27 giugno 2019

Salvatore Manfreda

METTIAMOCI
IN RIGA

Metodi speditivi per la mappatura del rischio idraulico su larga scala

DEM-based Methods for Flood Risk Mapping at Large Scale

UNIONE EUROPEA
Fondo Sociale Europeo
Fondo Europeo di Sviluppo Regionale

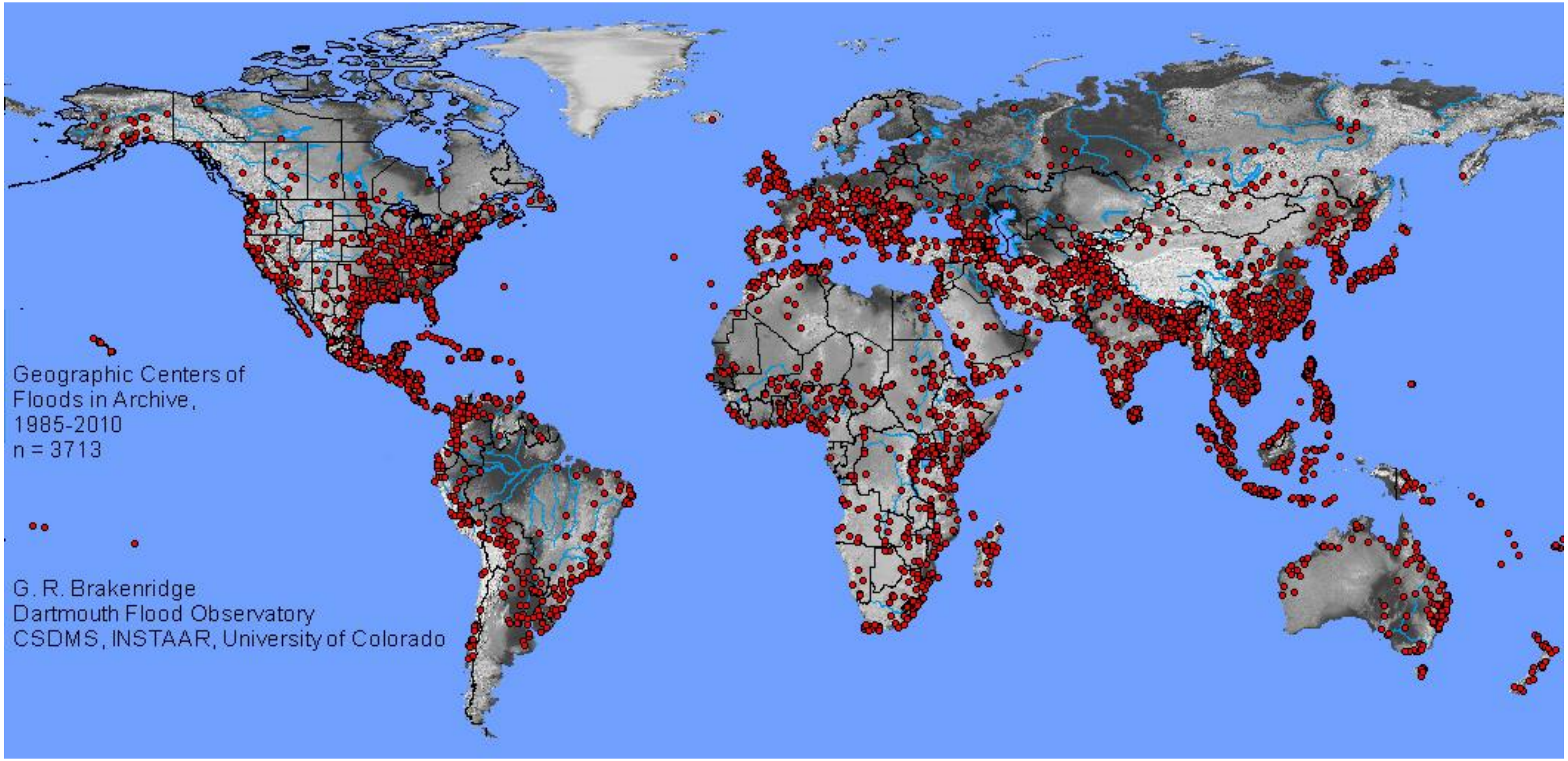
Agenzia per la Coesione Territoriale

MINISTERO DELL'AMBIENTE
E DELLA TUTELA DEL TERRITORIO E DEL MARE

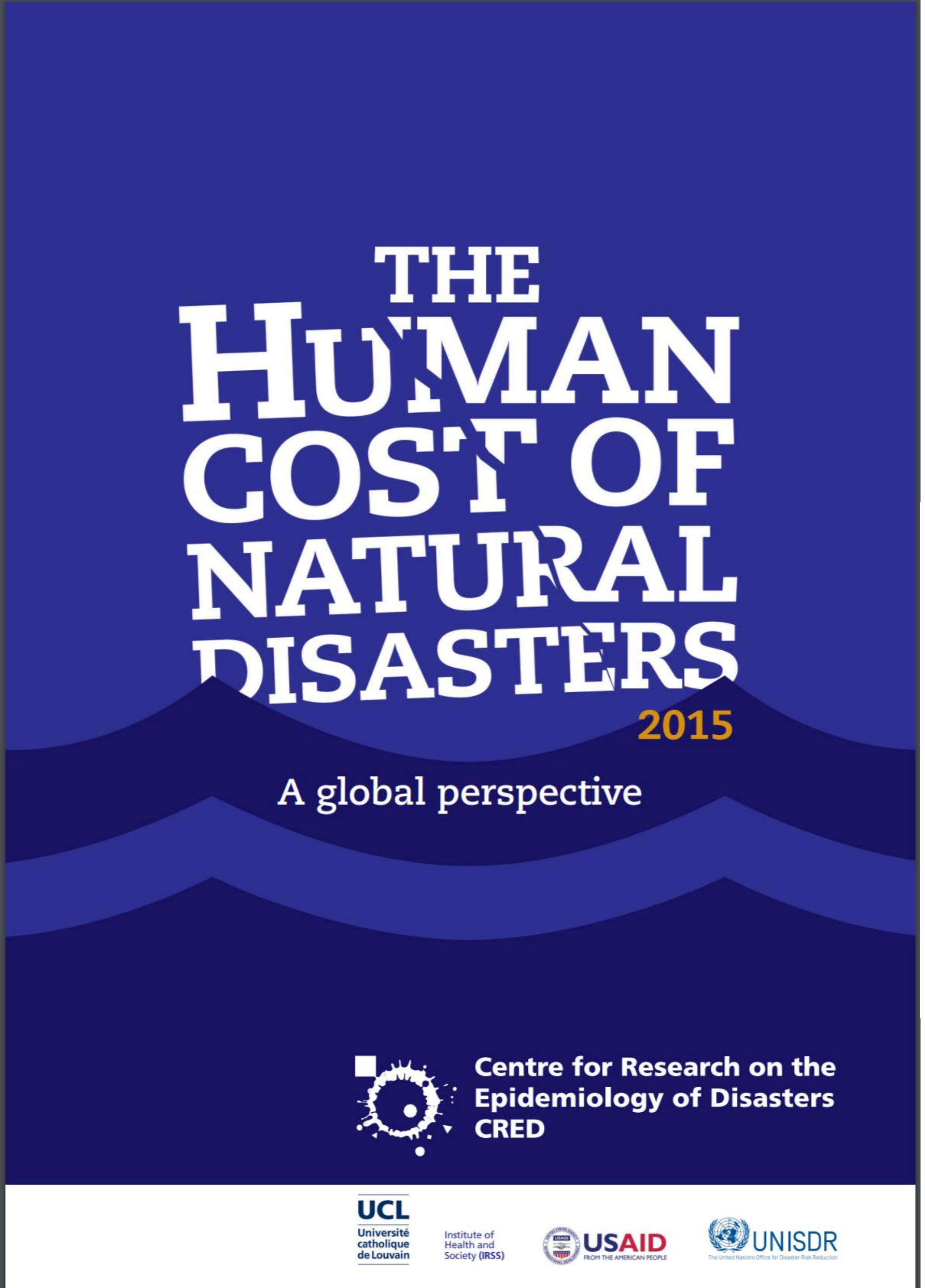
PON GOVERNANCE E CAPACITÀ ISTITUZIONALE 2014-2020

SOGESID SPA
INGEGNERIA TERRITORIO AMBIENTE

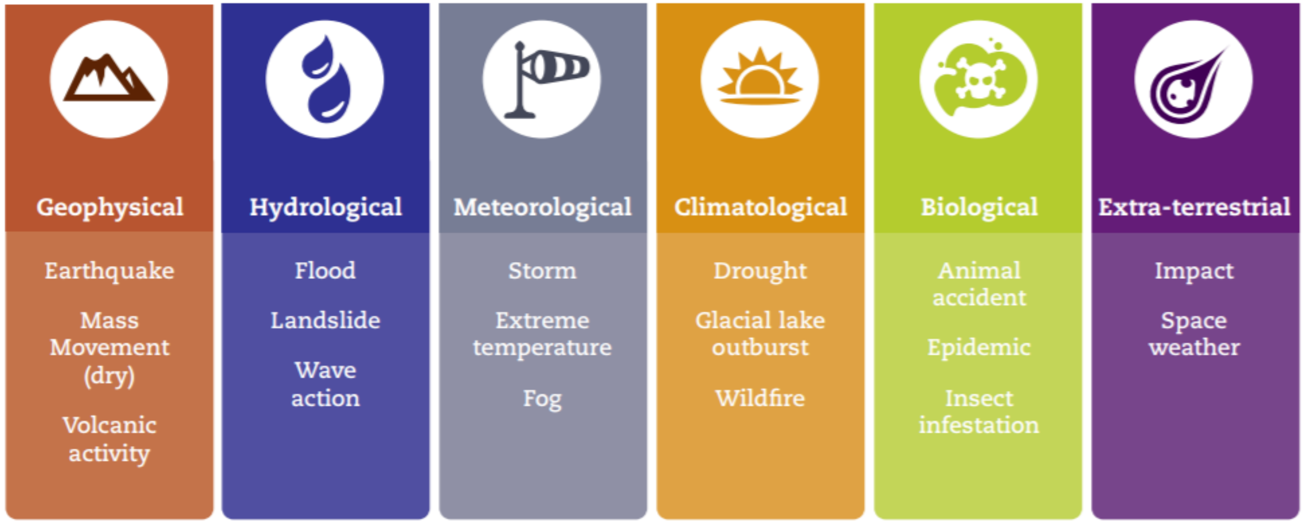
Flood events recorded during the period 1985-2010



G.R.Brakenridge, "Global Active Archive of Large Flood Events", Dartmouth Flood Observatory, University of Colorado, http://floodobservatory.colorado.edu/Archives/index.html.



Impact of Natural Hazards at global scale



https://www.researchgate.net/lab/Centre-for-Research-on-the-Epidemiology-of-Disasters-Debarati-Guha-Sapir

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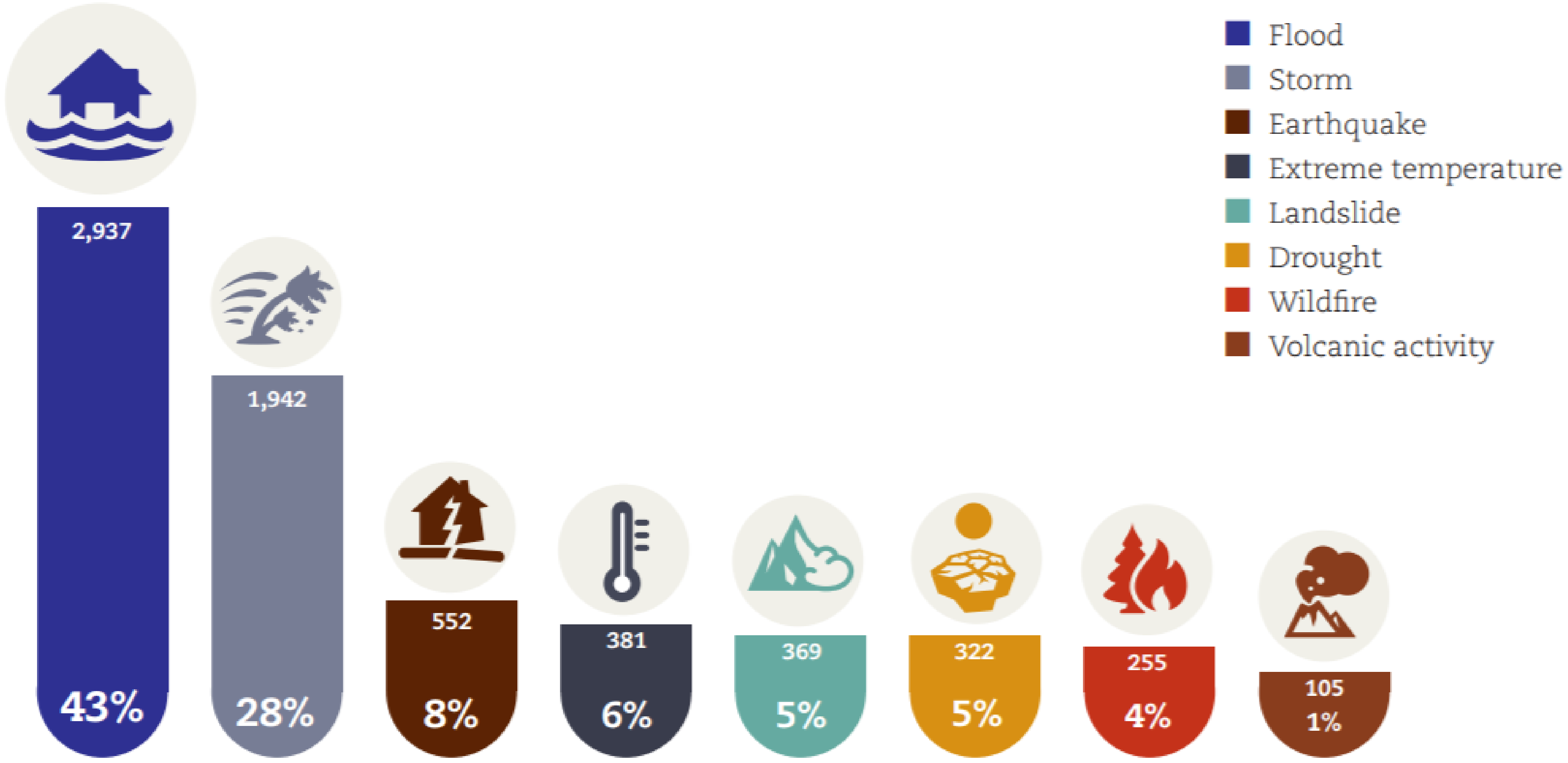
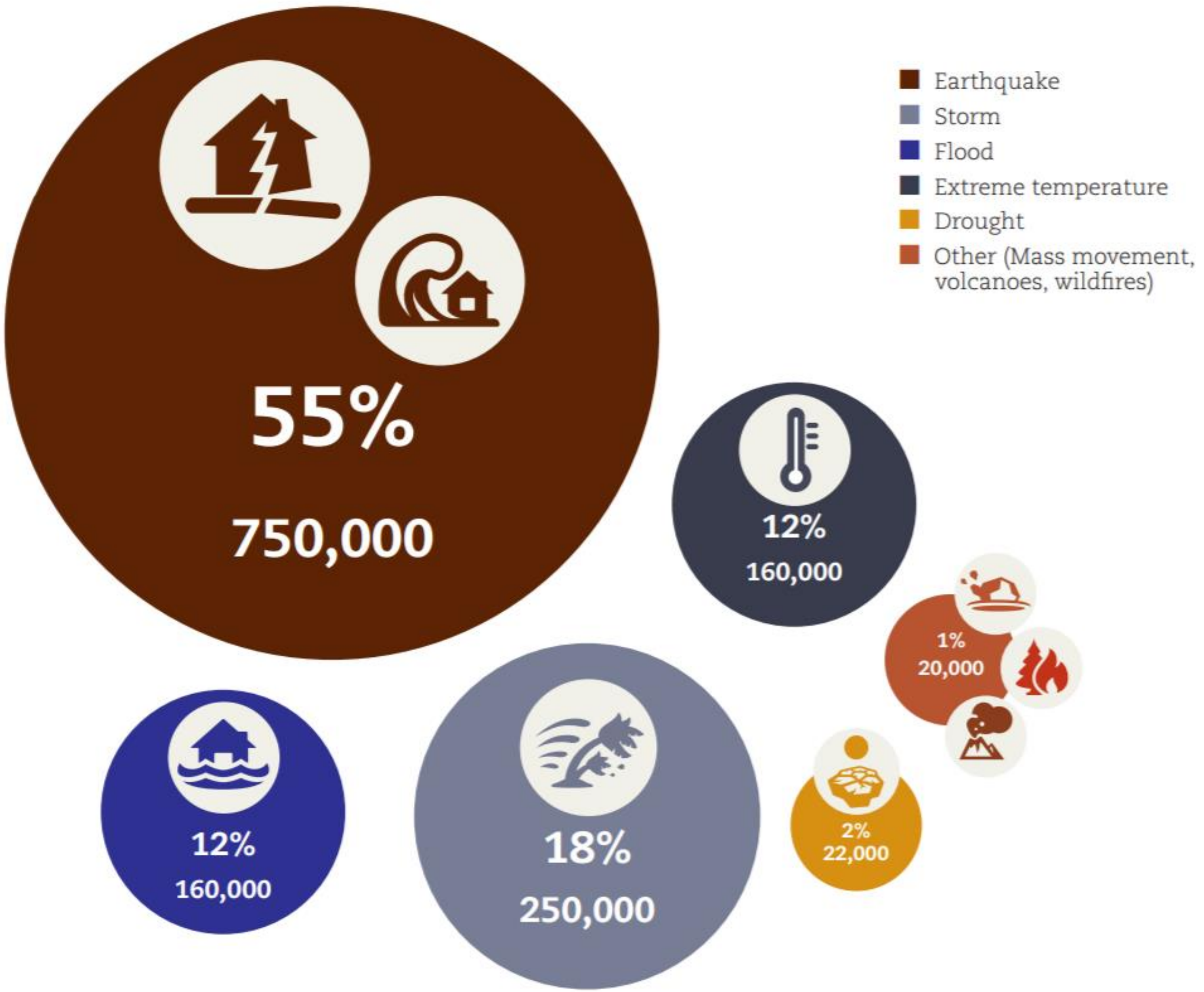
Distribution of Natural Hazards (1994-2013)

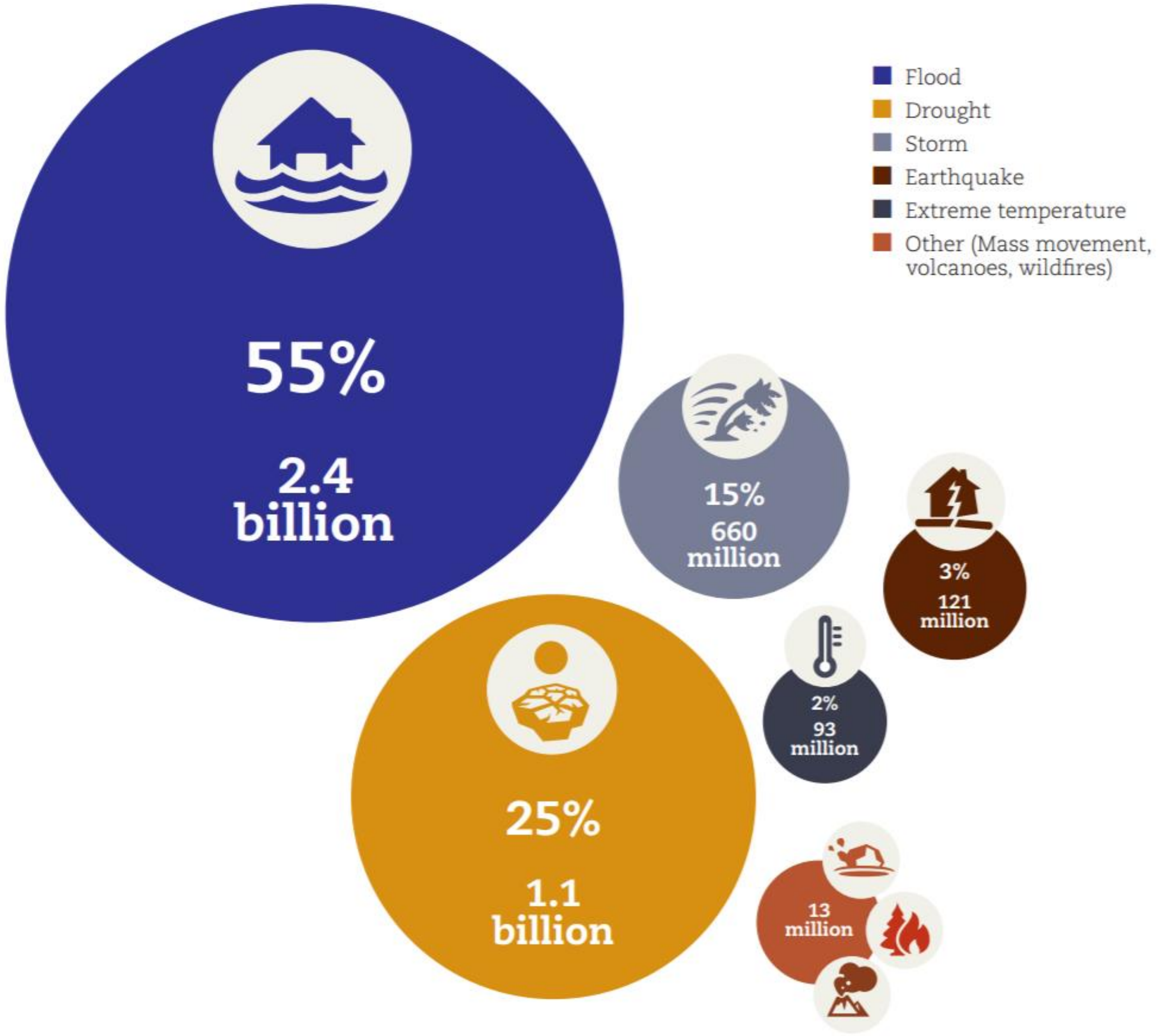


Floods have also become more frequent, rising from 123 per year on average between 1994 and 2003 to an annual average of 171 per year in the 2004-2013 period.

Number of deaths by disaster type (1994-2013)



Number of people affected by disaster type (1994-2013)
(NB: deaths are excluded from the total affected)



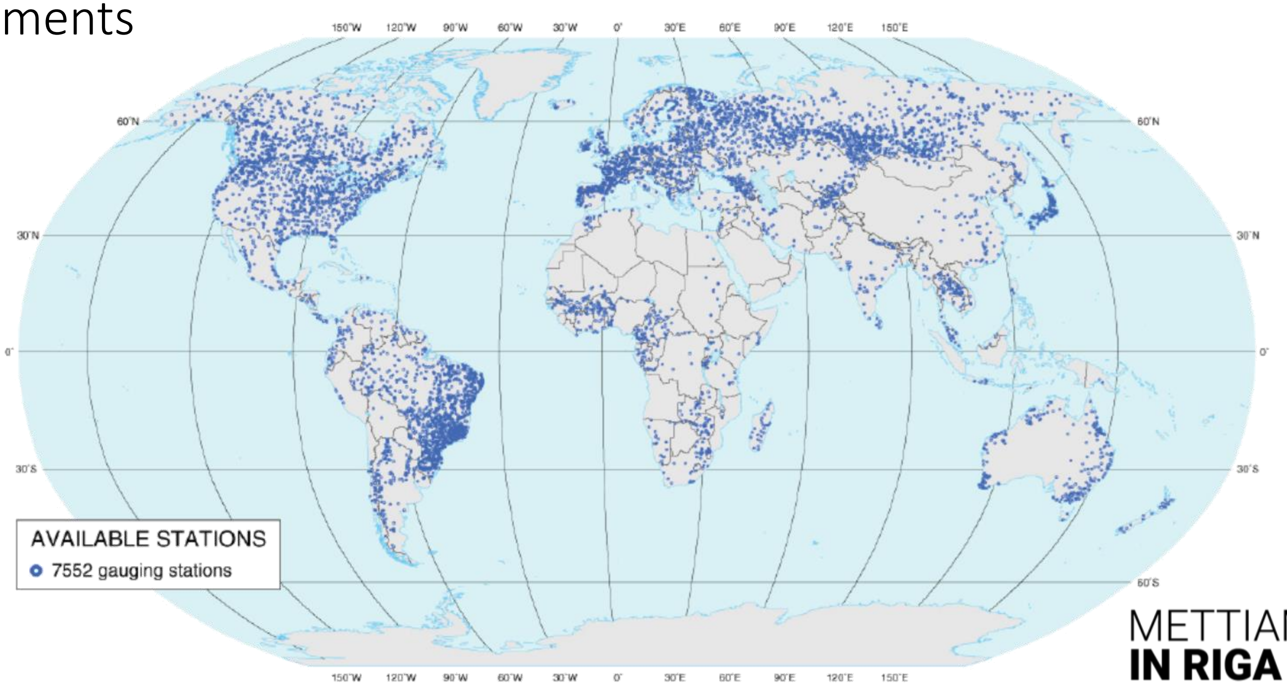
Motivation: Why Simplified Procedures?

Hydrological and hydraulic models are the best approach for deriving detailed flood hazard maps, but they require large amounts of:

- ✓ Cost;
- ✓ Time;
- ✓ Data and parameters **not available for all areas.**

Flood risk assessment in data poor environments poses a great deal of challenge.

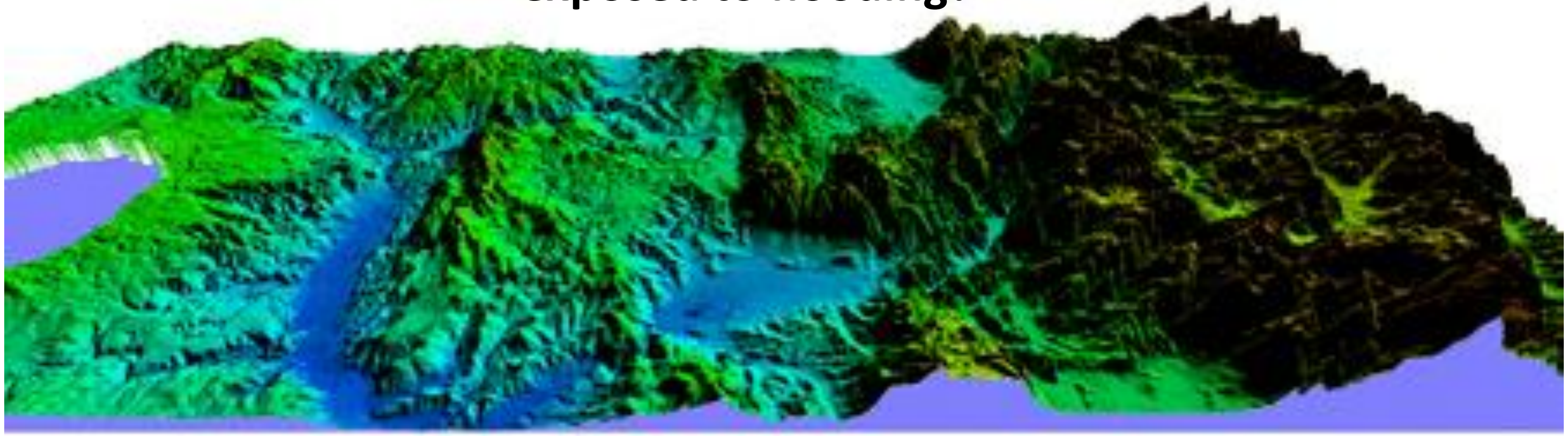
Poor density of gauging stations in some regions (Asia, Africa, Australia).
(Herold and Mouton, 2011)



Geomorphic Procedures

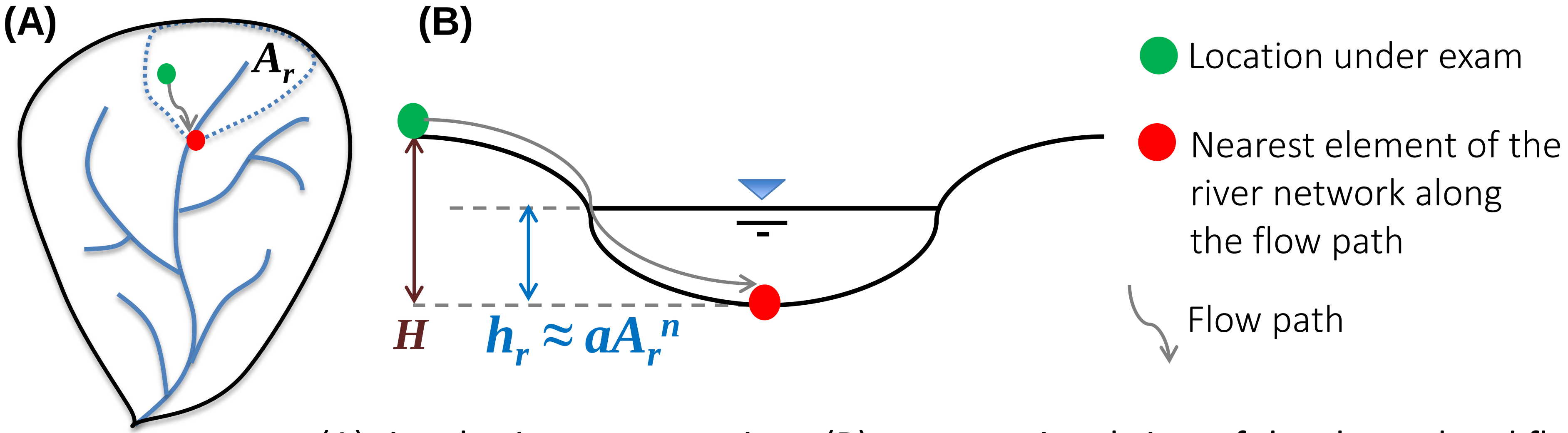
Basin morphology contains an extraordinary amount of information about flood exposure

Does exist a physical attribute of the surface able to reveal if a portion of a river basin is exposed to flooding?



Best performing geomorphic descriptor: GFI

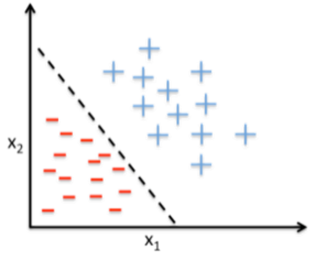
Geomorphic Flood Index → $GFI = ln\left(\frac{h_r}{H}\right)$



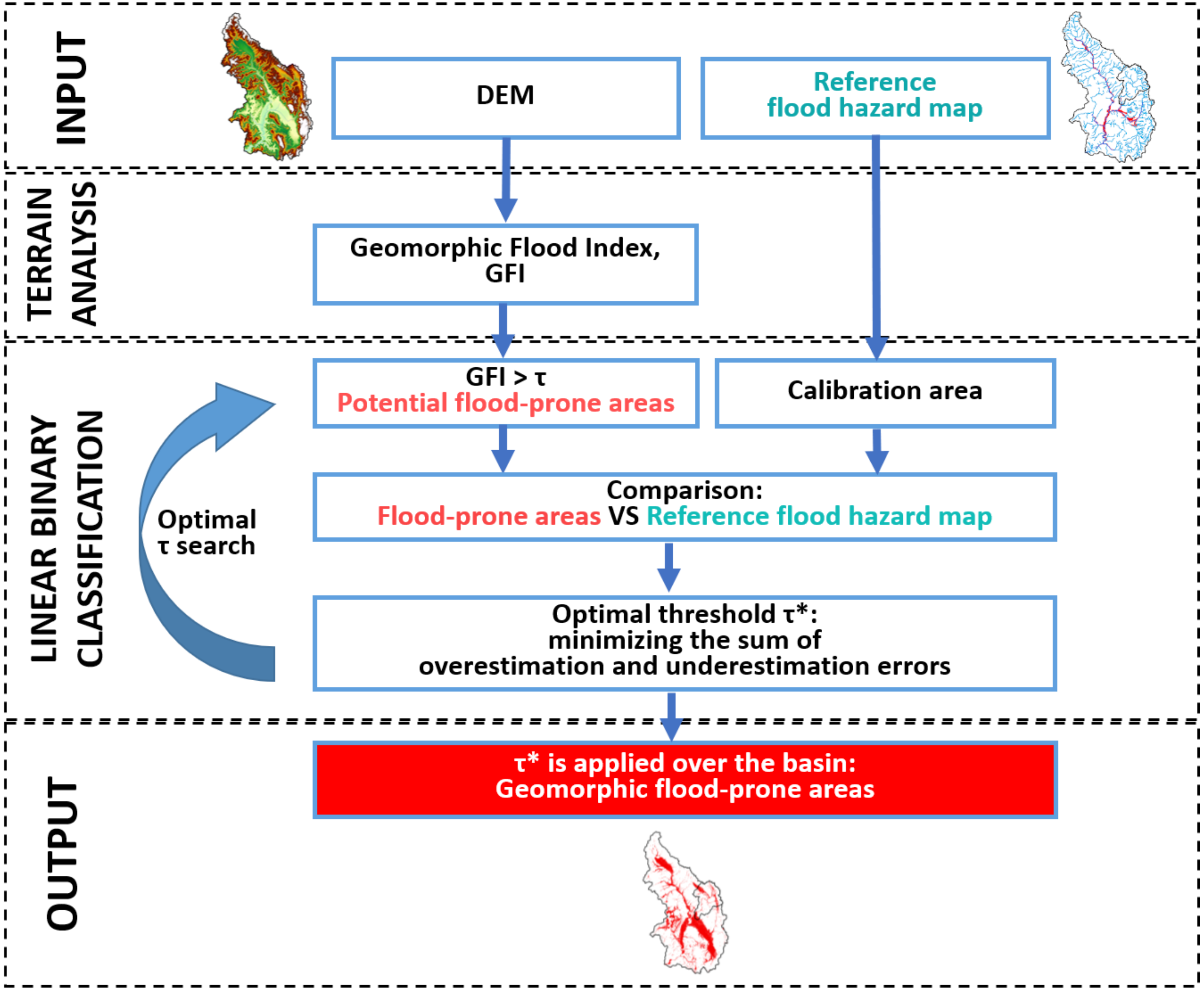
(A) river basin representation; (B) cross-sectional view of the channel and floodplain.

- *Ar*, upslope contributing area;
- *hr*, river depth ('r' stands for river) calculated using a hydraulic scaling relationship (Leopold and Maddock, 1953): $h_r \approx aA_r^n$;
- *H* is the elevation difference to the nearest stream (i.e. HAND: Rennó et al. (2008); Nobre et al. (2016); Zheng et al. (2018)).

Linear Binary Classification based on the GFI



Example of a linear decision boundary for binary classification: threshold value τ



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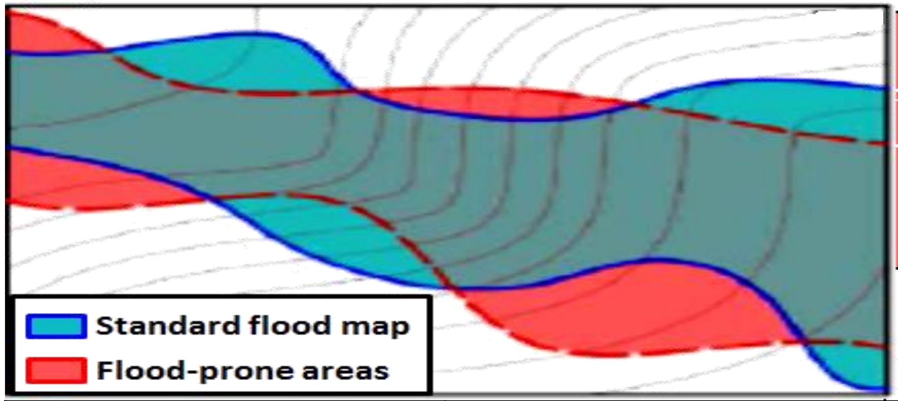
Measures of Performances

- **True positive rate:** $R_{TP} = TP/(TP+FN)$ → SENSITIVITY
- **False negative rate:** $R_{FN} = 1 - R_{TP}$ → Underestimation

- **True negative rate:** $R_{TN} = TN/(TN+FP)$ → SPECIFICITY
- **False positive rate:** $R_{FP} = 1 - R_{TN}$ → Overestimation



		MODEL PREDICTION (Morphological method)	
		EVENT	NO EVENT
GOLD STANDARD TRUTH (Standard map)	EVENT	**TRUE POSITIVE**	**FALSE NEGATIVE**
	NO EVENT	**FALSE POSITIVE**	**TRUE NEGATIVE**

Testing the reliability in different contexts

Full continental U.S.A.

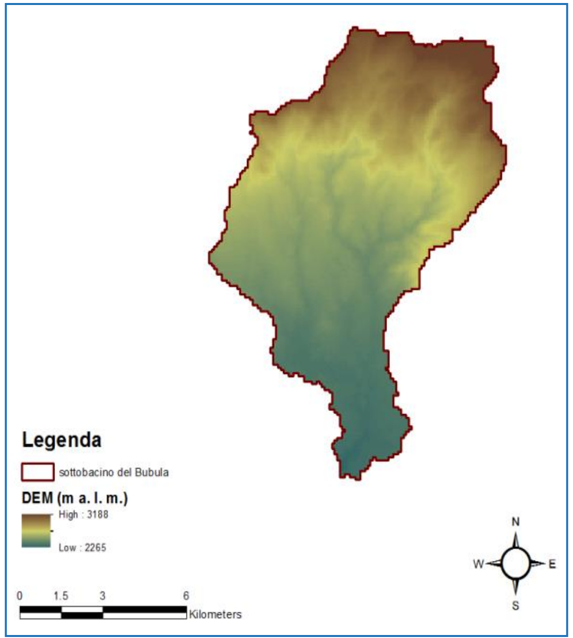
(Samela et al., 2017a,b)

Pan-European region

(Tavares Da Costa et al., 2019)

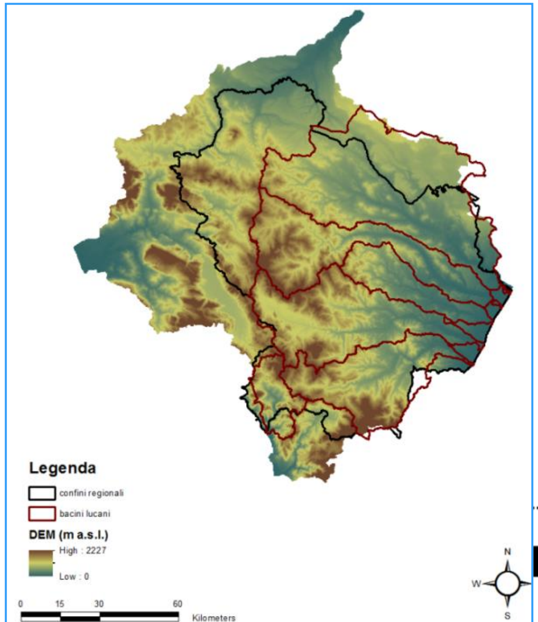
1 basin in Ethiopia, AFRICA

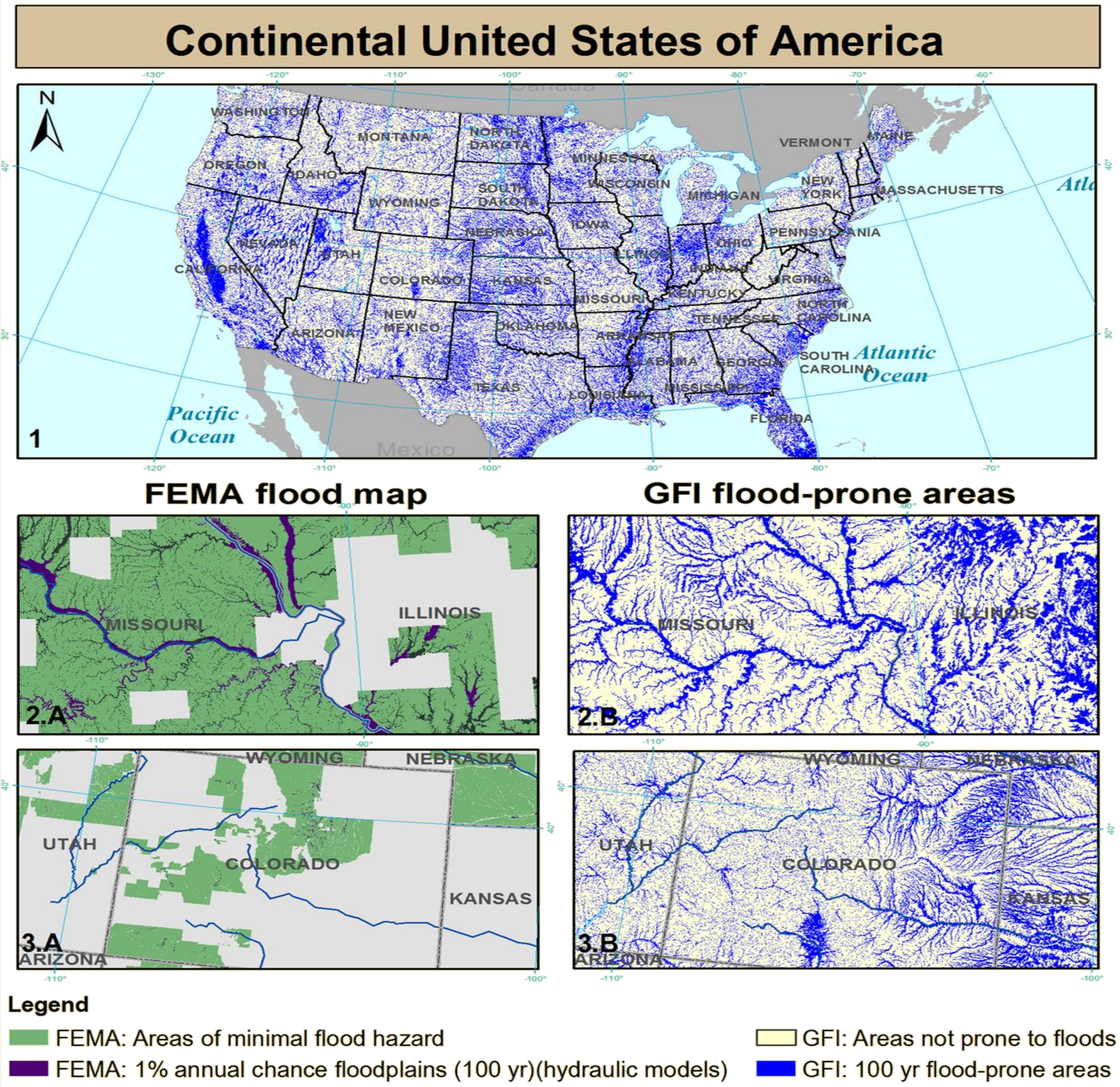
(Samela et al., 2016)



8 river basin in ITALY:

(Manfreda et al.,2014,2015)





EXAMPLE OF APPLICATION

100-yr flood-prone areas for the continental U.S. according to the linear binary classifier based on the GFI.

The large-scale map allows to see that the index produces a realistic description of the flood prone areas, with the possibility to extend the flood hazard information where the Federal Emergency Management Agency (FEMA) maps are lacking (grey areas).

The method has been implemented in a QGIS plugin called Geomorphic Flood Area Tool that **can be downloaded from the repository**: https://plugins.qgis.org/plugins/GeomorphicFloodIndex/

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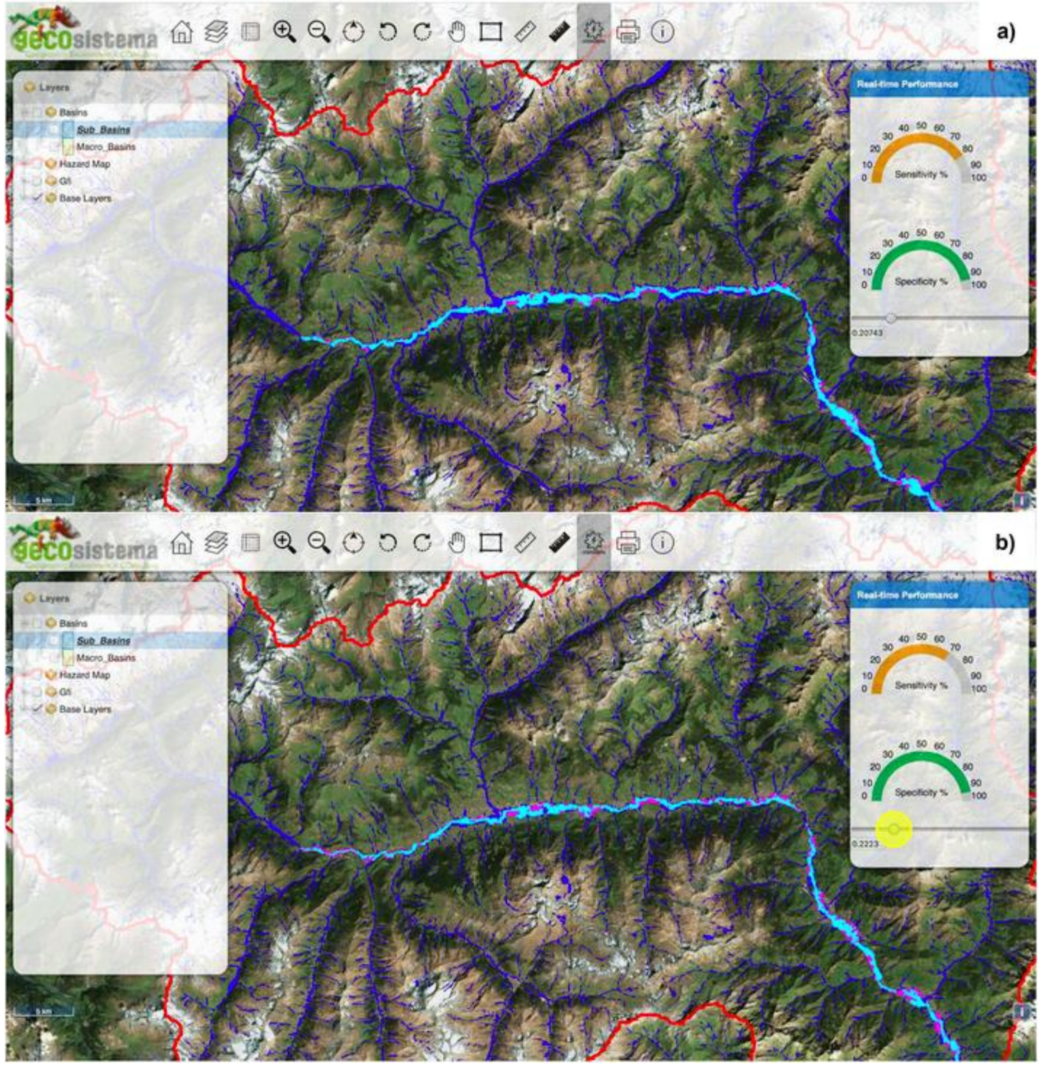
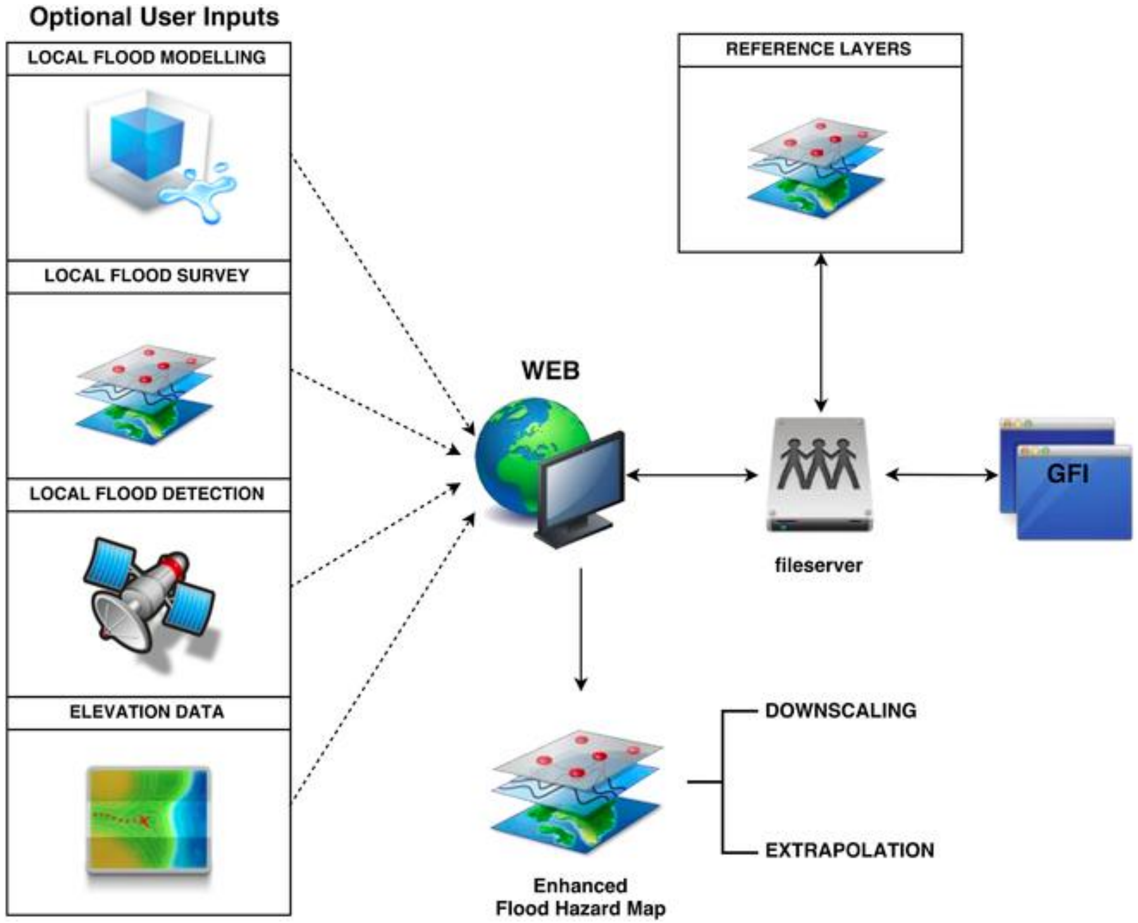
Smartflood





http://gecosistema.com/smartflood

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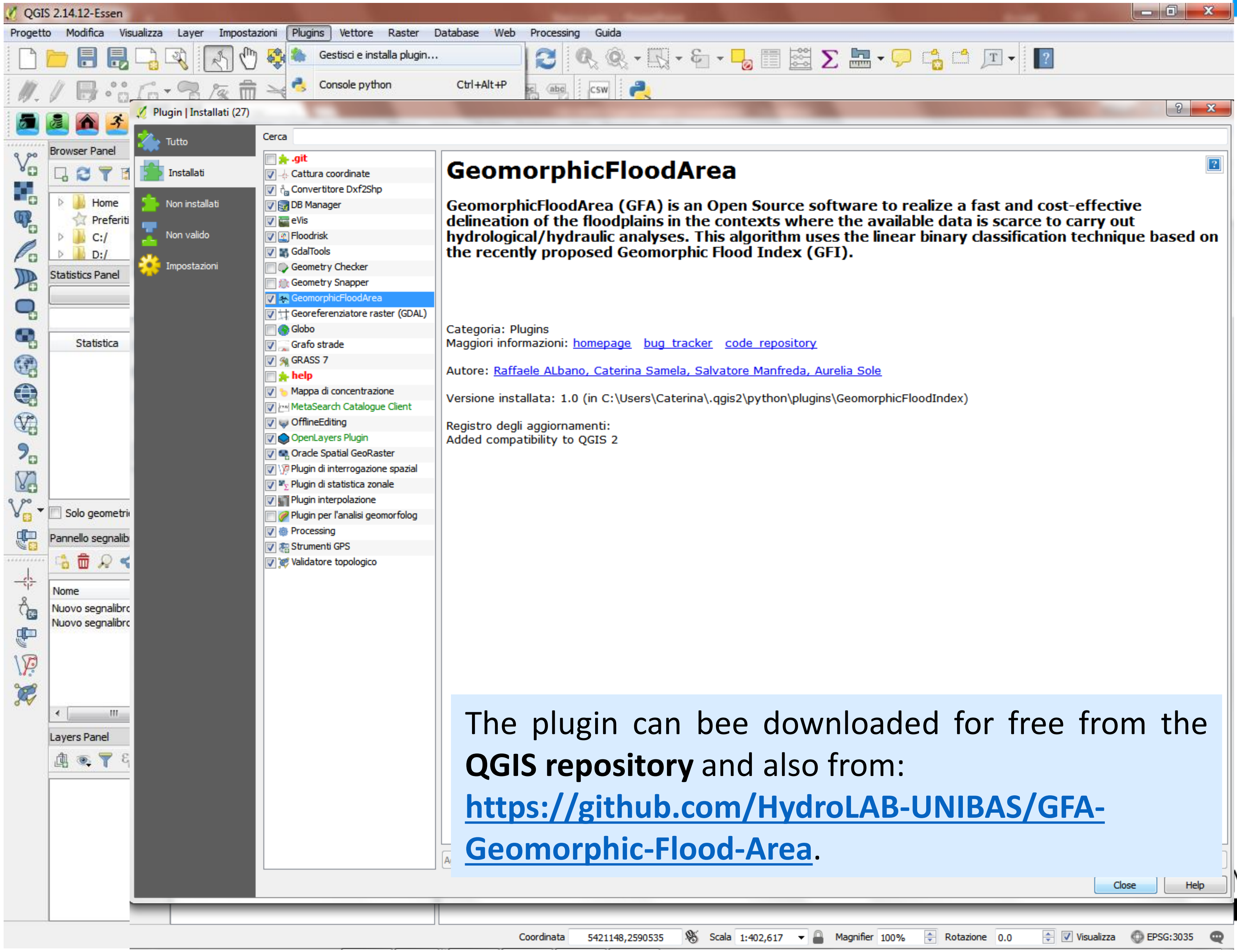
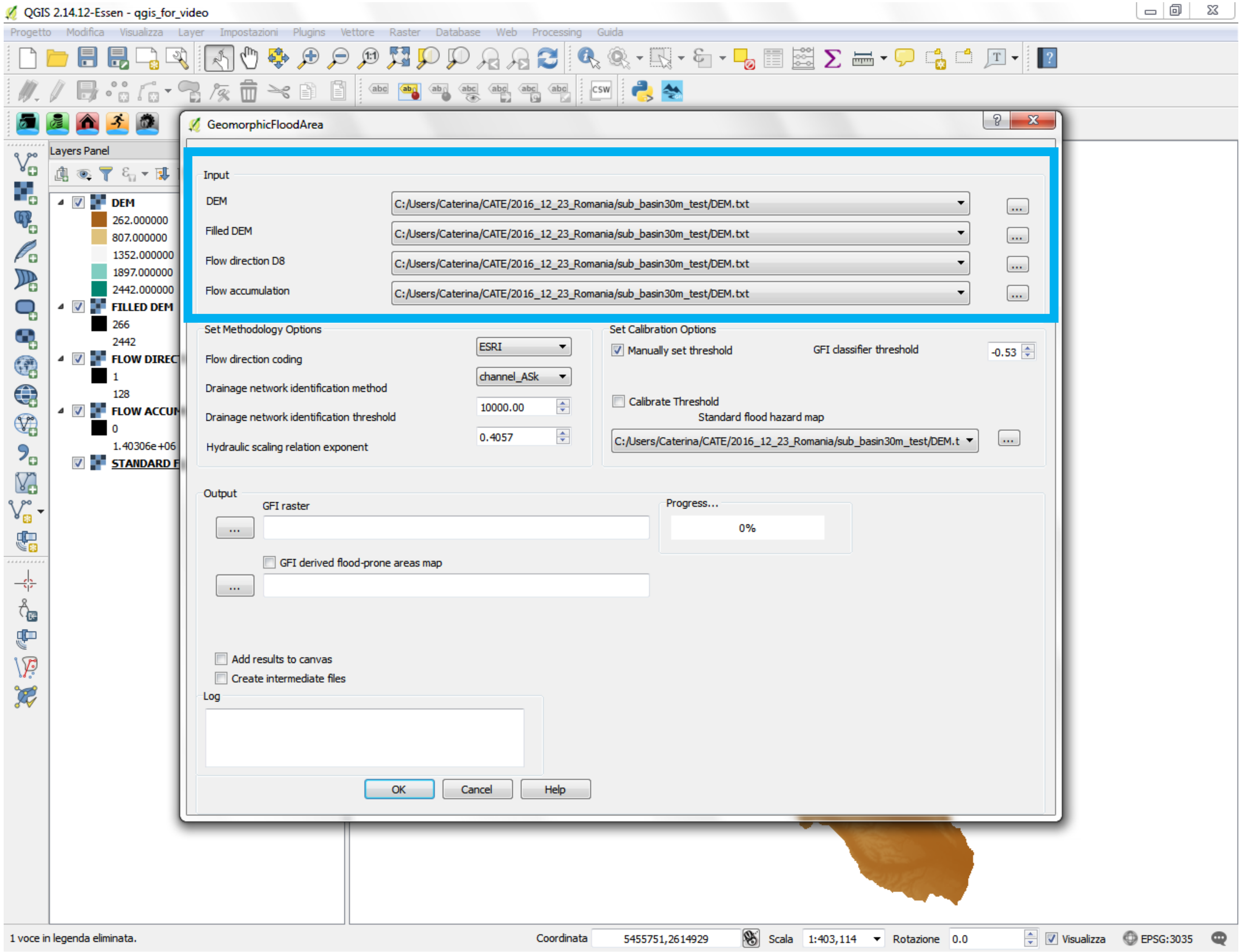
QGIS plugin: Geomorphic Flood Area (GFA) tool



The plugin can bee downloaded for free from the **QGIS repository** and also from: https://github.com/HydroLAB-UNIBAS/GFA-Geomorphic-Flood-Area.

GFA TOOL



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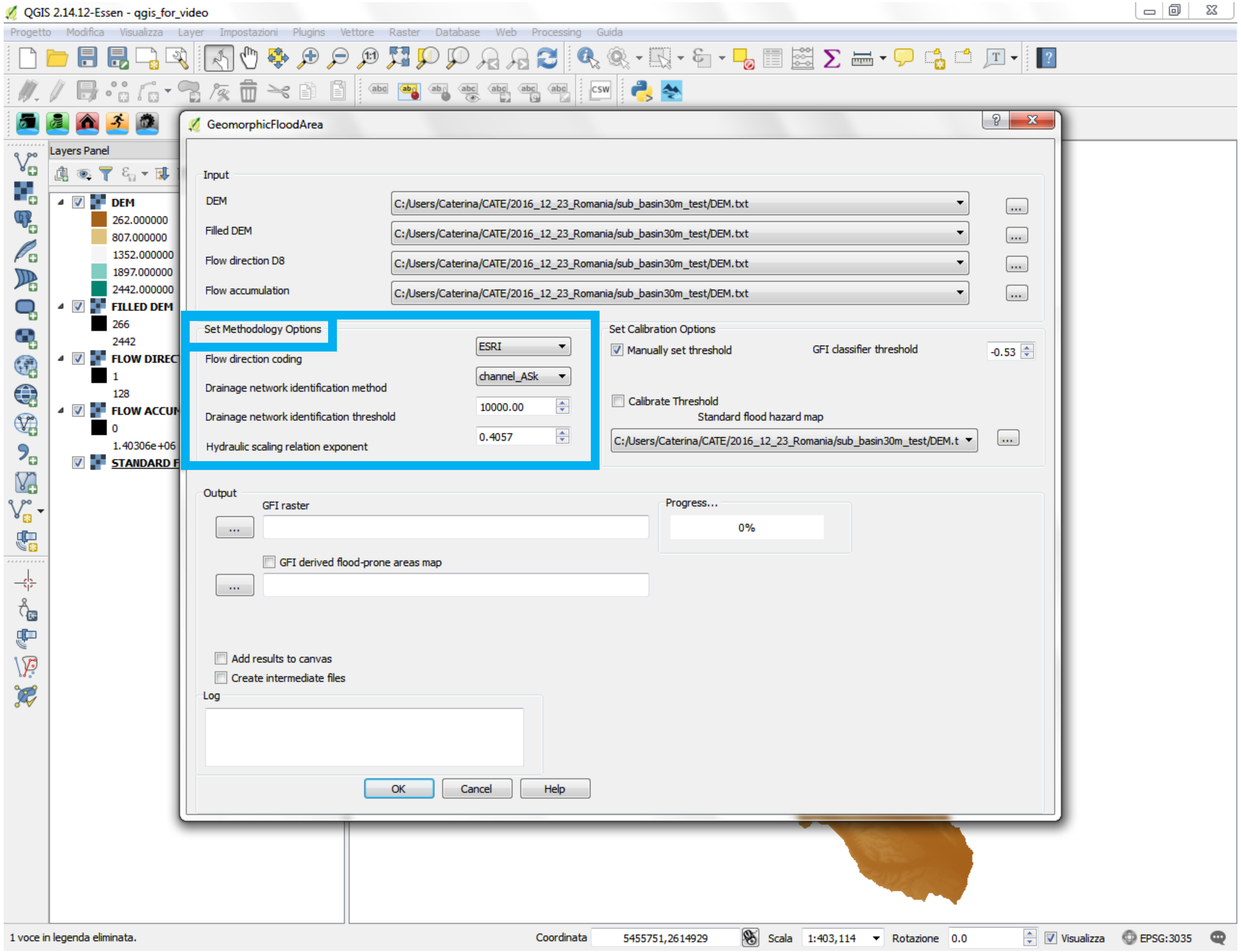
GFA TOOL



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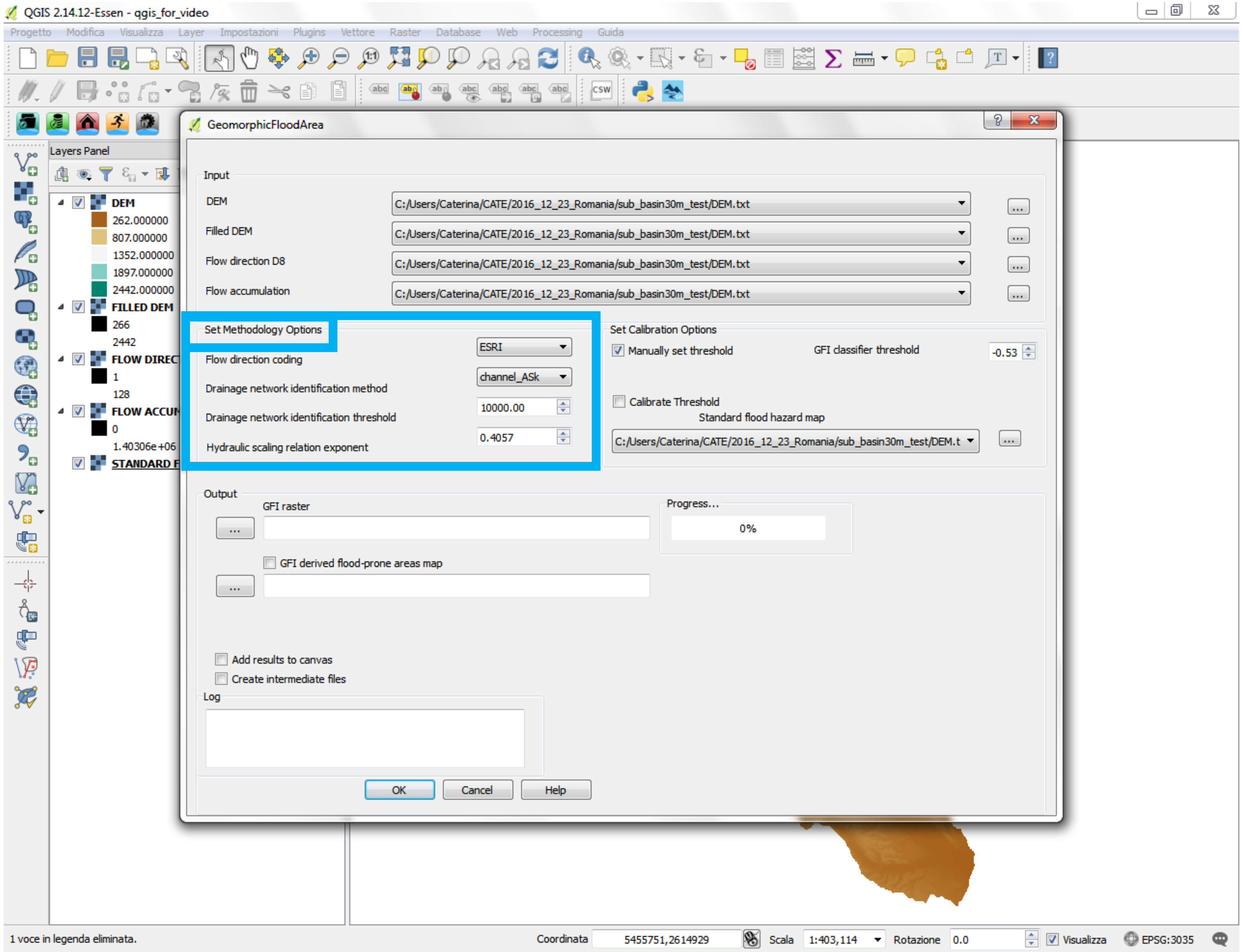
GFA TOOL



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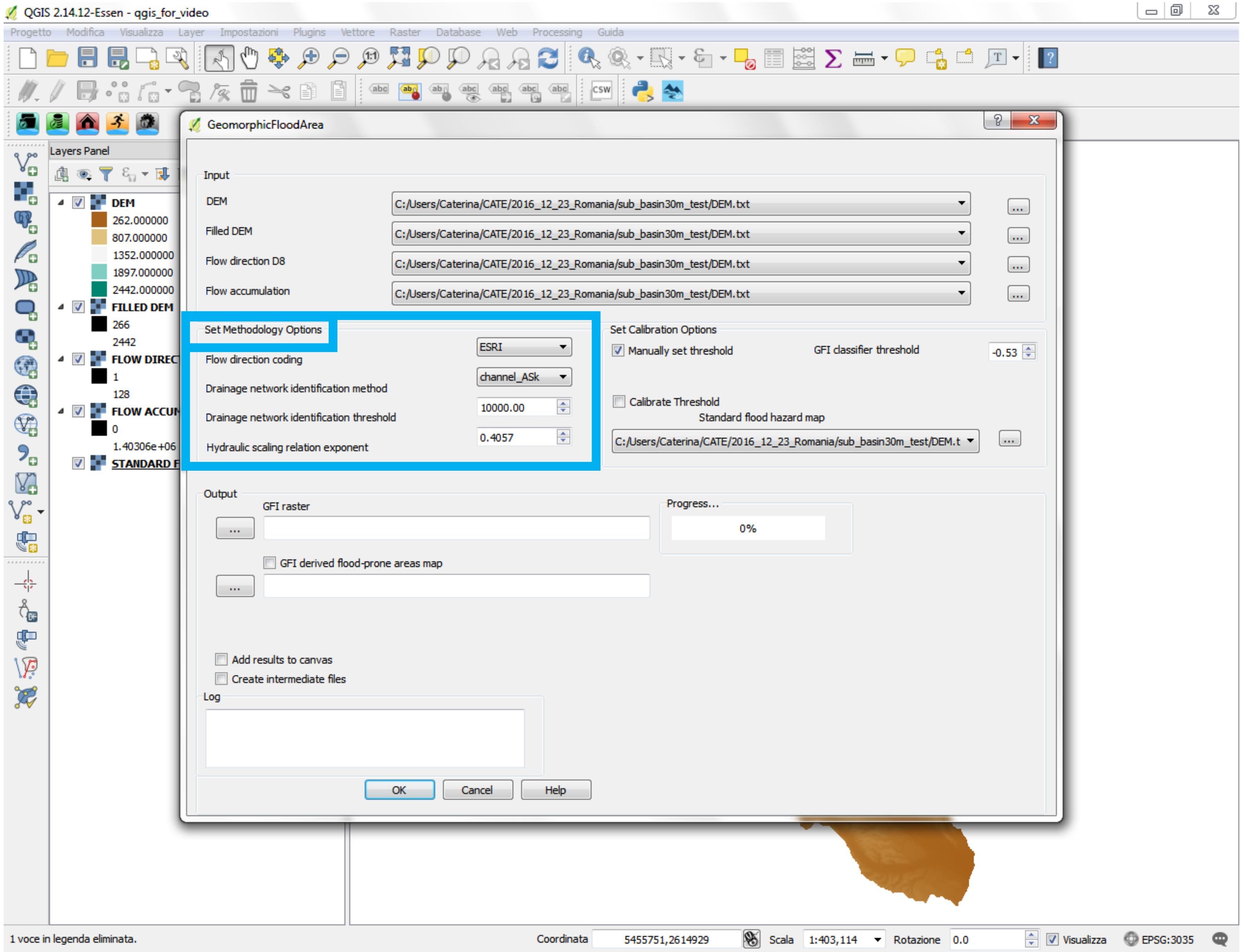
GFA TOOL



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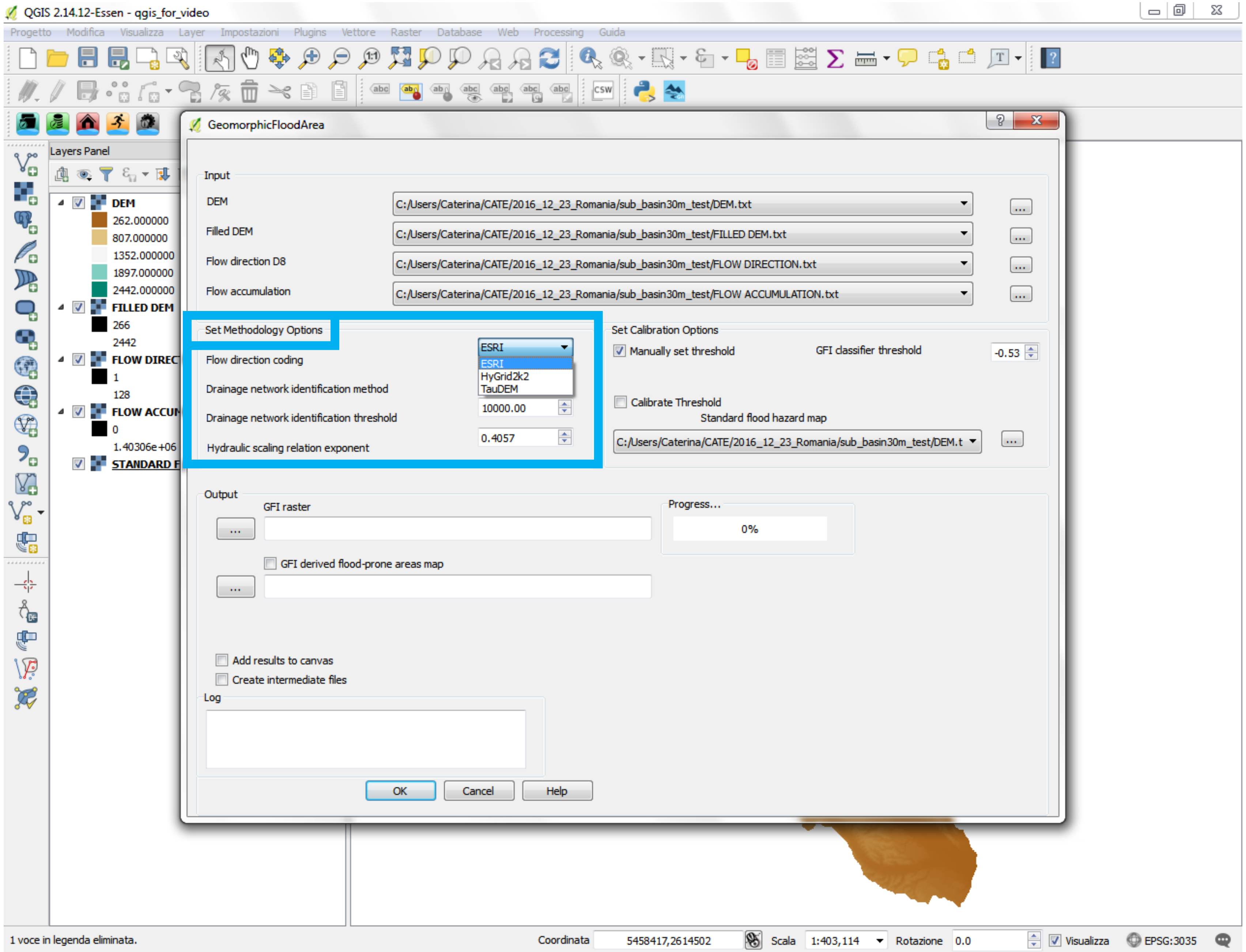
GFA TOOL



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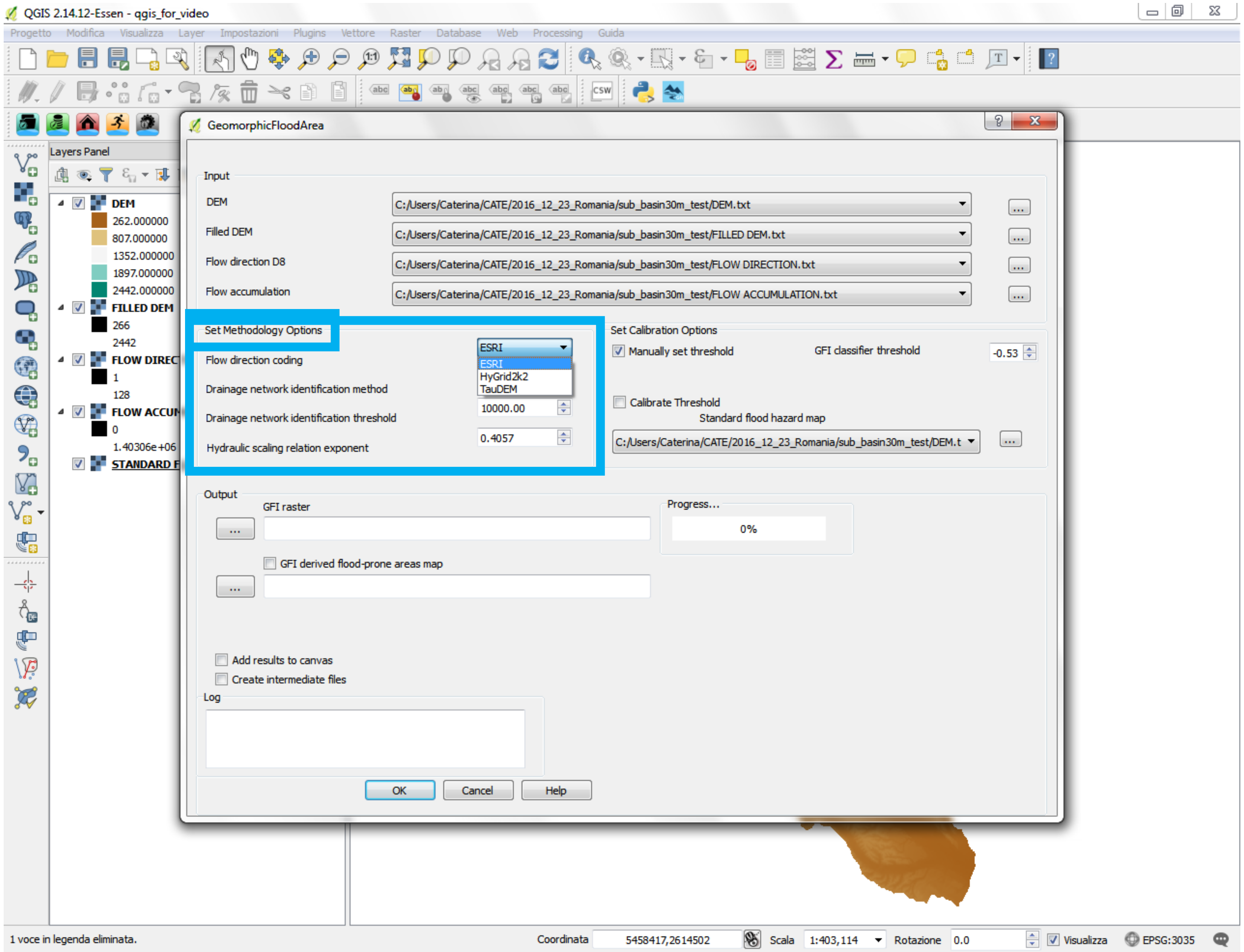
GFA TOOL



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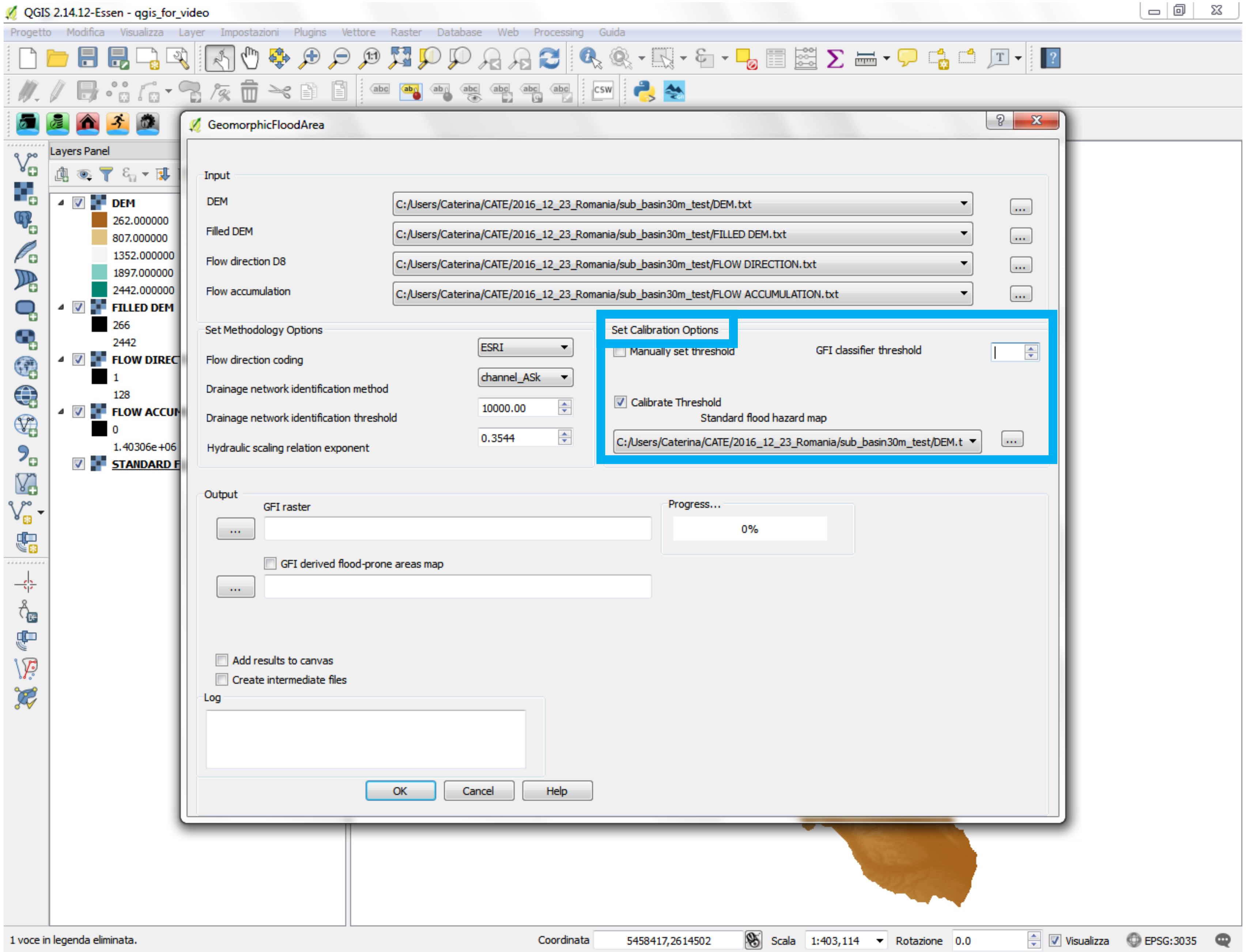
GFA TOOL



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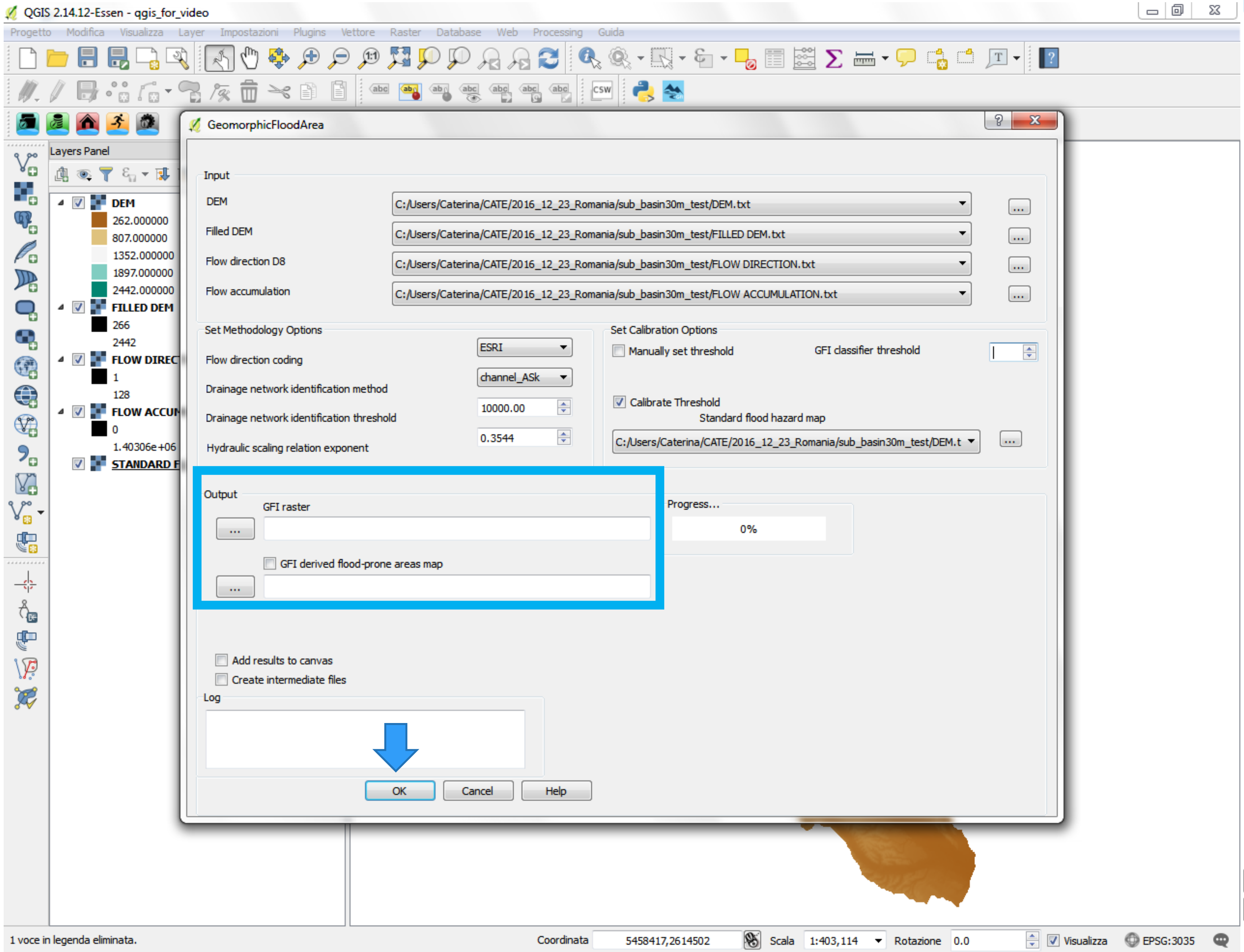
GFA TOOL



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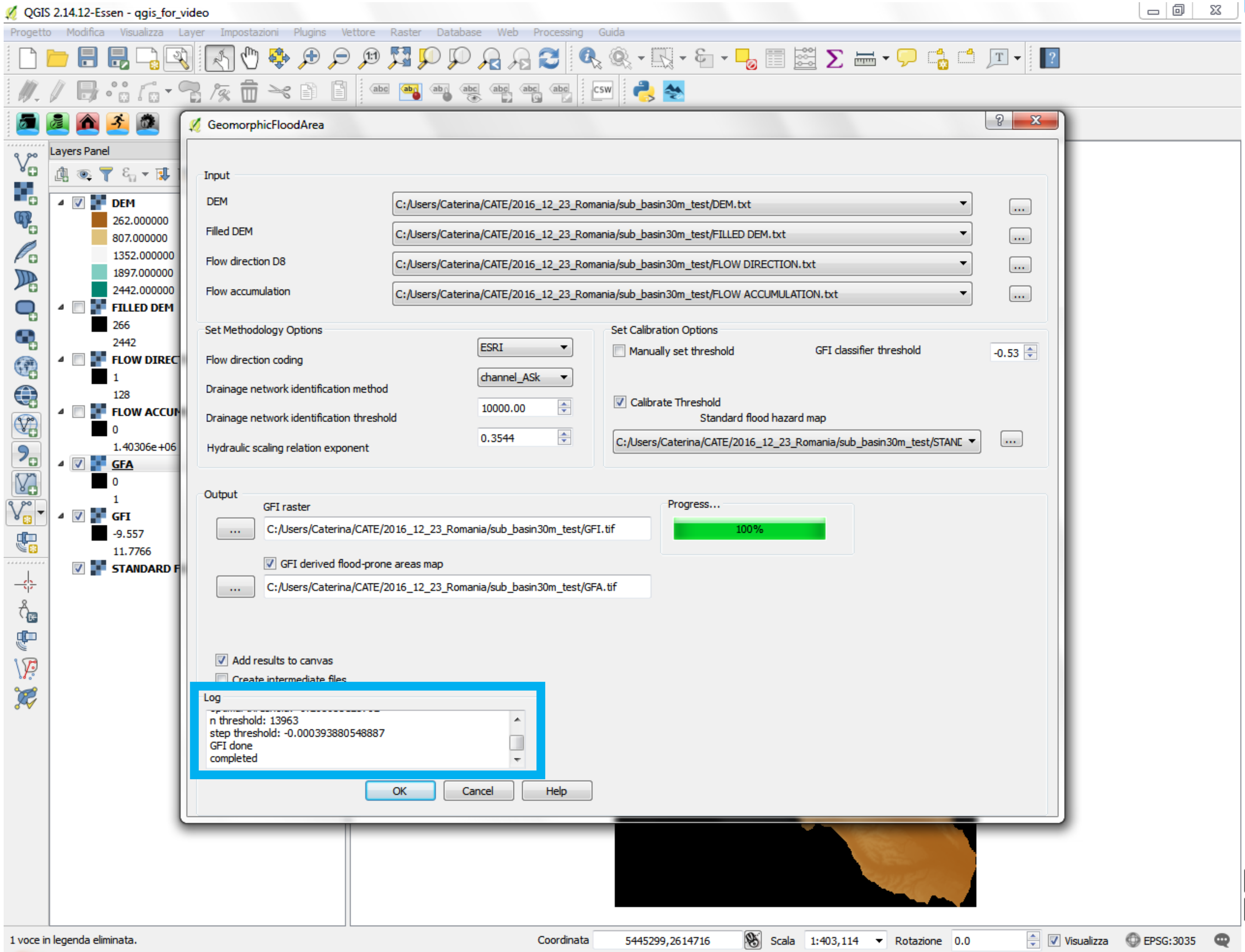
GFA TOOL



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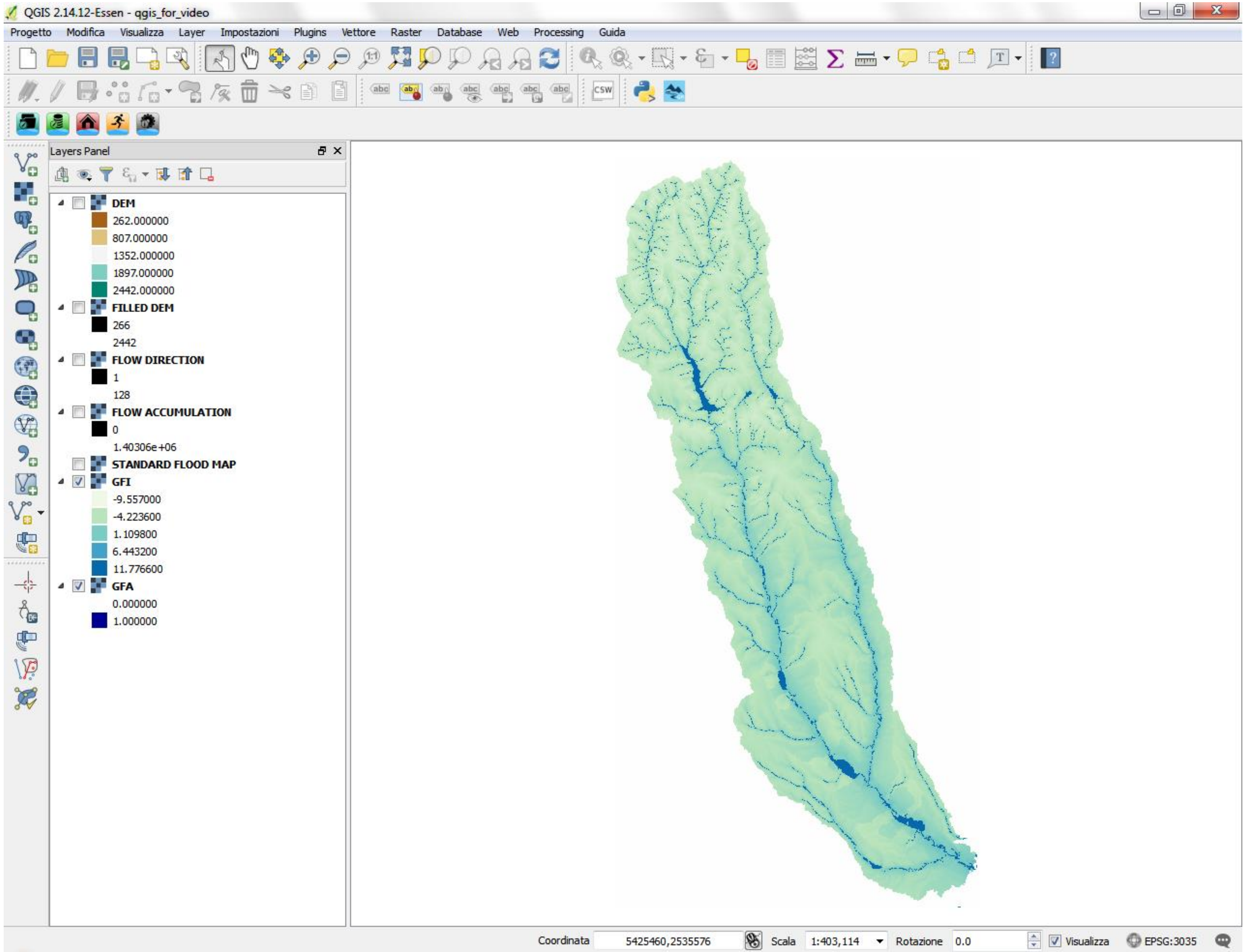
Geomorphic flood Index map



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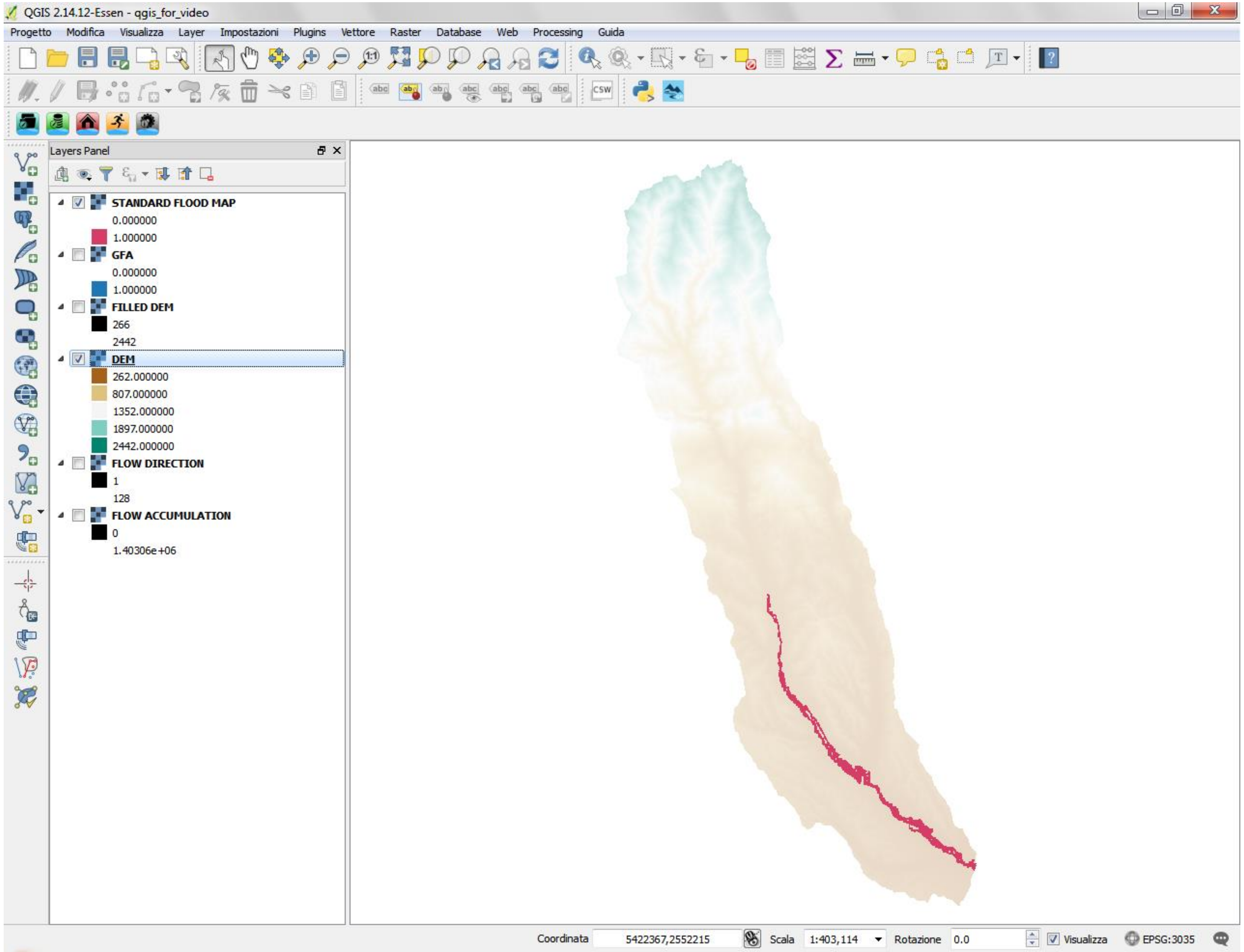
Calibration map



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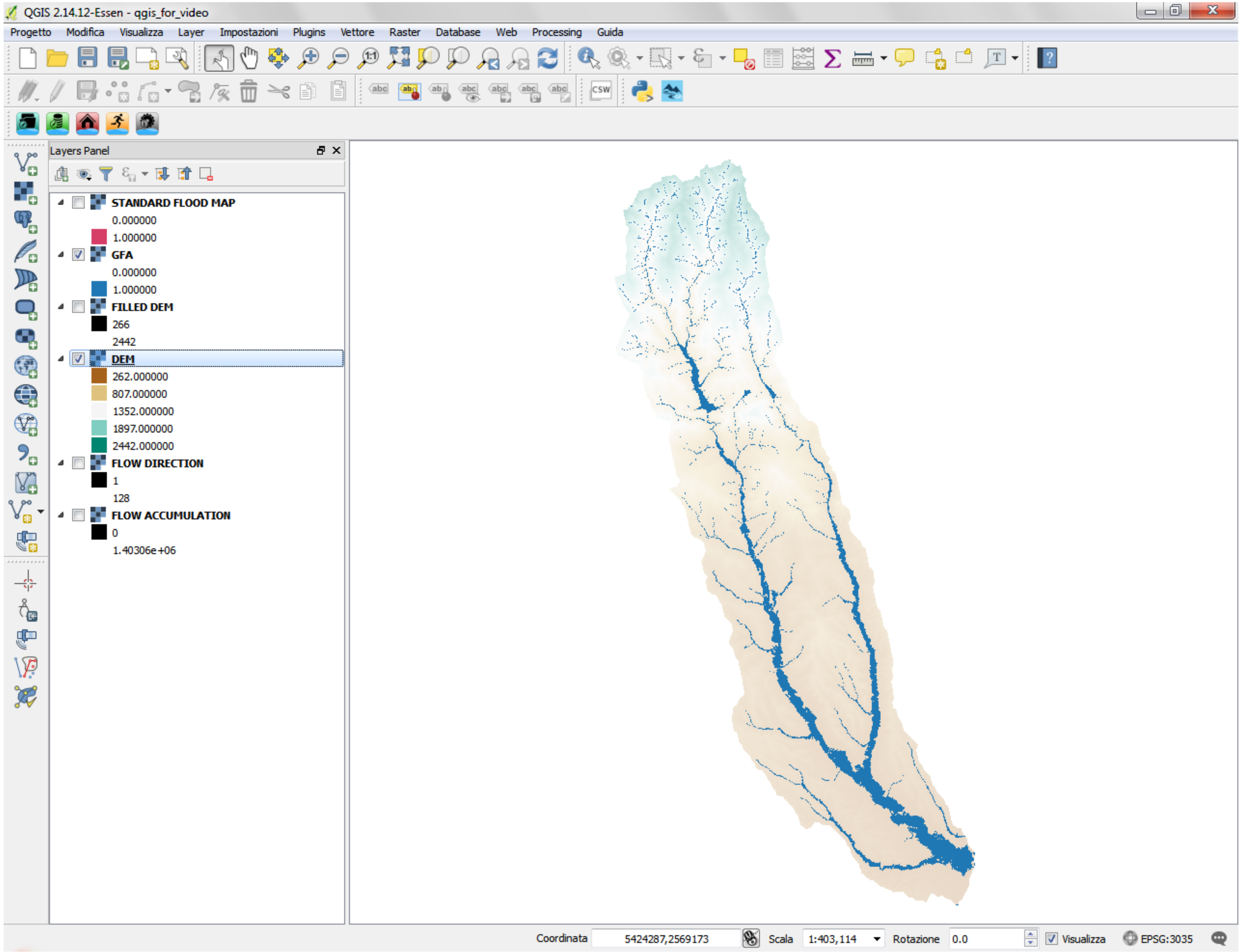
Geomorphic flood Areas map



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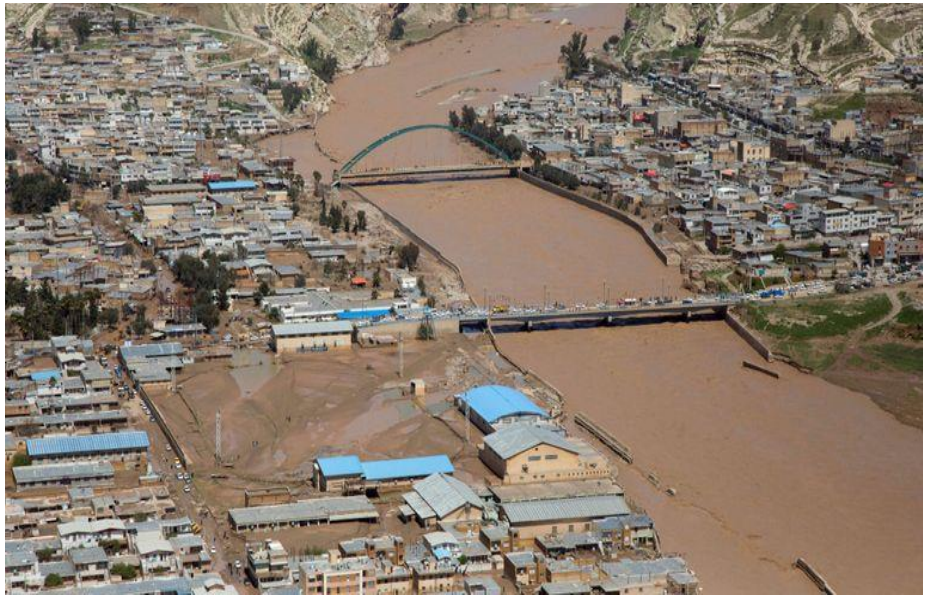
Water Depth Estimate

In addition to flood extent, the inundation depth is a key factor in many riverine settings for estimation of flood induced damages.

Therefore, recently the GFI method has been further exploited to derive in a simple way an approximate, but immediate, estimate of the water surface elevation in a river and surrounding areas.

Nepal, July 2018



Iran, April 2019

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Water Depth Estimate

Hydraulic scaling relationship (Leopold and Maddock, 1953):

$$h_r \approx a{A_r}^n$$

- The hydraulic scaling relationship might be difficult to calibrate, since it requires streamflow observations and paired values of (h_r, A_r) from a number of gauging stations sufficient to carry out a linear regression.
- Therefore, in case calibration is not possible, the **exponent *n* may be assigned based on literature***, while the parameter ***a* is assumed equal to one.**
- This implies that the ***ln(a)* will be included** in the computed GFI and therefore its value will be incorporated **in the calibrated threshold.**

Geomorphic Flood Index:

$$GFI = ln\left(\frac{h_r}{H}\right) = ln\left(\frac{aA_r^n}{H}\right) = ln(a) + n\,ln(A_r) - ln(H)$$

(*e.g. Samela et al., 2017; Nardi et al., 2006; Engelund and Hansen, 1967; Ibbitt, 1997; Ibbitt et al., 1998; Knighton, 2014; Leopold et al., 1965; Leopold and Maddock, 1953; Li, 1974; McKerchar et al., 1998; Park, 1977; Rodriguez-Iturbe and Rinaldo, 1997; Smith, 1974; Whiting et al., 1999)

Water Depth Estimate

In this case, the obtained GFI may be expressed as:

$$GFI' = GFI - \mathbf{ln(a)} = ln\left(\frac{A_r^n}{H}\right) = ln\left(\frac{h_r}{\mathbf{a}H}\right)$$

<u>Along the boundary of decision/calibrated threshold:</u>

$$ln\left(\frac{h_r}{aH}\right) = \tau \quad \text{and} \quad \frac{h_r}{H} = 1;$$

$$ln\left(\frac{1}{a}\right) = \tau \quad \rightarrow \quad a = \left(\frac{1}{exp(\tau)}\right)$$

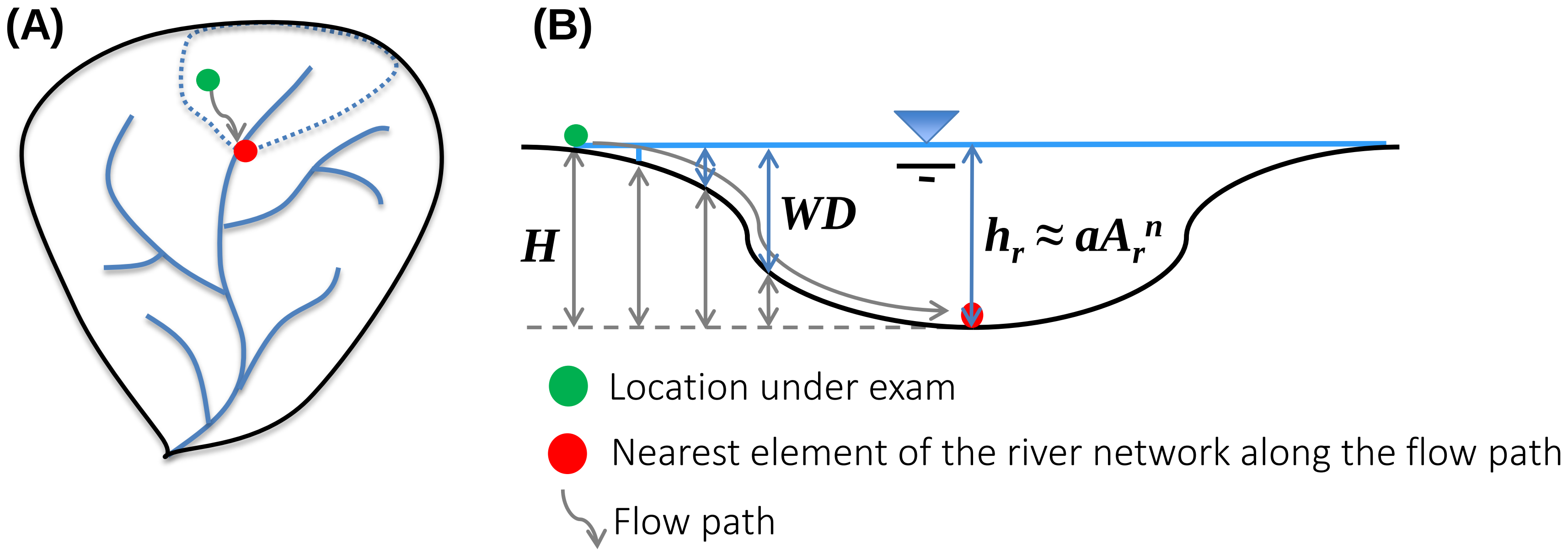
In this way, we can correct the values of river water depth $\boldsymbol{h_r = a A_r{}^n}$.

Water Depth Estimate

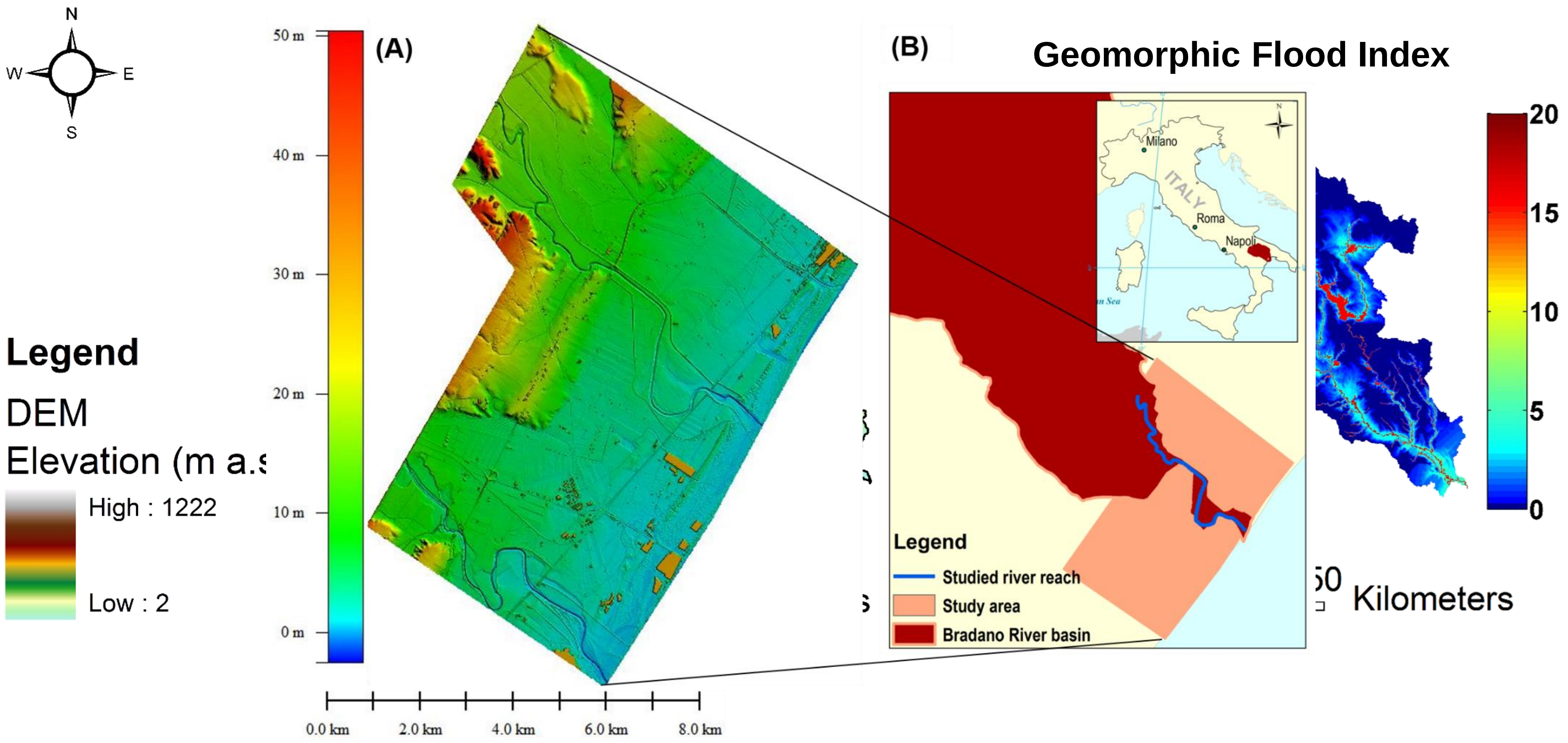
At this point, we can use the h_r values to estimate, in a simple and direct way, **the water depth (WD)** cell by cell of the flood-prone areas:

$$WD = h_r - H$$

Schematic description of the parameters used to derive the GFI and the water level depth estimated in a hypothetical cross-section:



Case study: Bradano River, Italy (outlet)



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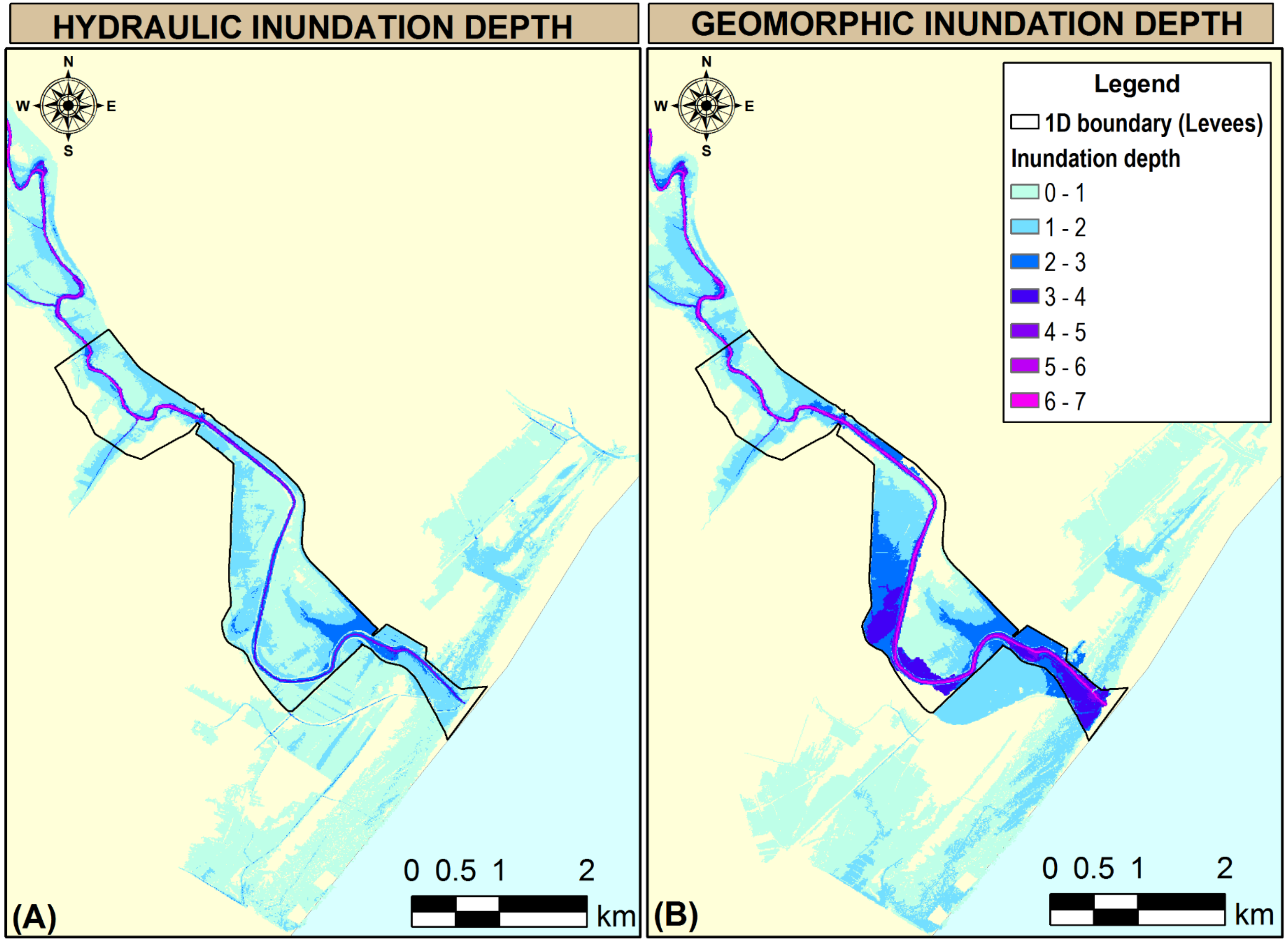
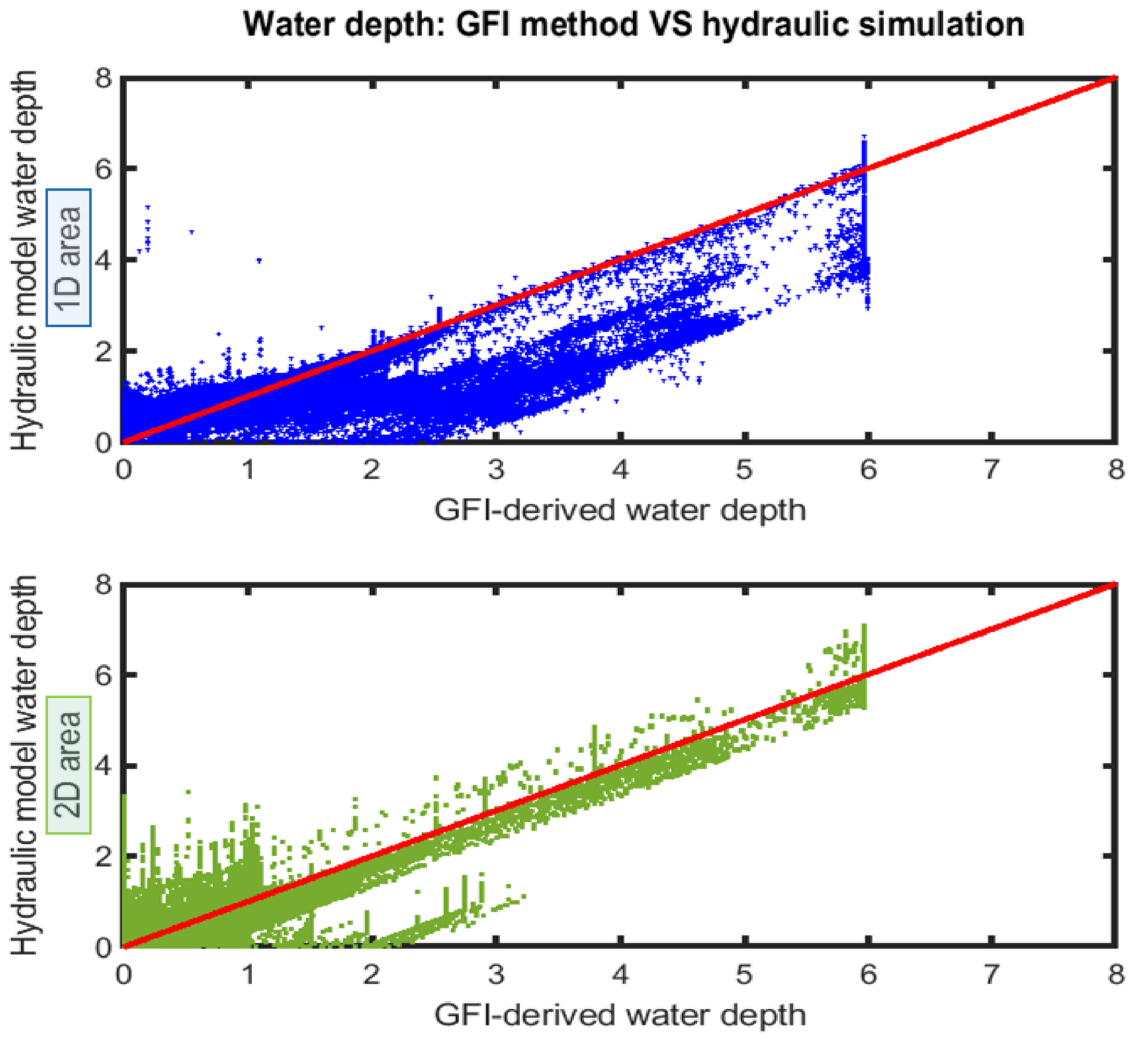
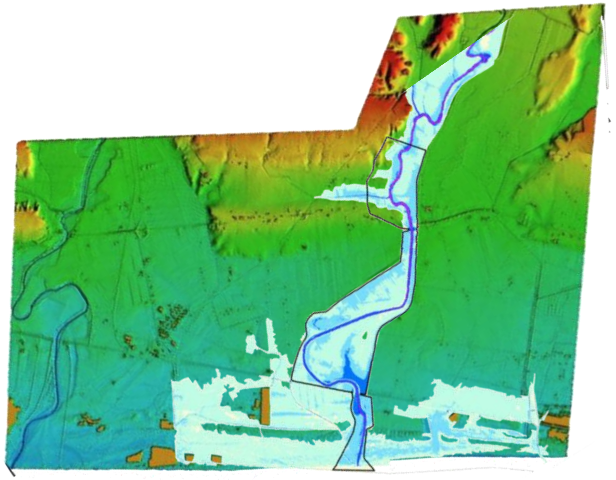
Case study: Bradano River, Italy (outlet)
Hydraulic model VS GFI method



Hydraulic model VS Geomorphic approach





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Case Study: Bradano River (Italy)

Table 1. Performances of the linear binary classification based on the GFI during Calibration.

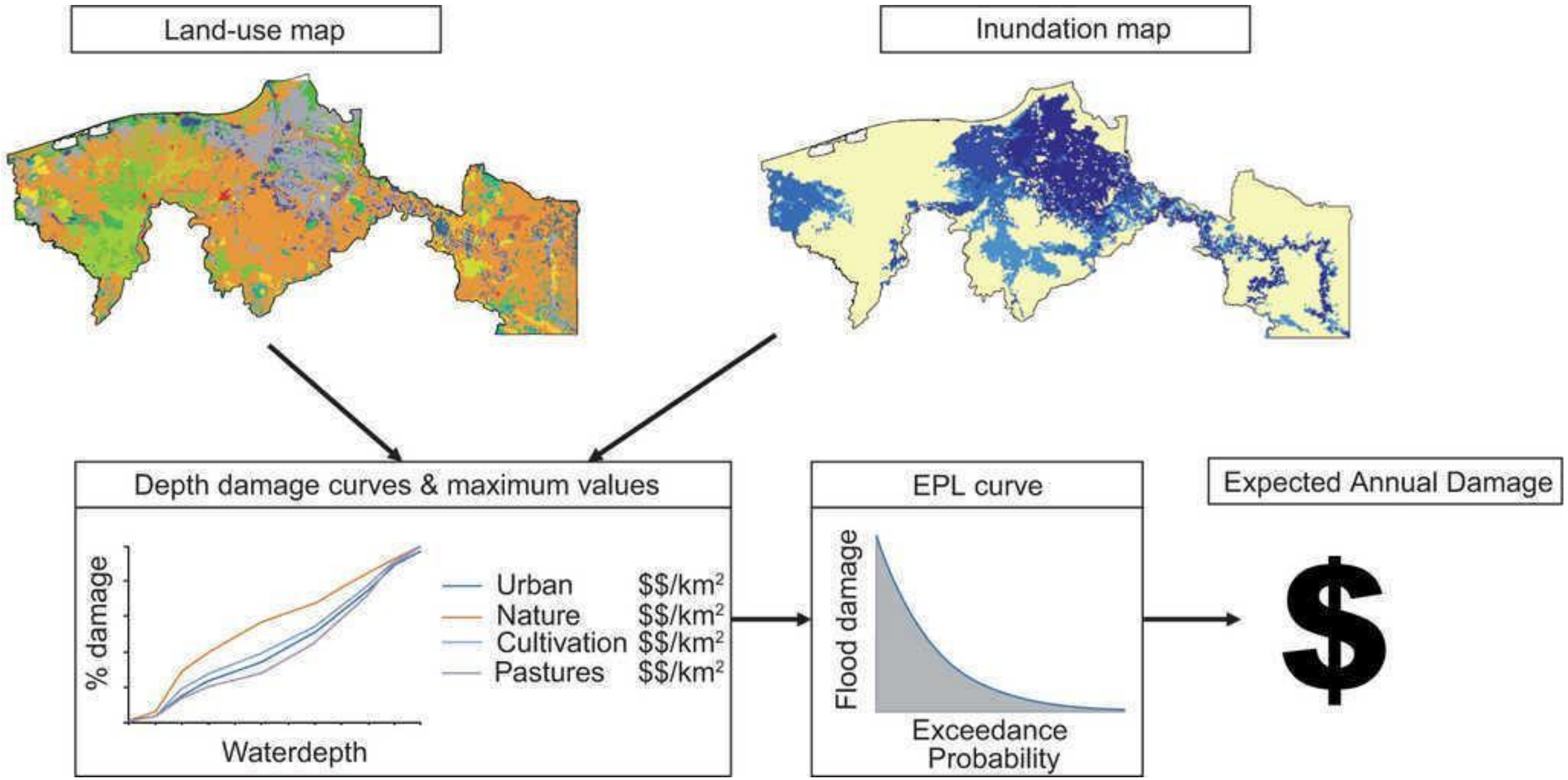
FLOOD EXTENT PERFORMANCES						
Calibrated threshold, τ	**Scale factor, a**	**SENSITIVITY: True Positive Rate, R_{TP}**	**ERROR Type II: False Negative Rate, R_{FN}**	**SPECIFICITY: True Negative Rate, R_{TN}**	**ERROR Type I: False Positive Rate, R_{FP}**	**Objective function: $R_{FP} + R_{FN}$**
1.014	0.3627	89%	11%	90%	10%	21%

Table 2. Performance measures calculated comparing the water depths estimated using the Geomorphic Flood Index method and the FLORA-2D hydraulic model.

INUNDATION DEPTH PERFORMANCES		
	Comparison over the 1D-domain of the hydraulic simulation	Comparison within the 2D-domain of the hydraulic simulation
Linear correlation coefficient, r	**0.917**	**0.906**
Root Mean Square Error, RMSE (m)	0.620	**0.335**

Flood risk as the conjunction of hazard and vulnerability

As next step, we are working with **stage – damage functions,** which relate inundation depth to damage level.



Case Study: Romania

INPUT DATA:

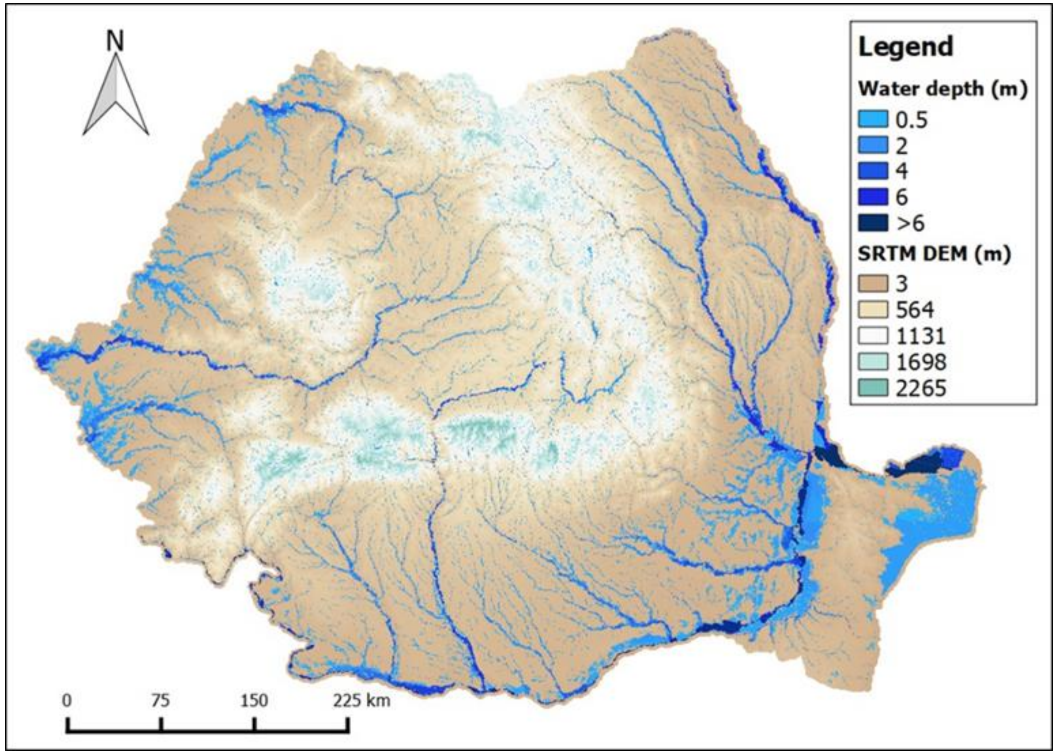
✓**Reference flood hazard study**: pan-European 100-years flood hazard maps at 100m resolution derived by the Joint Research Centre (JRC) for river basins with an upstream area greater than 500 km^2 (Alfieri et al., 2014);

✓**DEM**: 30-m resolution SRTM 1 Arc-Second Global elevation data.

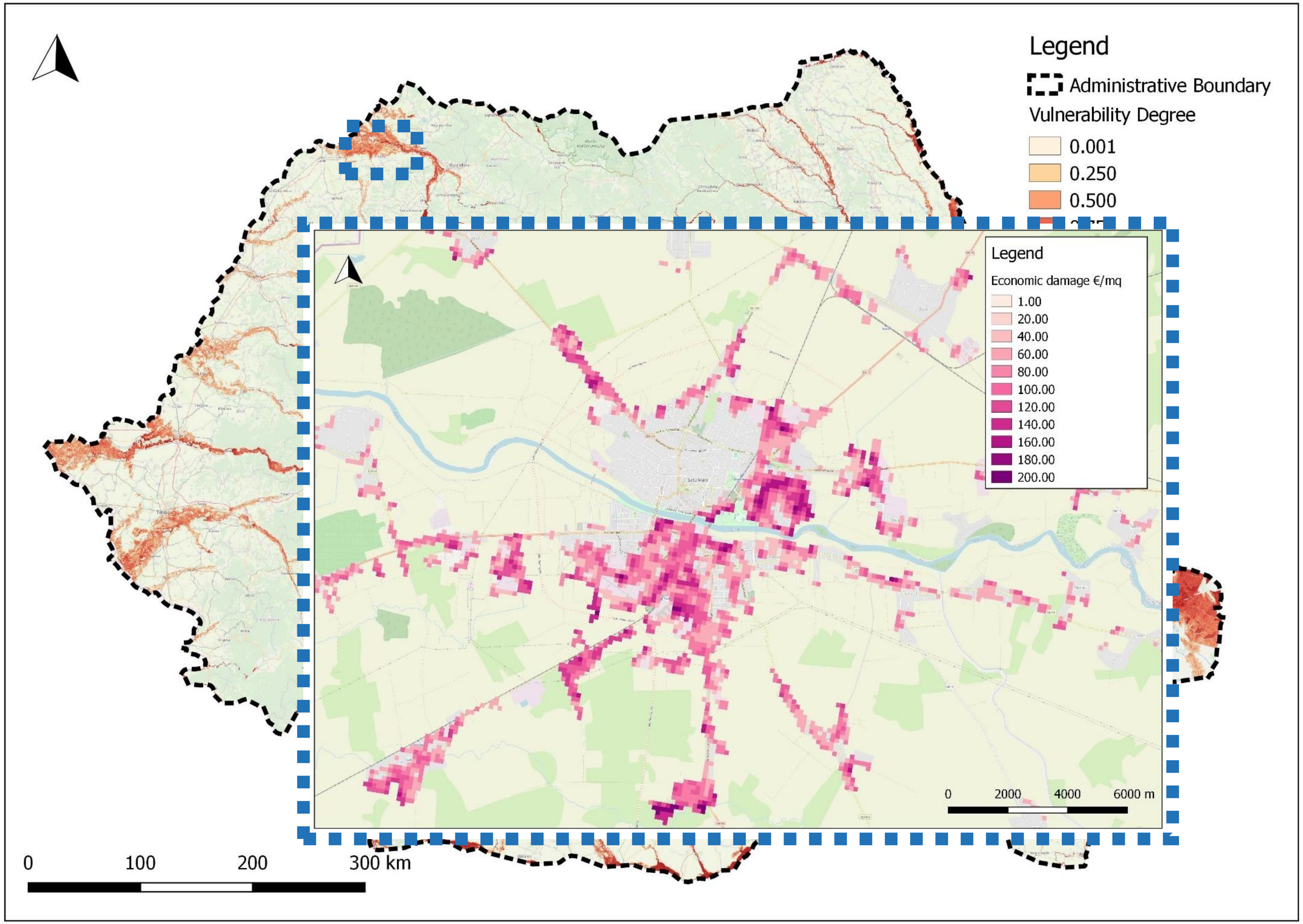
OUTPUT:

Geomorphic flood-prone areas and expected inundation depth for Romania

(30m resolution and delineation also in basins with a drainage area lower than 500 km^2).



Flood Risk Map derived for Romania



Limitations

- The method does not perform a hydrologic analysis (no use of precipitation); it is calibrated using a flood hazard map derived for a specific return period, and this is the only link to hydrology.
- It does not solve the fluid hydrodynamic equations: it cannot describe the flood wave propagation;
- It is based on two input data and is therefore dependent from the accuracy of those data: **DEM** (quality vertical accuracy, and resolution, pre-processing conditioning procedure) and flood hazard map (accuracy, size of the calibration area);
- It is not able to consider the presence of transversal structures (e.g. bridges and culverts) and other man-made features, especially sub-grid scale features, for example embankments;
- This simplified method produces errors, with a general tendency to overestimate both extent and water depth.

Advantages and Potentials

- Low cost and simple data requirement: use of data freely available;
- Computationally efficient method;
- Ability to map at high resolutions large geographic areas both in data-poor and data-rich environments.

Possibility to start from **detailed flood studies** existing for **limited areas** and **extend** and downscale **the delineation over large undetermined areas**, enhancing both spatial detail and coverage of flood hazard information.

Suitable for applications in **undetermined/unstudied areas,** over **large-scale basins, or minor tributaries**, **data-scarce regions** and **across political borders,** providing information that, although approximate, may be of practical utility for preliminary assessment of expected flood damage, flood management and mitigation at regional/national/continental/global scale.

Related Publication

Manfreda & Samela (2019). A DEM-based Method for a Rapid Estimation of Flood Inundation Depth. ***Journal of Flood Risk Management***.

Samela, Albano, Sole, & Manfreda (2018). A GIS tool for cost-effective delineation of flood-prone areas. ***Computers, Environment and Urban Systems***.

Tavares da Costa, Manfreda, Luzzi, Samela, Mazzoli, Castellarin, Bagli (2019). A web application for hydrogeomorphic flood hazard mapping. ***Environmental Modelling and Software***.

Manfreda, Samela, Troy, (2018). The use of DEM-based approaches to derive a priori information on flood-prone areas, in ***Flood monitoring through remote sensing***, *Springer Remote Sensing/Photogrammetry, 61-79*.

Samela, Troy, & Manfreda, (2017a). Geomorphic classifiers for flood-prone areas delineation for data-scarce environments. ***Advances in Water Resources***.

Samela, Manfreda, Troy, (2017b). Dataset of 100-year flood susceptibility maps for the continental U.S. derived with a geomorphic method. ***Data in Brief***.

Samela, Manfreda, De Paola, Giugni, Sole, & Fiorentino, (2016). Dem-based approaches for the delineation of flood prone areas in an ungauged basin in Africa, ***Journal of Hydrologic Engineering***.

Manfreda, Samela, Gioia, Consoli, Iacobellis, Giuzio, Cantisani, & Sole, (2015). Flood-Prone Areas Assessment Using Linear Binary Classifiers based on flood maps obtained from 1D and 2D hydraulic models, ***Natural Hazards***.

Manfreda, Nardi, Samela, Grimaldi, Taramasso, Roth, Sole (2014). Investigation on the Use of Geomorphic Approaches for the Delineation of Flood Prone Areas, ***Journal of Hydrology***.

Manfreda, Samela, Sole & Fiorentino (2014). Flood-Prone Areas Assessment Using Linear Binary Classifiers based on Morphological Indices, ***ASCE-ICVRAM-ISUMA*** 2014.

Di Leo, Manfreda, Fiorentino, (2011). An automated procedure for the detection of flood prone areas: r.hazard.flood, *Geomatics Workbooks n. 10 - "FOSS4G-it: Trento 2011"*.

Manfreda, Di Leo, & Sole, (2011). Detection of Flood Prone Areas using Digital Elevation Models. ***Journal of Hydrologic Engineering***.

Thanks for your attention

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Stefano Bagli

Fernando Nardi

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Hydrological and Environmental Modeling: From Observations to Predictions

Guest Editors

Prof. Dr. Félix Francés, Prof. Dr. Salvatore Manfreda, Prof. Dr. Zhongbo Su

Deadline

31 July 2019

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Invitation to submit