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A cost-effective approach for estimating flood hazard-scenarios induced by climate change

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Abstract

Floods are a matter of concern as they are a common natural hazard in many parts of the world. For this reason, in compliance with the EU Flood Directive, implemented in Italy by Legislative Decree 49/2010 in the Flood Risk Management Plan (FRMP), the District Basin Authorities have developed river flood hazard maps to provide a knowledge tool for critical infrastructure planning. These maps, obtained by analyzing the frequency of floods in the past, characterize the national territory (at least of the main hydrographic network) for three distinct hazard scenarios depending on the return period (RP): scenario P1 (rare events typically with RP = 500 years), scenario P2 (infrequent events, RP = 100-200 years), scenario P3 (frequent events, RP = 20-50 years).

Short and heavy rainfalls are the main causes of floods. Since they are expected to increase in both frequency and intensity over Italy (Faggian and Trevisiol, 2024), some studies are carried out in RSE to estimate future changes in hazards for the National Electricity Transmission Grid (NTG), due to climate change, by using precipitation data from 1971 to 2100 provided by 11 regional Euro-CORDEX climate models.

Because NTG spans the entire country, it is necessary to proceed with multilevel approaches, having increasing degrees of depth and complexity, to generate hazard maps covering the entire domain of interest.

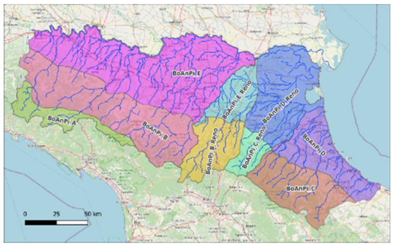
This study is a first level of analysis with the aim to provide in a relatively short time a description of flood hazards at the national scale, which could be followed by more detailed studies focused on areas of highest risk, developed by means of hydrologic-hydraulic models in hydrological downscaling. The process, presented below for the sample area of the Italian region Emilia-Romagna, consists of the following points:

- on the basis of climate models, for each homogeneous rainfall sub-area defined by the VAPI project (VAlutazione delle PIene project, http://www.idrologia.polito.it/gndci/Vapi.htm, last access: 6 June 2025), extreme daily rainfall levels (RL) are evaluated for the historical period (REF = 1971-2000) with RP 20, 200, and 500 years. Then, for the same RL, the RP are computed in the three future periods 2021-2050, 2041-2070, and 2071-2100;
- considering that heavy rainfalls are the main cause of flooding, the change in flood frequency is assumed to be equal to the change in frequency of extreme precipitations: RP changes for P1, P2, and P3 are inferred from each climate model, applying the Extreme Value Analysis technique, and from the range of ensemble model variation the uncertainty of the results is estimated;
- starting from the EU-DEM digital terrain model at 25 m of resolution, hydrologically conditioned to make the runoff paths consistent with the FRMP maps, the Geomorphic Flood Index (GFI) (Albano et al., 2025) with unit threshold value (Fig. 1a) is evaluated, hence, for each homogeneous zones, three threshold values (Fig. 1b) are calibrated to optimally reproduce the FRMP maps of P1, P2 and P3;
- to evaluate hazard maps in the three future periods at RP= 20, 200, and 500 years, the so-called "lookup method" (Kimura et al., 2023) is used to find the correspondence between flood levels and RP in historical and future periods.

In Tab. 1, in addition to the map of homogeneous sub-areas in Emilia-Romagna, the RP values obtained from the median of the ensemble of climate models are reported. Despite modeling dispersion (Fig. 1c), the analysis indicates a general trend toward reduced RP in the future, i.e., an increase in flooding frequency in comparison with REF. For each future 30-year period, by interpolating the data in Tab. 1, for RP 20, 200 and 500 years, the corresponding historical RPs are calculated. Then, from the GFI vs. RP relationship in the historical period,

threshold values of GFI in the future are inferred by using the RPs calculated in the previous step. Finally, from the new GFI values, future flood areas P1, P2 and P3 are deduced (Fig. 1d).

Tab. 1 – Map of homogeneous sub-areas in Emilia-Romagna and related values of RPs, calculated as the median of the model ensemble, in the periods 2021-2050, 2041-2070, 2071-2100 and corresponding to RP 20, 200, 500 years in REF.



Future Periods	2021-2050			2041-2070			2071-2100		
Zones / RPs	**20**	**200**	**500**	**20**	**200**	**500**	**20**	**200**	**500**
BoAnPi_C	12	64	104	11	40	69	7	55	118
BoAnPi_B_Reno	15	81	141	12	44	71	20	69	126
BoAnPi_A	11	82	85	10	39	63	8	65	59
BoAnPi_D	10	39	56	9	69	110	6	25	37
BoAnPi_E	17	115	213	9	40	56	6	36	91
BoAnPi_D_Reno	15	77	145	9	45	38	7	67	181
BoAnPi_B	19	83	188	11	95	186	12	107	133
BoAnPi_C_Reno	15	92	168	12	41	68	12	83	211
BoAnPi_E_Reno	17	117	134	12	57	91	9	42	96

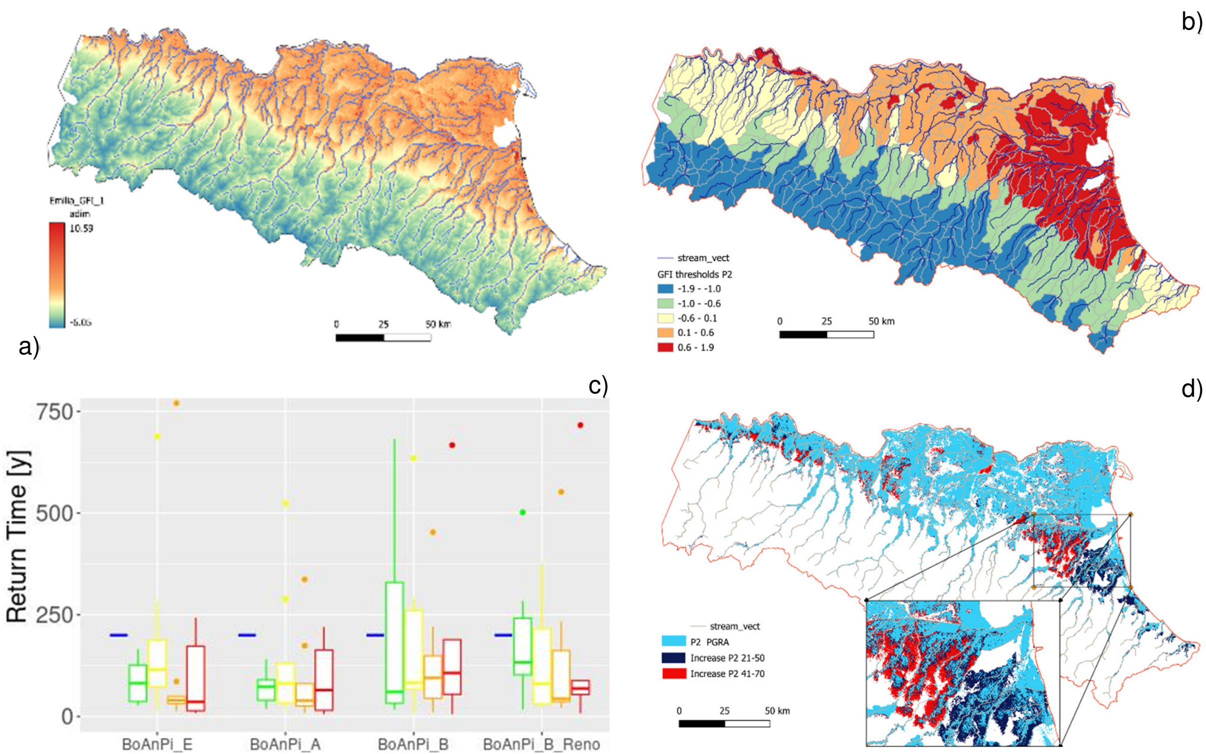


Fig. 1- a) Map of GFI with unitary threshold; b) Map of GFI threshold values calibrated against the P2 scenario of the FRMP; c) Boxplot of modeled RPs for four homogeneous area in the period 1971-2000 (blue), 2001-2030 (green), 2021-2050 (yellow), 2041-2070 (orange), and 2071-2100 (red) corresponding to RP=200 year in REF; d) Map of floodable areas obtained through GFI for the historical P2 scenario and for 2021-2050 and 2041-2070 projections.

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