	1966	119	464	3.90	70
Frigido @ Canevara	1949	115	637	5.54	46
Greve @ Falciani	1991	50	261	5.19	120
Lima @ Fabbriche Casabianca	1966	286	519	1.81	263
Lima @ Fabbriche di Casabasciana	1967	384	864	2.25	263
Lima @ P.te di Lucchio	1950	122	605	4.96	170
Massera @ M.no del Balzone	1988	43	188	4.34	58
Melacce @ L'Antea	1996	3	26	8.35	65
Merse @ Ornate	1940	252	613	2.43	583
Messera @ M.no del Balzone	1988	43	188	4.34	58
Milia @ Grillandino	1976	12	86	7.07	77
Nievole @ Colonna	1953	8	56	6.72	33
Ombrone @ Buonconvento	2022	129.3	322	2.49	760
Ombrone @ Sasso d'Ombrone	1940	1020	2377	2.33	2657
Ombrone @ Sasso d'Ombrone	1966	2260	3110	1.38	2657
Ombrone PT @ P.gio a Caiano	1995	117	261	2.23	435
Ombrone PT @ P.te Calcaiola	1990	33	81	2.43	31
Ombrone PT @ Poggio a Caiano	1996	237	332	1.40	435
Orcia @ Monte Amiata	1940	122	736	6.03	580
Orcia @ Monte Amiata	1965	211	825	3.91	580
Pesa @ Sambuca	1993	36	212	5.92	119
Pescia @ M.no Narducci	1940	44	112	2.52	47
Serchio @ Borgo a Mozzano	1940	836	1740	2.08	1061
Serchio @ Calavorno	1996	219	358	1.63	2054
Sieve @ Fornacina	1966	917	1340	1.46	831
Sieve @ Ponte del Bilancino	1966	231	546	2.36	150
Terzolle @ Le Masse	1949	14	125	8.87	14
Trasubbie @ La Castellina	1975	26	157	6.06	154

DATA AND METHODS

For this study, the data published on the *Annali Idrologici* (Hydrological Annales) by the National Hydrographic Service (Servizio Idrografico, 1997) were used. In Tuscany, the data cover the 1921-1997 interval. In the late 1990s, the river monitoring activities, data collection and processing were decentralised to the Regional Governments that organised their own hydrologic survey department. Since the year 2000, hydrologic data of Tuscany have been in the public domain and can be consulted and downloaded from a specifically designed website (http://www.sir.toscana.it/consistenza-rete).

The data obtained for each gauging station are: the area of the basin undertaken, the highest flow peak ever recorded (in a few cases also the second and the third highest peak discharge data were considered in this study) and the values of the corresponding average daily discharge (Tab. 1, Fig. 3).

The archives of the Tuscany Hydrology Department include the values of the average monthly and daily discharge and the average daily flow level, whereas the flow level data monitored at 15-minute interval may be obtained on request. The highest flow levels can be easily extracted from the 15 minutes series but the corresponding discharges cannot be because only the rating curves valid for 2022 and 2023 are reported. Unfortunately, unlike the former *Annali Idrologici*, in the web archives of the Tuscany Hydrology Department, only the most recent rating curve is reported, whereas the previous ones are missing.

In the extensive reports of extreme events that occurred in Tuscany since the year 2012, the highest flow levels are tabulated and the corresponding flow level hydrographs are included as well. Nevertheless, since the rating curve of the past years are not available, only in two cases it was possible to calculate the peak discharge through the rating curve. However, in the last two decades, though high floods occurred in several rivers of Tuscany, none of them was higher than those recorded in the XX century and published in the hydrologic data website.

In this study, the data of flow gauges downstream of large dams (e.g.: the Arno River downstream of Arezzo) were discarded. Peak discharge data measured before the construction of large dams (e.g.: the Sieve River) were considered, so as data of rivers with a very small dam or weir in a small sub-basin in the headwaters, given the neglectable influence of the small volume of runoff retained on the flood development.

It is worth emphasising that the peak discharge values obtained from the *Annali Idrologici* are not associated with any return interval since not all the highest annual peak flow values are reported. In Fig. 3, the number of recorded years for each flow gauge is reported. The length of the time series varies widely, but this is

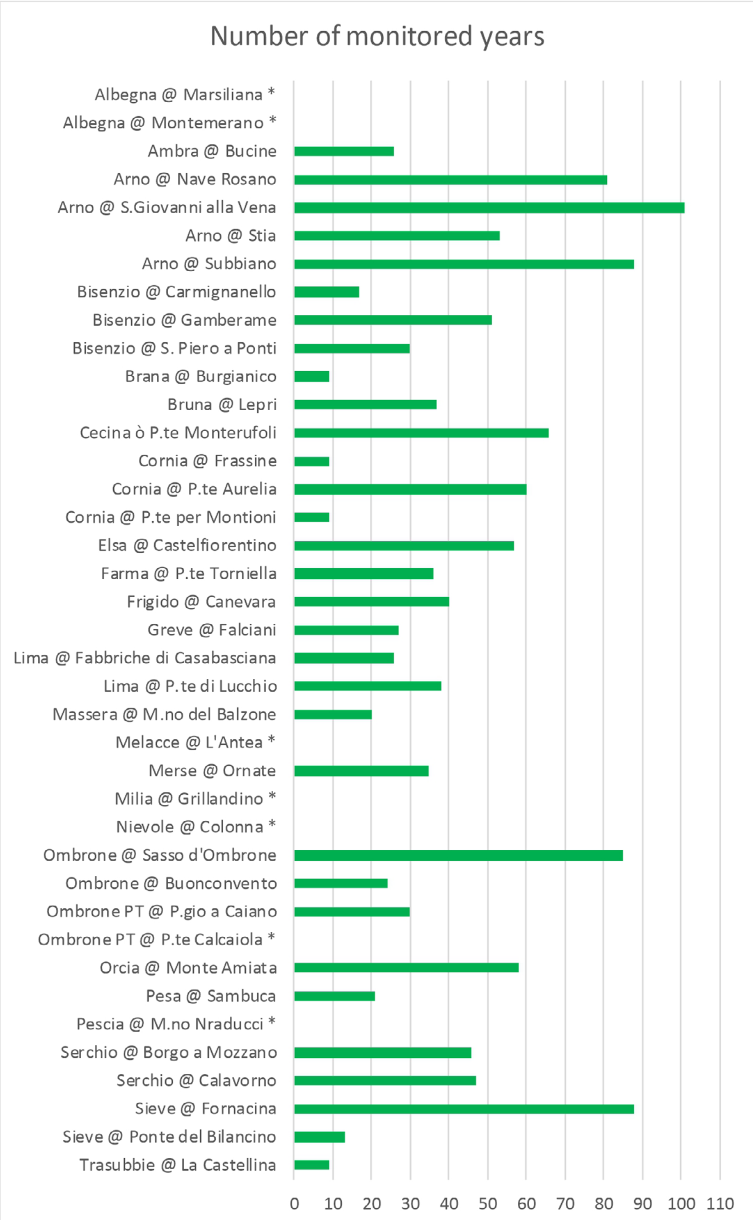

Figure 3 Length of the data sets used in this study. * = very short time series that include extreme flood discharge data (for more explanations see text).

not a limitation since any flow data could be used for the investigation of the relationship between the daily and the actual peak discharge. The highest peak discharge data were used simply because they are the only available. Moreover, the peak discharge of the shortest (those with the asterisk in Fig. 3) and short time series were often recorded on the same day on which many rivers in the vicinity or other parts of Tuscany experienced long return time floods. By contrast, for the investigation of the relationship between catchment area and extreme floods, only the time series longer than 30 years were considered. The highest flow peaks considered were the highest or very close to the highest ever recorded across an interval of 30-100 years and, therefore, can be considered flood peaks with, at least, 30-50 years of return time.

To assess the strength of the regressions reported in this study, other than the classic coefficient of determination R^2, also the *p*-value was calculated for the significance levels a of 0.05 and 0.001. The *p*-value is commonly used to verify if the goodness of fit of a regression is due to chance or if it is statistically significant, that is the independent variable influences in a statistically significant way the variability of the dependent variable. In this study, the F statistics was used to determine the *p*-value with significance levels of 0.05 and 0.001.

Results

The data of Qd and Qp (Tab. 1) were plotted to obtain a regression diagram (Fig. 4) in which the interpolating line is expressed by the following power law:

$$Qp = 13.941\ Qd^{0.6903} \quad [1]$$

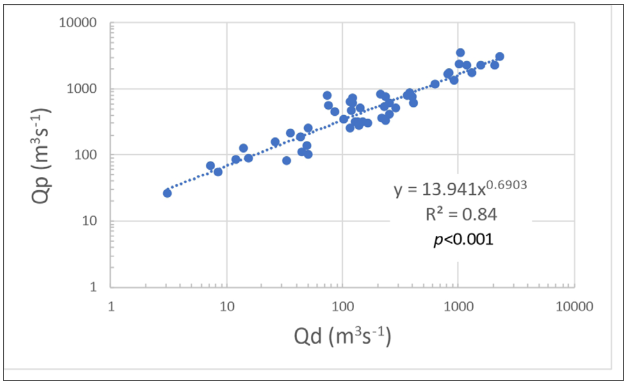

Figure 4. Regression diagram of average daily discharge (Qd) vs peak discharge (Qp) using all the data of Tab. 1.

The regression of Fig. 4 has a determination coefficient R^2 rather high of 0.84. However, if only the time series longer than 30 years are considered (Fig. 5) the correlation is stronger and it is expressed by the following power function:

$$Qp = 14.943\ Qd^{0.6812} \quad [2]$$

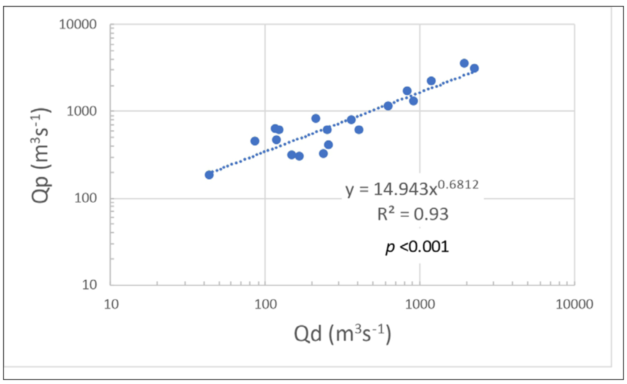

Figure 5 Regression diagram of average daily discharge (Qd) vs peak discharge (Qp) only using data of rivers with time series longer than 30 years.

Eq. [2] coefficient and exponent are rather similar to those of Eq. [1], but the determination coefficient of the former is higher, $R^2 = 0.93$, which indicates that the average daily discharge explains 93% of the variability of the corresponding peak discharge that occurred on the same day. The significance of this result is corroborated by the *p*-value, which confirms the statistically high probability at the confidence level of 0.001 that Qd and Qd are correlated.

Aiming at predicting, though at a preliminary stage of the investigation, the highest peak flow in a non-monitored river or in case of too short time series, Qp and Qd data of the study rivers with more than 30 years of recordings were plotted against catchment area (Fig. 6). The respective interpolating equations are the following:

$$Qp = 35.536A^{0.5229} \quad [3]$$

$$Qd = 4.1022A^{0.7438} \quad [4]$$

in which A is the basin area in km^2.

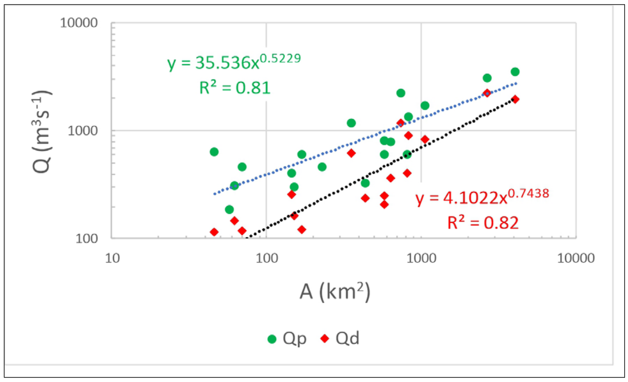

Figure 6. Correlation between catchment area (A) and average maximum daily discharge (Qd) and peak discharge (Qp).

The correlation coefficients of these regressions are rather high: $R^2 = 0.81$ for Qp and $R^2 = 0.82$ for Qd. Moreover, the *p*-value is <0.001 for both the data sets confirming that the control of catchment area on the variability of Qp and Qd is not accidental and the correlations are significant.

From Fig. 6 it is evident that as the catchment area increases the two interpolating lines tend to merge, thus confirming that in large basins Qp and Qd tend to assume similar and ultimately coinciding values given the typical longer duration of the high flow phase and the relatively less peaked shape of the hydrograph at the daily scale.

Some authors (e.g.: Fuller, 1914) found a strong correlation between basin area and the Qp/Qd ratio (Rq), which is expressed by an equation of the type of Eq. [1]. In the case of the Tuscany rivers considered in this study, the correlation is rather poor ($R^2 = 0.46$) (Fig. 7), but the *p*-value is <0.01and, though it is weaker than the previous correlations, it indicates a significant influence of basin area on Rq variability.

$$Rq = 14.024A^{-0.28} \quad [5]$$

The diagram of Fig. 7 shows that, as catchment area increases, the Qp/Qd ratio tends to unity, thus confirming the indications of Fig. 6, i.e. Qp and Qd tend to assume similar values in large basins.

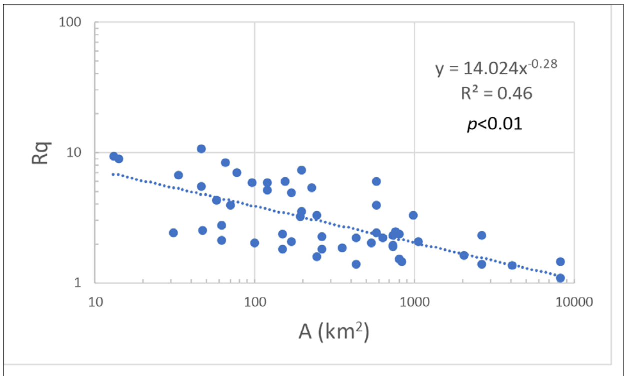

Figure 7. Regression of catchment area (A) vs the ratio Rq = Qp/Qd.

The Rq values of the study rivers are rather variable, but the majority of the values (58%) are comprised between 1 and 3, that is peak discharge is on average equivalent to 1.5-2.5 Qd (Fig. 8).

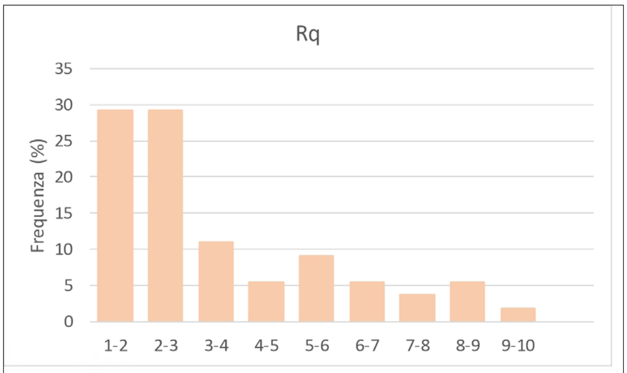

Figure 8. Histogram of the Rq = Qp/Qd ratio of the Tuscan rivers.

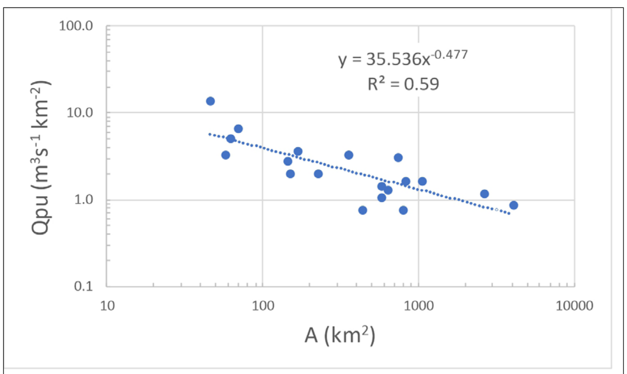

Figure 9. Correlation between catchment area (A) and unit peak discharge (Qpu).

The variability of unit peak discharge (Qpu) with catchment area was also analysed (Fig. 9) using data of rivers with longer than 30 years of recordings. The correlation of figure 9 has a low determination coefficient ($R^2 = 0.59$) and it is not significant at the significance level a = 0.05. Nevertheless, in Fig. 9, it is evident that smaller basins tend to experience higher unit peak discharges. This result confirms the trend observed in the recent decades in Tuscany where the most devastating flash floods predominantly occurred in rivers with relatively small watersheds.

Discussion

The time series considered in this study have a variable length ranging between 10 and 100 years (Fig. 1). The peak discharge data used in this study is the only one available for Tuscany rivers. The old *Annali Idrologici* and the new regional web archives do not report data of the instantaneous peak discharge. In the latter, some reports about extreme events of precipitation and high flow can be consulted. Unfortunately, information about larger floods is reported only in the form of the highest flow level data and flow level hydrograph. Though the detailed datasets of flow level measured at the interval of 15 minutes can be easily obtained, the rating curves reported in the regional web archives are available only for the last two years. This did not allow to calculate the instantaneous peak discharge of high floods occurred in the last two decades, except for a couple of cases. Fortunately, from the comparison of the high flow levels of the past with those of the last two decades reports of extreme hydro-meteorological events, it resulted that the highest peak discharge occurred in the past century and, therefore, they are all included in the dataset used in this study. Some uncertainty about this last statement derives from lack of information about possible changes of the cross-section geometry at the flow gauge site. Commonly, in the selection of the most appropriate site for the installation of the flow gauge, the condition for a potentially long term stability of the cross-section geometry is one of the most stringent parameters.
Throughout the last century, many Tuscany rivers underwent substantial channel morphology changes (Rinaldi, 2003; Billi & Bartholdy, 2024) and for this reason, the regional hydrology department has been keeping on monitoring the cross-section geometry of the gauged rivers through repeated surveys. Though the high flow levels observed in the last two decades are not fully comparable with those of the past century, from the reports on extreme events which occurred since 2012 it seems that the highest peak discharge ever recorded in the monitored rivers occurred in the XX century.

The time series considered in this study (Tab. 1 and Fig. 1) are discontinuous and span different time interval. Most of the peak discharge data reported for rivers with a very short dataset, however, occurred on the same day of large floods recoded for near rivers with long time series or during extreme rainfalls that affected the whole Tuscany region. Though it is not possible to calculate the return time of peak discharge recorded during such short monitoring intervals, a return time much longer than the actual time series can be presumed. It is for such uncertainty that the analysis of the variation of Qp, Qd and the Qp/Qd ratio with catchment area was carried out only with time series exceeding 30 years.

For the investigation of the possibility to predict Qp from Qd, the former assumption is less important. Any average daily discharge could be compared with the respective instantaneous peak discharge to analyse their mutual frequency variability (Canuti & Moisello, 1988). By restricting the analysis from the whole data set (Tab. 1) to only the data of rivers with longer than 30 years datasets, the correlation determination coefficient (R^2) increase from 0.84 to 0.93 (Eqs. 1 and 2). This improvement is partly a reflection of the higher probabilistic component of the long time series data, but it also depends on the fact that the highest floods commonly tend to last longer and, virtually, the difference between Qp and Qd tends to decrease, especially in the larger river catchments (Fig. 6).

The correlation between Qp and Qd is highly significant and can be used for a first-hand assessment of floods with long return intervals expected in rivers with short hydrological time series or with no information about high flood peaks. To improve the reliability of this method it would be necessary to consider the maximum average daily discharge frequency distribution as well. In a given year, in fact, the maximum daily discharge and the highest peak flow may not occur on the same day. This issue was not considered in this study but it deserves to be investigated in greater detail in future studies.

Ding *et al.* (2015), using Qp and Qd data of 100 years return time floods derived a linear correlation with a determination coefficient $R^2 = 0.95$. These authors used data from the Aller-Leine River tributaries but, unfortunately, did not report the row data used. In their figure 4, the Qp/Qd ratio is about 1.5. In the Tuscany rivers, instead, the Qp/Qd ratio is more variable with a mean value of 3.5 for the whole dataset and 2.7 for the time series longer than 30 years and about 30-20% of the values higher than 4. The smaller Qp/Qd ratio of Ding *et al.* (2015) may depend on the larger size of these author's study river, the catchment area of which is six times larger than the largest river considered in this study. Even in the rivers of Tuscany, however, the Qp/Qd ratio approaches the value of one as the catchment size increases (Fig. 7).

Taguas *et al.* (2008) used a similar approach to investigate the Qp/Qd ratio of a few small rivers on the southeastern coast of Spain. Though these authors gathered their study basins into four groups on the base of geographic position uniformity, the correlation coefficients they obtained are lower than 0.56 and only in one group the correlation is significant with $R^2 = 0.95$. The number of data Taguas *et al.* (2008) used for each group of basins is modest (only in one case higher than ten) and this may explain the lack of correlation between Qp and Qd. Moreover, these authors explain their poor correlations with the ephemeral character of their study rivers. The climate and the hydrologic response of ephemeral streams are rather different from those of perennial or seasonal rivers (Billi *et al.*, 2018) as are the Tuscan rivers. Moreover, the rivers considered by Taguas *et al.* (2008) are rather small as the majority of them have a catchment are smaller than 200 km^2 and, as shown by this study figure 7, the Qp/Qd ratio is more variable in small rivers.

In a study on the long-term flow variability of several Italian rivers, Billi & Fazzini (2017) obtained a good correlation ($R^2 = 0.95$) between Qp and Qd expressed by the following power function:

$$Qp = 7.9117Qd^{0.7518} \qquad [6]$$

In this regression analysis the data of the Po River were not included for two main reasons: a) the Po is a large river, by far much larger the all the other rivers in Italy; b) for this reason, the very large flow values of the Po tend to increase the correlation coefficient simply because the paired data distribution is strongly influenced by the weight of extreme values of the Po River Qp and Qd data. The exponents of Eq. [1] and Eq. [6] are very close but the increase of Qp with Qd is less pronounced in the Tuscany rivers. This may depend on the smaller range of catchment area and discharge variability of the latter rivers compared to the larger sample of Italian rivers subjected to very different climatic and physiographic conditions.

Bartens & Haberlandt (2021) investigated the effect of the hydrograph shape on the Qp/Qd ratio. They found that Qp/Qd can be predicted with better accuracy if the ratio between Qp and the flood volume reduced by subtracting base flow is considered. This method is complex and requires the availability of several flood hydrographs, which, usually, are not available.

A few authors, also including a few Italian scholars (Tab. 2), investigated the control of catchment area on the Qp/Qd ratio. Their results are expressed by an equation of the type

$$Q_p/Qd = cA^{-b} \qquad [7]$$

in which c is a constant and b is the exponent. The structure of Eq. [7] is similar to that of Eq. [5].

Table 2. Values of the b exponent in Eq. [5] retrieved from the literature.

Authors	b	comment
Tonini (1939)	-0.50	Unknown number of Italian rivers
Cotecchia (1965)	-0.313	Italian rivers; basin area > 140 km^2
Cotecchia (1965)	-0.19	Italian rivers; basin area > 140 km^2
Tonini *et al.* (1969)	-0.112	A few rivers in the Dolomites
Ellis e Gray (1966)	-0.22	Central Canada; basin area 155-777 km^2
"	-0.46	" " ; basin area 129-518 km^2
"	-0.36	" " ; basin area 116-583 km^2
"	-0.30	" " ; basin area 39-129 km^2
This study	-0.253	Tuscany rivers

The values of the *b* exponent obtained by these authors are reported in Tab. 2 for a comparison with the Tuscan rivers. The average value of the *b* exponent for the Italian rivers is equal to -0.279, i.e. the same of Eq. [5] obtained for the Tuscan rivers. The average value of the *b* exponent for the Canadian rivers of Ellis & Gray (1966) is -0.335 and it is slightly different from that of Tuscany rivers. Such a difference is not surprising given the diverse characteristics of the Canadian rivers with much larger watersheds, a low relief contrast and flowing across the North American lowlands, subjected to a more continental climate.

The correlation coefficient of the regression between the catchment area and peak flow of the Tuscan rivers (Eq. [3]) is not very high (R^2 = 0.82), but other studies report much lower values. For several rivers in the Czech Republic, David & Davidova (2014) calculated a value of only 0.20, that is no correlation at all. Buttle *et al.* (2016) presented a good correlation between catchment area, peak discharge with 50 years return time and maximum daily discharge of several Canadian rivers. Unfortunately, these authors did not report the *p*-value of their regression, nor any value of the determination coefficient, which, however, seems rather high given the modest dispersion of data in their diagrams.

For several basins in Kentucky, Solyom & Tucker (2004), found a strong correlation (R^2 = 0.97) between catchment area and maximum average daily discharge. The *b* exponent of the power function presented by these authors is smaller (0.67) than that of Eq. [4] calculated for the rivers of Tuscany (0.82). Solyom & Tucker (2004) did not include the basic data used in their paper, hence it is not possible to explain why, in the Tuscan rivers, the rate of increase of Qd with catchment area is faster.

Though there are some relatively small differences with the regression coefficients and exponents presented in other papers, the results of this study do not differ substantially from previous investigations and confirm the appropriateness of the approach used. The equations obtained in this study may have practical applications for the appraisal of peak discharge from average maximum daily discharge for the preliminary assessment of long return time floods in small basins of Tuscany.

Conclusions

Flood risk investigations require the annual series of peak flow data. Unfortunately, these data are seldom available since public domain archives commonly include average daily discharge only. Annual series of average daily maxima can be used for flood prediction but the results obtained are lower than those calculated from peak discharge time series. This study used the average daily discharge and the corresponding highest peak discharge data of 43 rivers in Tuscany recorded on the same day. A significant correlation between daily and peak discharge was obtained and by the interpolation line equation (Eqs. 1 and 2) it is possible to obtain peak discharge from average daily discharge data. Correlation equations were also derived to asses peak and average maximum daily discharge from catchment area (Eqs. 3 and 4). Using these equations is possible to asses long (30-50 years) return time floods for ungauged rivers with short or missing flow data time series.

Conflict of interest statement

The author declares that he has no conflict of interest neither known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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