The most severe floods of the Tiber River in Rome

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Abstract The paper reviews the floods which caused inundations in Rome during the long period from 414 BC until 31 December 1999. Then an analysis of the rainfalls related to the most severe floods during the twentieth century shows the strong variability of the drainage basin inflows. The study examines the correlation between peak discharges, maximum mean daily discharges, flood volumes and rainfall on the basin, distributed among three different phases: a preparatory phase, an antecedent phase and a contemporary phase. Correct forecasts of future floods must take into account not only the contemporary rainfall, but also the moisture of the soil, caused by the first and/or the second phases of precipitation.

Key words extraordinary historical floods; rainfall–runoff; preparatory, antecedent and contemporary precipitation; Rome

INTRODUCTION

We can find records (Le Gall, 1953; Frosini, 1977) of the most severe inundations in Rome since the Ancient Ages. From 414 BC to 411 AD there were 31 years with inundations. In the Middle Ages, from 412 to 1476, there were only 19 years with inundations, and these were not uniformly distributed during this long period. Actually, during the 296-year period from 861 to 1156, we have no information about floods in Rome. In the twelfth century (Bencivenga & Liperi, 1995), they began to put inscribed memorial plaques on some buildings in the city. In the Modern Age, from 1477 to 1899, we find more and more information about the floods of the Tiber River, due to the widespread expansion of printing and the tradition of erecting commemorative plaques. We find records of 14 floods that were disastrous for the population, including the most severe historical flood, on 23–25 December 1598, during which the water level rose to 19.56 m. In the nineteenth and the twentieth centuries, we have a large number of records from gauging stations installed in the river basin. Except for the most severe of the extraordinary floods, the twentieth century floods have not caused overflowing and inundations so ruinous to the city, because of the embankments along the river. In the period between 1 January 1900 and 31 December 1999, 12 floods with peak discharges near or over the 2000 $m^3 s^{-1}$ threshold (extraordinary flood), took place. Figure 1 shows the number of flood occurrences in each century.

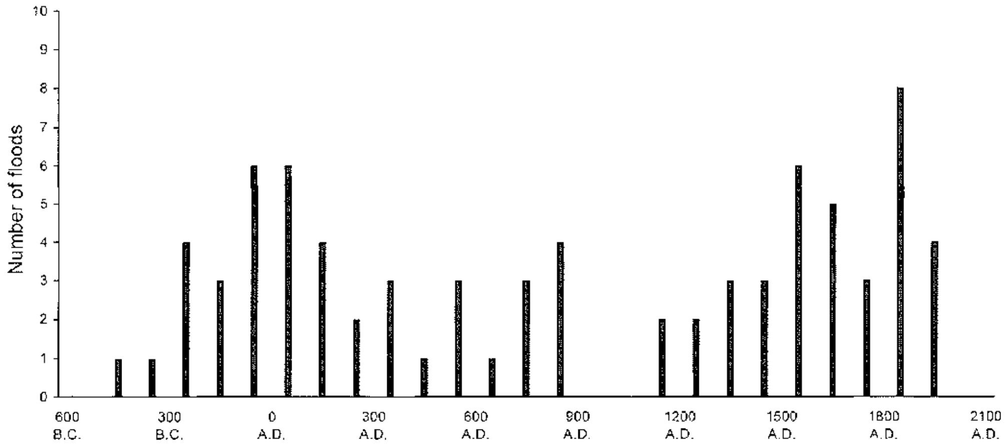

Fig. 1 Absolute frequency in centuries of the Tiber River floods which caused inundations in Rome, according to historical sources. From 1900 to 1999 the floods equal to or over the threshold 2700 $m^3 s^{-1}$ that are at risk of inundation are illustrated.

DATA

Extraordinary floods in great drainage basins result from various complex hydrometeorological phenomena, such as:

(a) a long preparatory phase, lasting some months, before the time of the flood, when it rains so much that the soil becomes and remains highly drenched;

(b) an antecedent phase, lasting several days, characterized by daily rains occurring on consecutive days, increasing the soil moisture even more, sometimes up to saturation point; and

(c) a contemporary phase, lasting some days just before the flood peak, characterized by daily rains occurring on consecutive days, causing high surface runoff in Horton and/or Dunne modes.

In this analysis the available rainfall data set that took into account the phases described above were assembled for the Tiber River basin. The data set also takes into account the frequent occurrence of snow precipitation over wide areas, sometimes at high altitudes of more than 900 m a.m.s.l. (an area of about 2500 km^2 in the basin), sometimes at low elevation, more than 300 m a.m.s.l. (an area of about 11 500 km^2).

The total drainage area of the Tiber basin above the Roma Ripetta gauging station is 17 160 km^2. By analysing the precipitation patterns over this area, the flow hydrographs at Ripetta and the peak discharge dates at Rome, it has been established that the preparatory phase lasts for 90 days, followed by the antecedent phase of 10 days, and then the contemporary phase precedes the peak discharge day for three days. According to these definitions, the mean areal precipitation during each of the three phases was computed for each storm, by using the total precipitation recorded by every raingauge in the basin.

Only after the establishment of the Servizio Idrografico in Italy (in 1921), did numerous comparable precipitation, discharge and hydrological continuous observations become available. Consequently the detailed study of the Tiber River's extraordinary floods has been conducted only from the 1920s onward. The resulting data set is shown in Table 1, where Q_c, $Q_{g,max}$, U_F, t, H_P, H_A, H_C are respectively the maximum instantaneous peak discharge, maximum mean daily discharge, flood total volume minus baseflow volume, flood duration, preparatory phase, antecedent phase, and contemporary phase computed mean areal rainfall.

Table 1 Data on Tiber River extraordinary floods from 1921 to 1999.

Date	Q_c ($m^3 s^{-1}$)	$Q_{g,max}$ ($m^3 s^{-1}$)	U_F (m^3 10^6)	t (days)	H_P (mm)	H_A (mm)	H_C (mm)	Number of rain-gauges
09/12/1923	2350	2020	461	9	347	76	83	185
04/01/1929	2090	1966	466	9	415	38	72	223
16/12/1934	1959	1876	550	9	363	27	68	213
17/12/1937	2800	2730	900	13	533	102	100	214
06/02/1947	2250	2190	284	5	577	62	74	123
03/09/1965	2700	2560	629	9	66	97	191	142
17/02/1976	2200	2004	338	7	292	41	84	124

METHOD

A simple linear regression model, using the contemporary phase rainfall as its regressor variable, is unsatisfactory. Linear multiple regression, using contemporary, antecedent and preparatory phases rainfalls as regressors, is a better fitting model. The obtained estimators of the regression and correlation coefficients and of the F statistics significance of the linear equation Q_C = f(H_P, H_A, H_C) are:

$$Q_c = 1.452H_C + 8.882H_A + 0.167H_P + 1572.281 \qquad (1)$$

where $R = 0.975$, $R^2 = 0.950$ and the significance of $F = 0.019 < 0.050$.

Similarly $Q_{g,max}$ = f(H_P, H_A, H_C) is calculated with the linear equation:

$$Q_{g,max} = 6.968H_C + 4.125H_A + 1.332H_P + 769.116 \qquad (2)$$

where $R = 0.957$, $R^2 = 0.917$ and the significance of $F = 0.040 < 0.050$.

The analogous investigation of the linear equations U_F = f(H_P, H_A, H_C) and U_F/t = f(H_P, H_A, H_C) resulted in models with low significance levels. Subsequently, the total volumes of the water, U_F, were replaced by the floods reduced volumes, U^*_F, which were calculated by considering only the water volume between the beginning of the flood at Ripetta and its peak day. The linear regression analysis according to the model U^*_F/t = f(H_P, H_A, H_C) resulted in estimators of the regression and correlation coefficients and of the F statistics significance which are:

$$U^*_F/t = 0.322H_C - 0.231H_A + 0.003H_P + 58.736 \qquad (3)$$

where $R = 0.934$, $R^2 = 0.872$ and the significance of $F = 0.075 \cong 0.050$.

RESULTS

The historical study of the Tiber River floods during the 2413 years from 414 BC to December 1999 (Alessandroni & Remedia, 1999) provides the estimated average frequency of inundations in Rome, as well as the extraordinary floods, equal to one every 38 years (Fig. 1).

Research carried out on the precipitation intensities connected with the severe floods in the twentieth century shows strong spatial and temporal variability, although the flood discharge values are sometimes alike. In all the extraordinary floods analysed, daily rainfall never fell simultaneously over the whole Tiber River basin with similar high intensity.

The models investigated show that the contemporary phase rainfalls are not the only causative agent of the most severe floods, but the antecedent phase rainfalls and, at a lower level, those of the preparatory phase are explanatory variables of great weight in this investigated phenomenon. The amount of moisture in the soil at the beginning of the contemporary phase resulted sometimes from precipitation during the antecedent phase and sometimes from precipitation during some months of the preparatory phase.

Thus the software to be used for analysis and real-time forecasting of floods and inundations defence must involve physically-based models using spatially distributed parameters and a large database with long time series. It is necessary to have information about the real degree of the soil moisture to limit the rainfall observations only to the contemporary phase, so reducing the too large computer memory needed for calculations and data storage. Soil moisture observations area by area may only be available from remotely sensed gauging systems associated with a local monitoring network (agrometeorological network of tensiometers, lysimeters, etc.) suitably distributed throughout the whole drainage basin. These comments then suggest an aim for future research.

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