Classification of homogeneous subareas of the Geomorphic Flood Index (GFI)

Geomorphic Flood Index (GFI) is a simple and efficient approach based on geomorphological features to delineate the extent of the areas exposed to flood hazards (Samela, Troy, & Manfreda, 2017). Furthermore, the geomorphic flood index (GFI) has been further exploited to predict inundation depth, which is useful for quantifying flood induced damages.

The evaluation of water depths requires considerable precision in the evaluation of the index in order to obtain values comparable to those of hydrodynamic models. For this reason we try to divide the study area into different homogeneous sub-areas with respect to the flooding phenomenon where it is possible to have a fine tuning of the threshold value of the flooding index.

Since the classification into homogeneous areas is a complex operation, we want to try to perform this task using methods based on machine learning.

Below is a description of the method and data relating to the case study.

The GFI: Flood extent estimation

The GFI (1) is a binary classifier, that is: based on a threshold value of the index, it divides the space between flood-prone and not flood-prone.

$$GFI = ln\left(\frac{h_r}{H}\right) \qquad (1)$$

$$h_r \approx b \cdot A_r^n \qquad (2)$$

Where:

h_r : water depth on the river
H : difference be-tween the elevation of the cell under exam and the elevation of the final point to the nearest element of the reference drainage network
A_r : the contributing area in the nearest point of the drainage network hydrologically connected to the point under exam (‘r’ stands for ‘river’)
b, *n* : b is a scale factor, and n is the exponent (dimensionless) that have been calibrated for the study area

The exponent n can be assigned equal to 0.354 using an average value extracted from literature (see Samela et al., 2018).

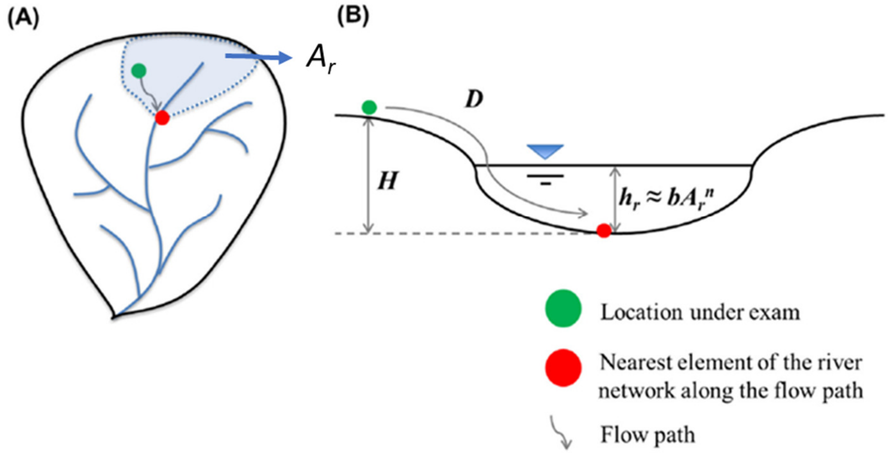


Fig. 1 – Description of the Geomorphic Flood Index (GFI), ln(h r /H). Representation of the parameters H and h r in plan (A) and cross-section (B) (Samela 2017).

The hydraulic scaling relationship typically follows a power law and might be difficult to calibrate, since it requires paired values of hr and Ar from a number of gauging stations. However, it is possible to apply a calibration procedure if official reference maps of floodable areas are available. To be applied, we start from a value of a standardized index GFI' (eq. 4) which corresponds to the case of GFI with a value of b=1.

$$\text{GFI} = ln\left(\frac{h_r}{H}\right) = ln\left(\frac{b\cdot A_r^n}{H}\right) = \ln(b) + ln\left(\frac{A_r^n}{H}\right) = \ln(b) + \; GFI' \qquad (3)$$

$$GFI' = GFI - \ln(b) = ln\left(\frac{h_r}{b\cdot H}\right) \qquad (4)$$

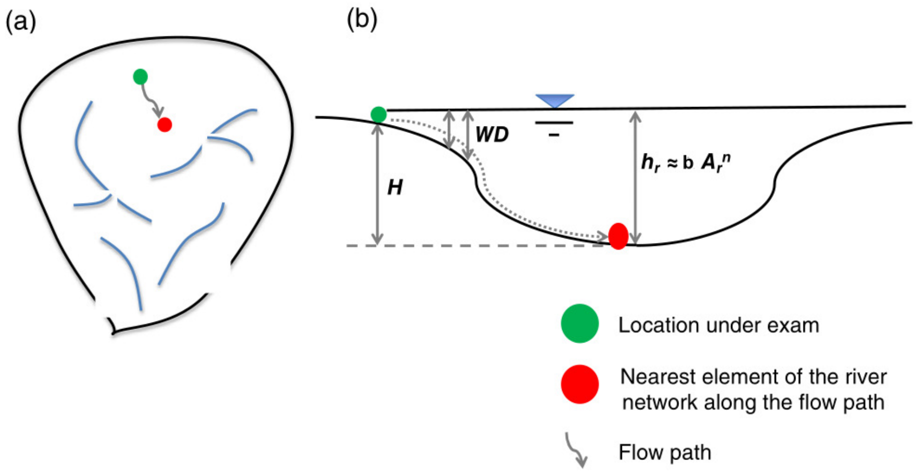


Fig. 2 – A schematic description of the parameters used to derive the geomorphic flood index (GFI) and the water reference level depth estimated in a hypothetical cross-section (Samela 2019).

The GFI'_{τ} is the threshold value that identifies the boundary of the official maps, where hr and H are equal

$$GFI'_{\tau} = ln\left(\frac{h_r}{b\cdot H}\right) = ln\left(\frac{1}{b}\right) \quad where \;\; h_r = H \qquad (5)$$

The optimal threshold —for a flood hazard map of a return period used for calibration—is evaluated by iterating the threshold of the classifier and by looking for the minimizing of the sum of the false positive rate RFP (overestimation) and the false negative rate RFN (underestimation) calculated by comparison with the official map, assigning equal weights to both rates.

Therefore, the estimated optimal threshold GFI'_τ can be used to derive the parameter a of the scale factor b (eq. 6)

$$b = \frac{1}{exp(GFI'_\tau)} \qquad (6)$$

After the training phase based on the reference maps, the model links the geomorphic descriptors to the flood hazard. Thus, the model can be efficiently applied to any area where a DEM is available and the relationship between flood hazard and descriptors is assumed to be the same.

The GFI: Inundation depth estimation

Assuming the value of literature for *n*=0.354 and once the value of scale factor *b* has been calculated from equation 2 it is possible to estimate also the water level in the river network.

From the previously performed geomorphic analysis we know for each point of the river (for each DEM pixel) all the upslope basin locations connected to it, and the difference in elevation H between them (see Figure 1). At this point, we can use the *hr* values to estimate, in a simple and direct way, the water depth WD cell by cell of the flood-prone areas, as in Equation (7),

$$\mathrm{WD} = h_r - H \cong b \cdot A_r^n - H \qquad (7)$$

This method is useful for predicting water depth for a given flood scenario.
However, it should be underlined that, when there are notable variations in river morphology along the watercourse, the scaling factor b varies accordingly. For this reason, in such cases, only by analyzing the watercourse in homogeneous sections is it possible to obtain good results in terms of water depth.

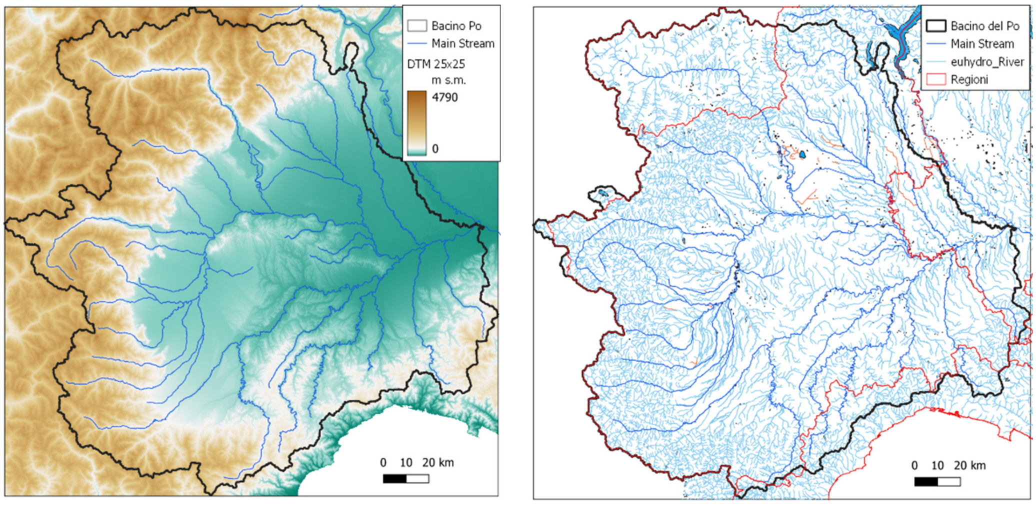
The Study area and dataset: the upper part of the Po river basin in Italy

The study in the upper part of Po river basin in Italy having a drainage basin of about 29,000 km².

Morphology data were evaluated from the following datasets:

- Digital Elevation Model over Europe (EU-DEM) - Pixel size 25 meters resolution
- EU-Hydro River Network Database 2006-2012 (vector), Europe

Figure 3 shows the clip of the two datasets for the study area, while figure 4 represents the value of the calculated GFI' index.



(A) (B)

Figura 3 – A) Clip of EU-DEM Copernicus, B) clip EU-Hydro.

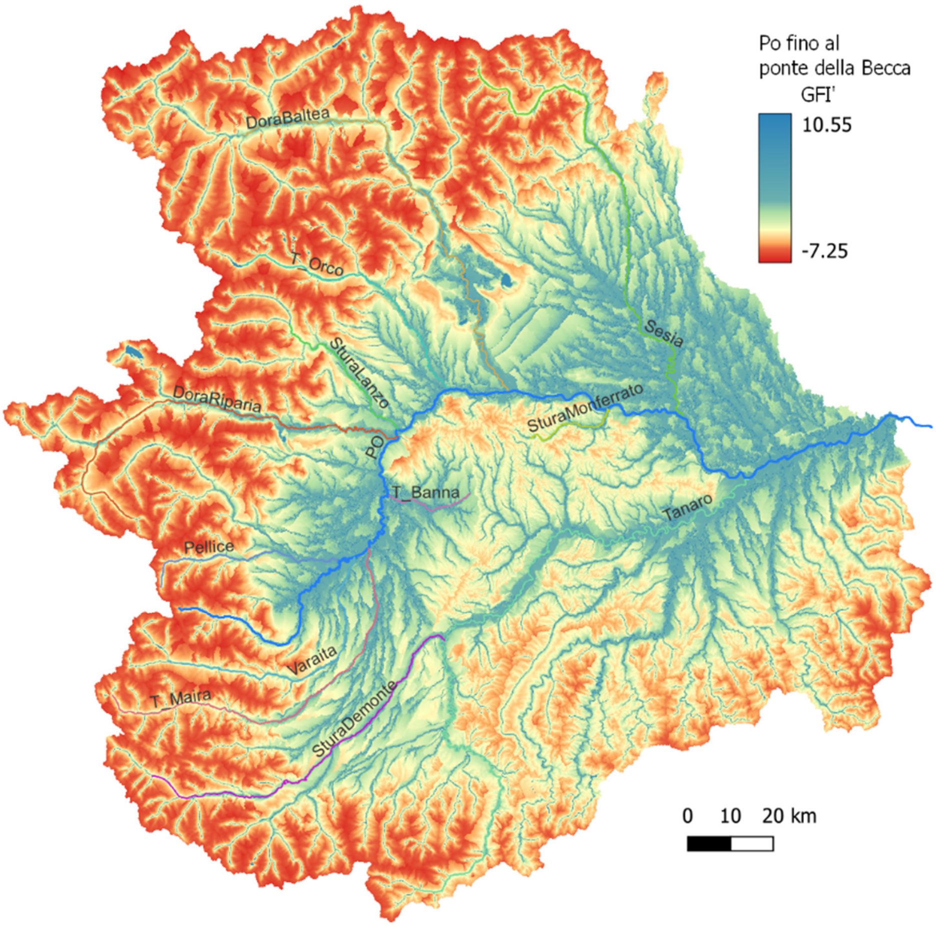


Figura 4 – Standardized GFI' index map.

For training phases, as reference maps, we use the flood hazard maps provided by Po River Basin District Authority to fulfil the EU Floods Directive of the European Commission (2007/60/EC). These maps refer to three different scenarios called P1, P2 and P3 which refer respectively to the return periods of 500, 200 and 20 years. Figure 4 shows the maps relating to the main rivers.

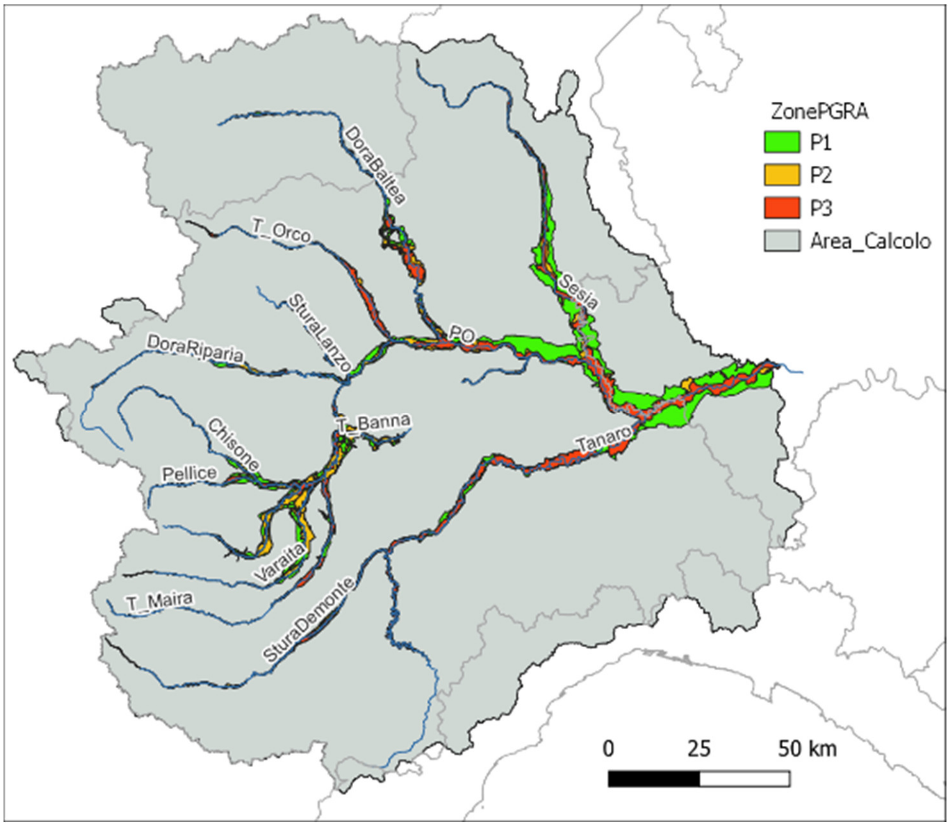


Figure 5 – Flood-hazard reference map for the study area.

Example of the detailed analysis of the Dora Riparia river

A first analysis test of the variability of the scale parameter b was carried out on the Dora Riparia river, for which, after calculating the GFI', the watercourse was divided into river branches of 2 km in length and the areas contributors to each of them have been delimited.

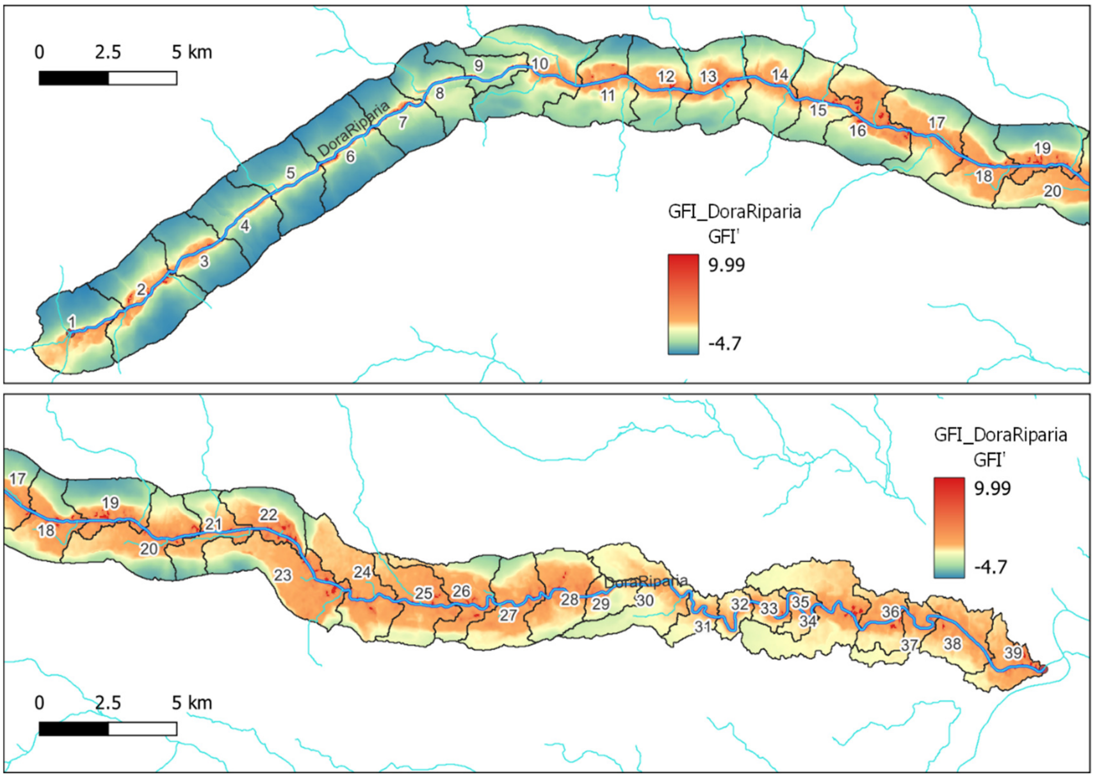


Figure 6 – Map of river branch of Dora Riparia and GFI'.

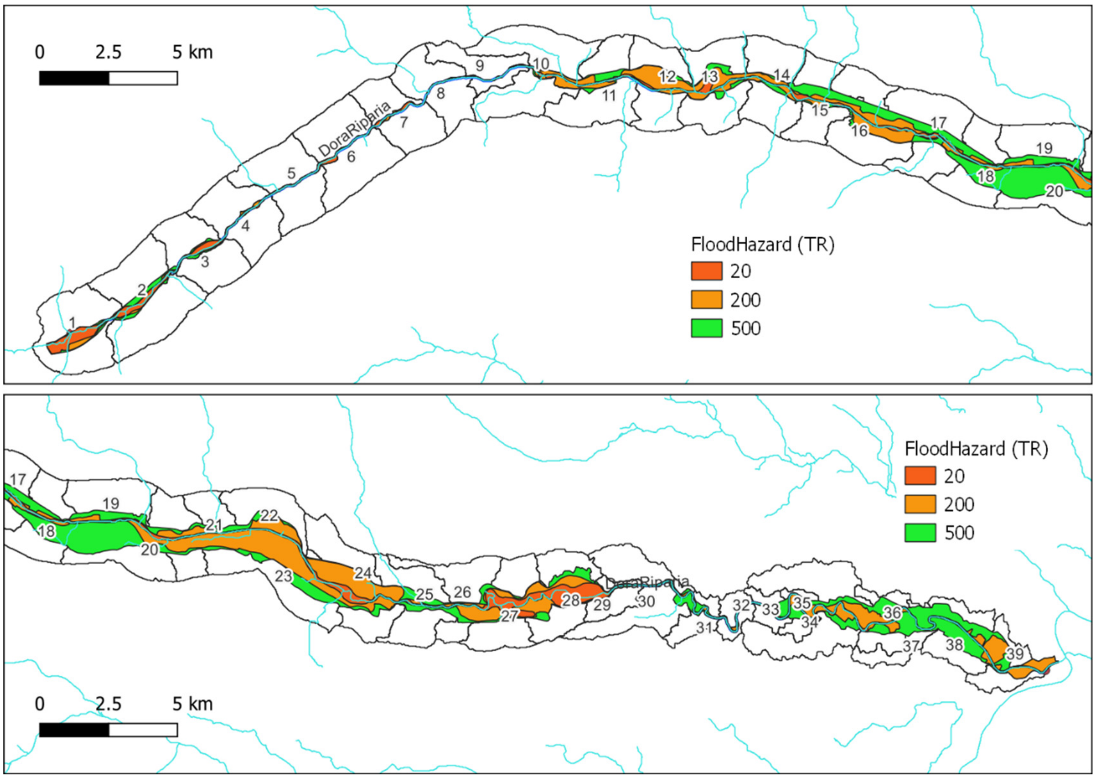


Figure 7 – Map of river branch of Dora Riparia and flood hazard for 20,200 and 500 year of return period.

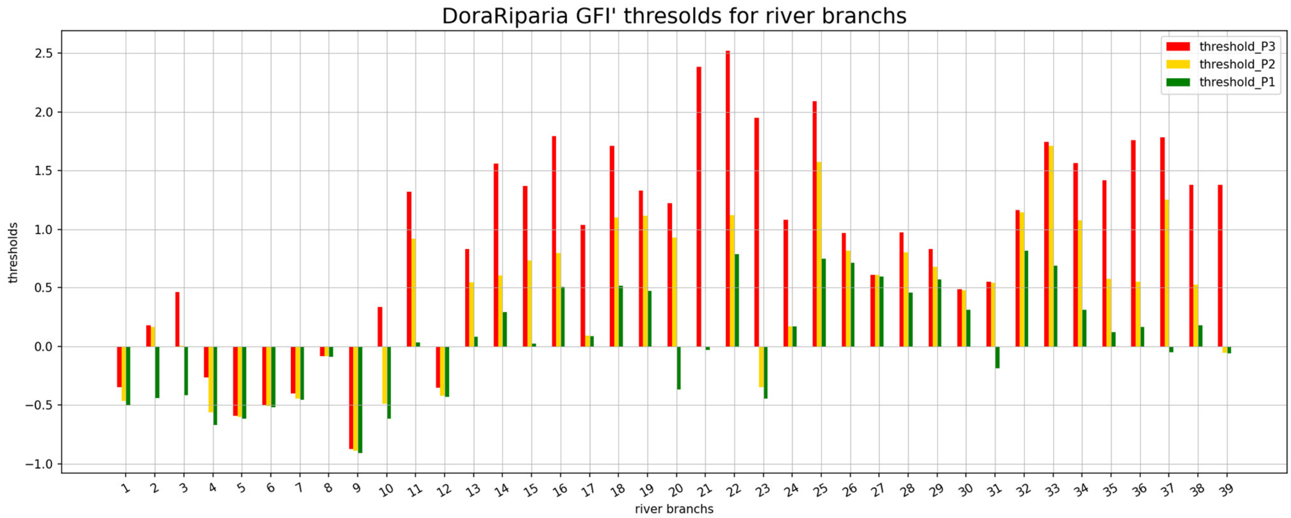


Figure 8 - Dora Riparia : GFI' tresholds in river branch for flood hazard of 20,200 and 500 year.

To explain the variability of the thresholds in the various branches we try to analyze the 3D shape of the valley and .

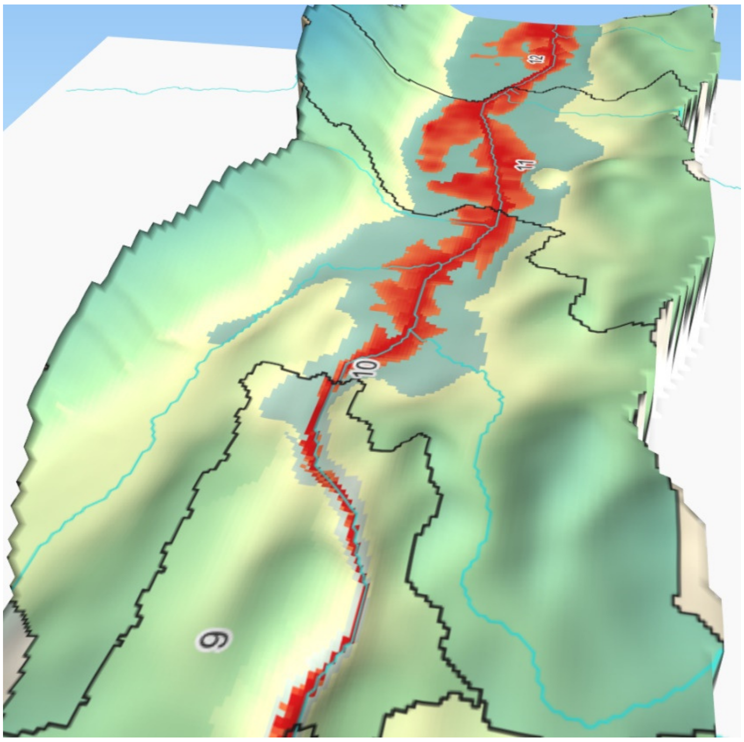
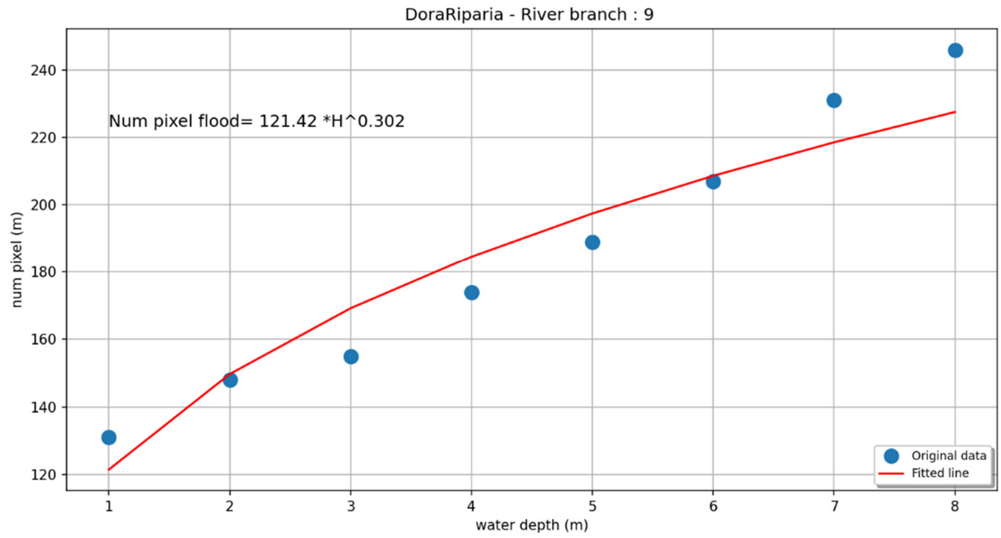
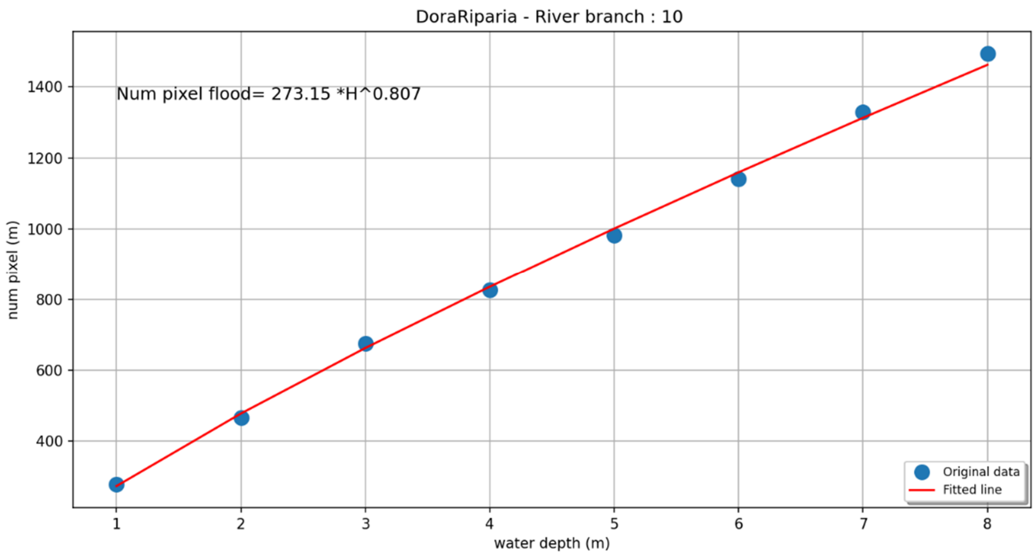
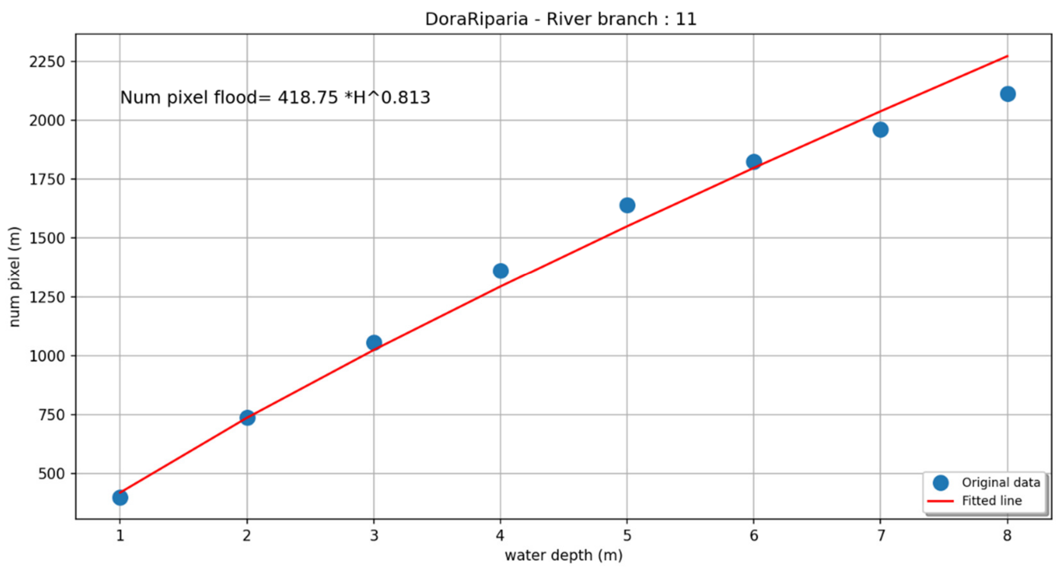


Figure 9 - Dora Riparia : 3D view .

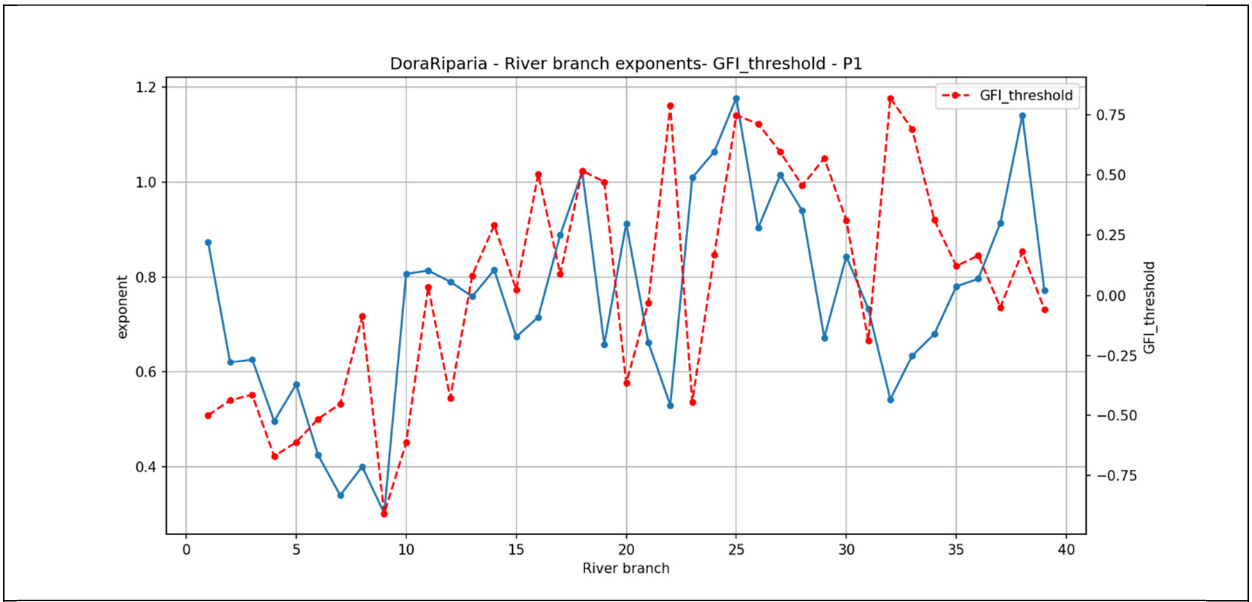
In particular, for each branch, the curve representing the flood-prone areas is calculated as a function of the height H above the riverbed.

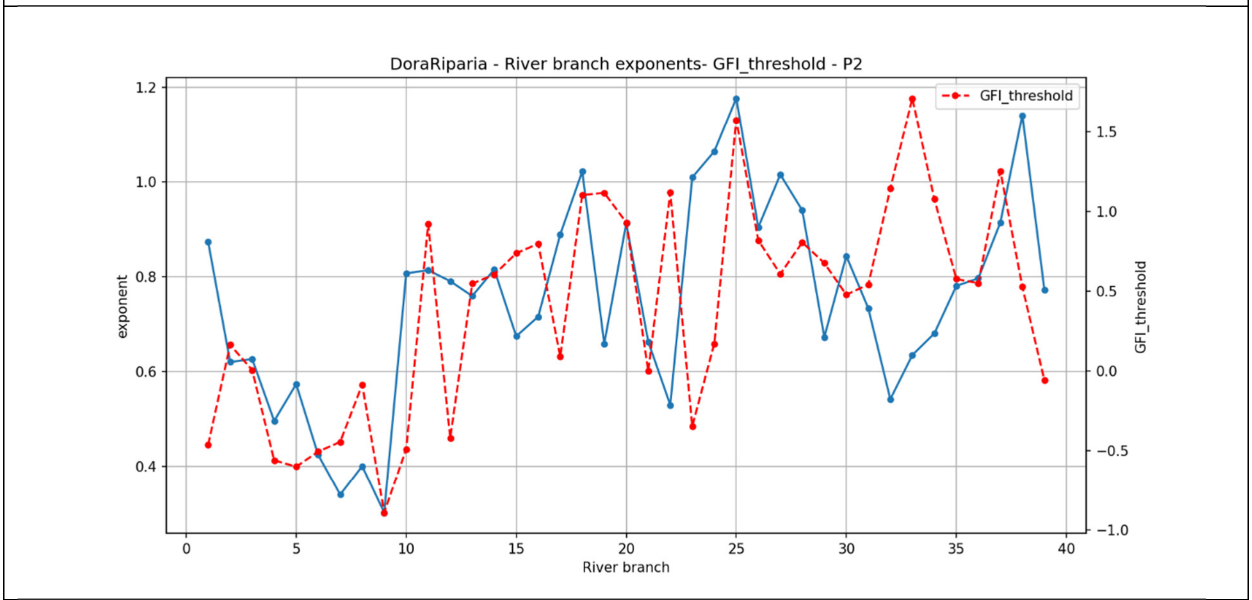

DoraRiparia - River branch : 9
Num pixel flood= 121.42 *H^0.302
num pixel (m)
water depth (m)
Original data
Fitted line
240
220
200
180
160
140
120
1
2
3
4
5
6
7
8

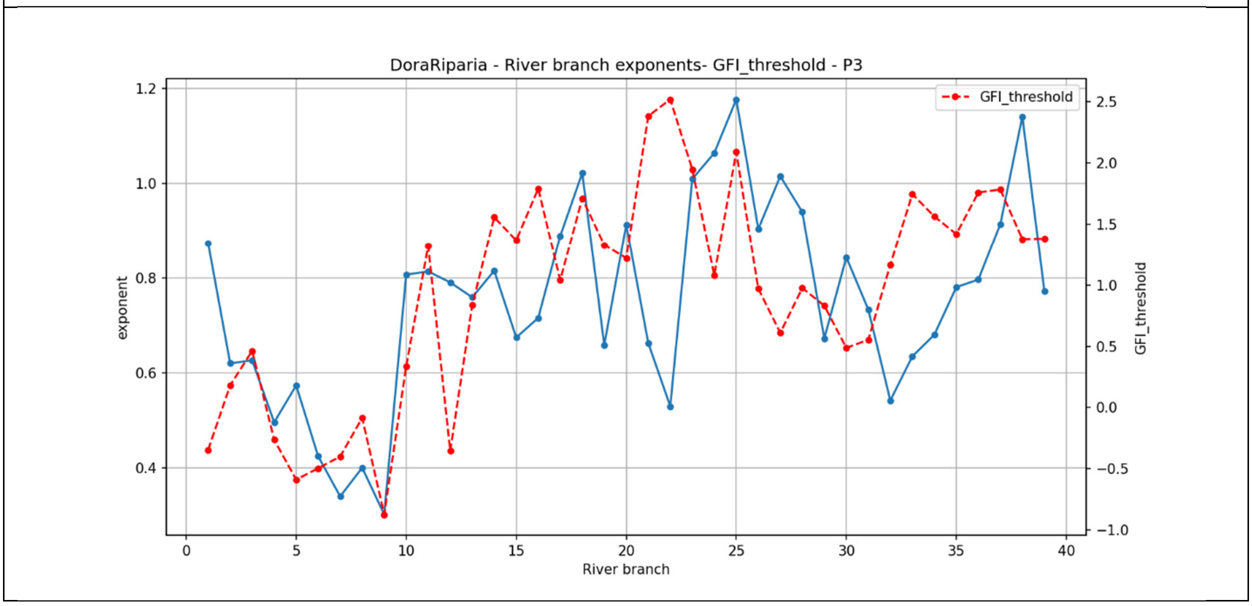

DoraRiparia - River branch : 10
Num pixel flood= 273.15 *H^0.807
num pixel (m)
water depth (m)
Original data
Fitted line
1400
1200
1000
800
600
400
1
2
3
4
5
6
7
8

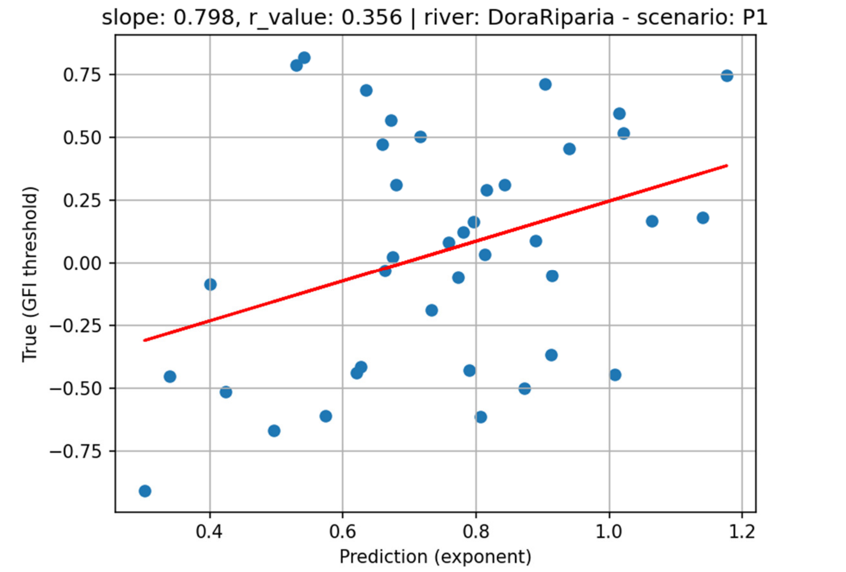

DoraRiparia - River branch : 11
Num pixel flood= 418.75 *H^0.813
num pixel (m)
water depth (m)
Original data
Fitted line
2250
2000
1750
1500
1250
1000
750
500
1
2
3
4
5
6
7
8

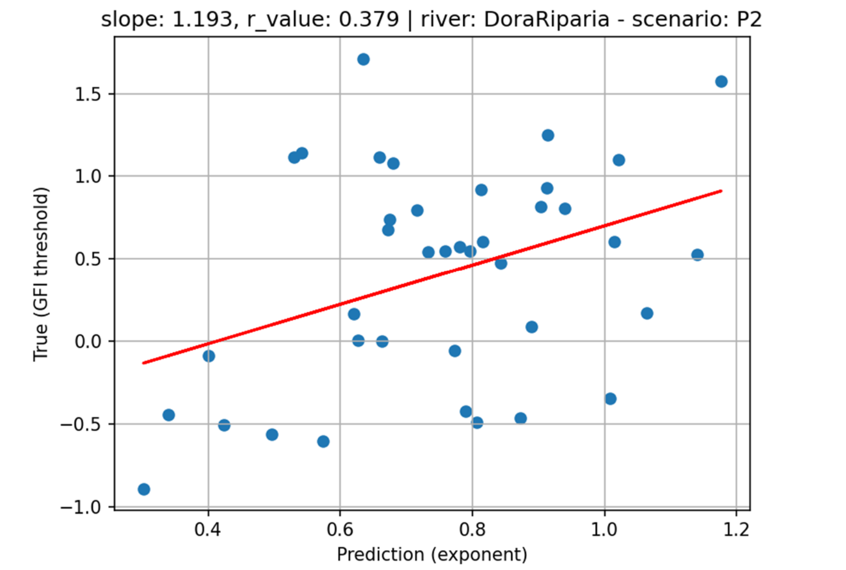
Branch	slope	elevation	Lon	Lat	const	exponent	threshold_P3	threshold_P2	threshold_P1
1	0.0123	1046.23	6.8482	45.0489	242.30	0.8731	-0.3450	-0.4622	-0.4999
2	0.0072	1023.98	6.8710	45.0595	467.29	0.6200	0.1805	0.1637	-0.4383
3	0.0155	1001.36	6.8915	45.0727	264.19	0.6263	0.4627	0.0059	-0.4150
4	0.0691	921.56	6.9136	45.0862	149.17	0.4959	-0.2631	-0.5600	-0.6705
5	0.0553	801.44	6.9379	45.0987	116.92	0.5735	-0.5886	-0.6004	-0.6124
6	0.0355	723.88	6.9601	45.1106	182.01	0.4242	-0.4956	-0.5056	-0.5157
7	0.0284	669.65	6.9831	45.1222	237.20	0.3399	-0.4003	-0.4445	-0.4534
8	0.0553	642.00	7.0045	45.1324	142.85	0.4003	-0.0842	-0.0859	-0.0876
9	0.0356	567.13	7.0297	45.1363	121.42	0.3021	-0.8725	-0.8900	-0.9078
10	0.0182	490.80	7.0549	45.1360	273.15	0.8068	0.3367	-0.4898	-0.6141
11	0.0073	470.12	7.0805	45.1356	418.75	0.8134	1.3206	0.9190	0.0349
12	0.0072	453.58	7.1064	45.1334	384.46	0.7903	-0.3538	-0.4198	-0.4281

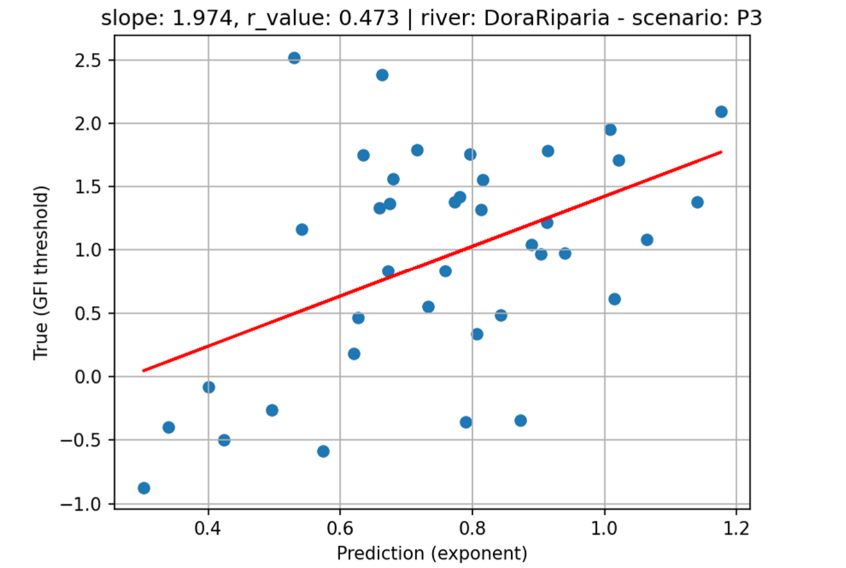

DoraRiparia - River branch exponents- GFI_threshold - P1
GFI_threshold
exponent
GFI_threshold
River branch


DoraRiparia - River branch exponents- GFI_threshold - P2
GFI_threshold
exponent
GFI_threshold
River branch


DoraRiparia - River branch exponents- GFI_threshold - P3
GFI_threshold
exponent
GFI_threshold
River branch


slope: 0.798, r_value: 0.356 | river: DoraRiparia - scenario: P1
True (GFI threshold)
Prediction (exponent)
0.75
0.50
0.25
0.00
−0.25
−0.50
−0.75
0.4
0.6
0.8
1.0
1.2


slope: 1.193, r_value: 0.379 | river: DoraRiparia - scenario: P2
True (GFI threshold)
Prediction (exponent)
1.5
1.0
0.5
0.0
−0.5
−1.0
0.4
0.6
0.8
1.0
1.2


slope: 1.974, r_value: 0.473 | river: DoraRiparia - scenario: P3
True (GFI threshold)
Prediction (exponent)
2.5
2.0
1.5
1.0
0.5
0.0
−0.5
−1.0
0.4
0.6
0.8
1.0
1.2

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Samela, C., Albano, R., Sole, A., & Manfreda, S. (2018). A GIS tool for cost-effective delineation of flood-prone areas. Computers, Environment and Urban Systems, 70, 43–52. https://doi.org/10.1016/j.compenvurbsys.2018.01.013

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