# Assessment of post-fire soil loss due to extreme rainfall using physics-based HPC models and satellite imagery


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## Introduction / Research Motivation

**The intensification and proliferation of large wildfires in the Mediterranean regions of southwestern Europe is one of the most immediate effects of climate change.**

- Difficulty to recover a healthy and efficient agroforestry system once the fire has been extinguished.
- Vegetation store humidity, protect the soil against atmospheric phenomena and helps on the soil fixation.
- The lack of vegetation increases erosion and degradation of the fertile soil layer in mountainous areas.

**Therefore, the effective implementation of protection and recovery measures after massive wildfires is mandatory.**

- Physics-based hydro-erosive High-Performance-Computing (HPC) models provide the most robust approach to characterize and quantify the soil loss.
- In this work, we use a novel HPC hydro-erosive 2D model (SERGHEI) supported by Sentinel-2

The Computational Hydraulics Group of the university of Zaragoza is focused on the computational modeling of hydraulic and hydrological processes, as well as other geophysical surface flows, developing numerical methods and advanced High-Performance-Computing (HPC) strategies.

## Model Equations

$$\frac{\partial \boldsymbol{U}}{\partial t} + \frac{\partial \boldsymbol{F(U)}}{\partial x} + \frac{\partial \boldsymbol{G(U)}}{\partial y} = \boldsymbol{S_0} + \boldsymbol{S_F} + \boldsymbol{E}$$

**$\boldsymbol{U}$: vector of conserved variables**
**$\boldsymbol{F}$ and $\boldsymbol{G}$ are the physical fluxes**
**$\boldsymbol{S_0}$, $\boldsymbol{S_F}$ and $\boldsymbol{E}$ are the source terms.**

**The developed model relies on 2D Shallow-Water-Equations (SWE) (Martínez-Aranda et al., 2019).**

$$\boldsymbol{U} = \begin{pmatrix} h \\ q_x \\ q_y \end{pmatrix}; \quad \boldsymbol{F} = \begin{pmatrix} q_x \\ \frac{q_x^2}{h} + \frac{1}{2} g h^2 \\ \frac{q_x q_y}{h} \end{pmatrix}$$

$$\frac{\partial h\phi}{\partial t} + \frac{\partial q_x \phi}{\partial x} + \frac{\partial q_y \phi}{\partial y} = N_b$$

$$\frac{\partial z_b}{\partial t} = -\xi N_b$$

**erosive model:**

- sediment transport equation
- equation for the net balance at the static bed layer.

$\phi$ is the sediment concentration,
$z_b$ is the bed depth and
$N_b$ is the net bulk exchange rate

### Slope Erosion Model

**The bulk exchange term is driven by:**

- **$D_{IR}$ : the rainfall driven detachment rate, mainly in the inter-rill zones.**
- **$D_R$ : the runoff driven detachment rate in the rills and gullies.**
- **$W$ : the falling rate of the sediment particles in terms of the settling velocity $\omega_s$**

$$N_b = (D_{IR} + D_R) - W$$

$$D_{IR} = k_{ir} KE \frac{I r_{60}}{3600 \rho_s} \exp\left(-\frac{h^2}{\sigma^2}\right)$$

$$D_R = K_r C_{VM} \omega_s \frac{q_s^*}{|q_s|}$$

$$KE = (1 - FVC)\underbrace{KE_{DT}}_{} + \overbrace{FVC}^{} \cdot \underbrace{KE_{LD}}_{}$$

**$FVC$ Vegetation cover**
**$KE_{DT}$ Direct impact**
**$KE_{LD}$ Leaf drainage**

$$C_{VM} = \frac{1 - BRE(x,y)}{\exp(FVC(x,y)LU(x,y))}$$

**$BRE$ bedrock exposure**
**$LU$ Land management**

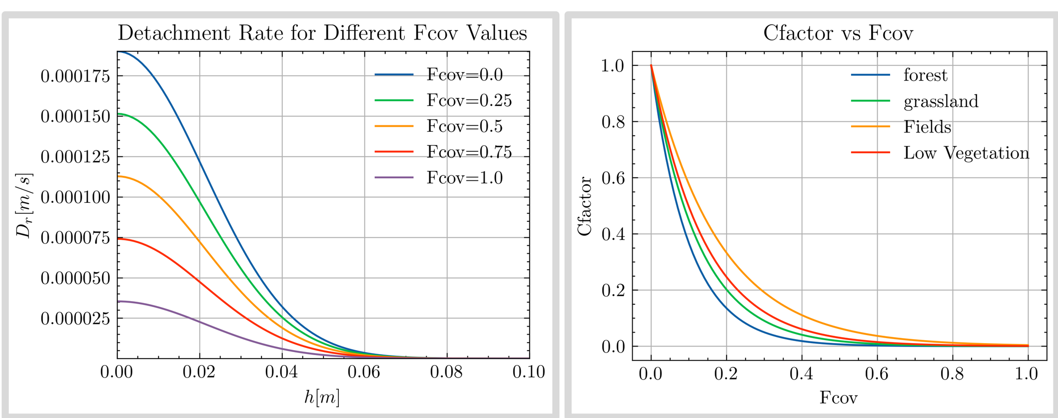


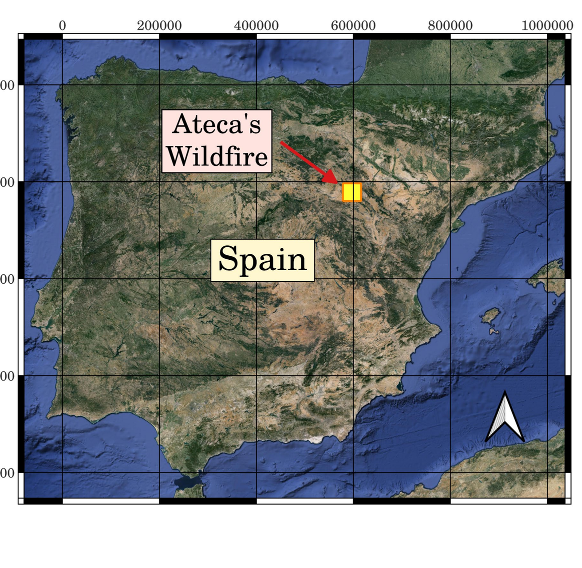

Figure 1: (a) $D_{IR}$ for several $FVC$ values; (b) $C_{VM}$ evolution with $FVC$ for several $LU$ soil types

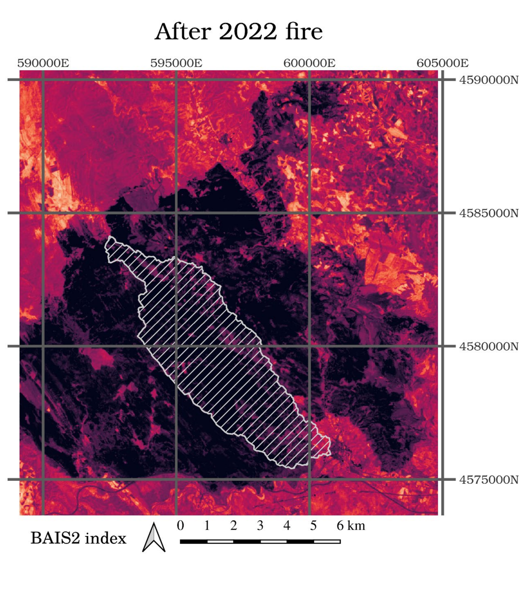
**This model runs on SERGHEI, an open-source, modular, multi-domain and multi-physics model framework for environmental and landscape simulation, with an outlook towards Earth system modeling (Caviedes-Voullième et al., 2023), which allows HPC multi-GPU implementations.**

**The plots illustrates how terrain characteristics influence our model through the Fractional Vegetation Cover (FVC). This spatial data can be acquired at high resolution using sentinel-2 imagery.**

## Study Test: Ateca's Wildfire

**For this work, a real case in the NE region of Spain is chosen. In Ateca (Aragón) an important wildfire occurred in July of 2022, extending to 10 nearby villages and burning a forestry area of 14,000 hectares. The Burned Area Index adapted to Sentinel-2 imagery (BAIS2) is utilized to assess the severity of the wildfire.**

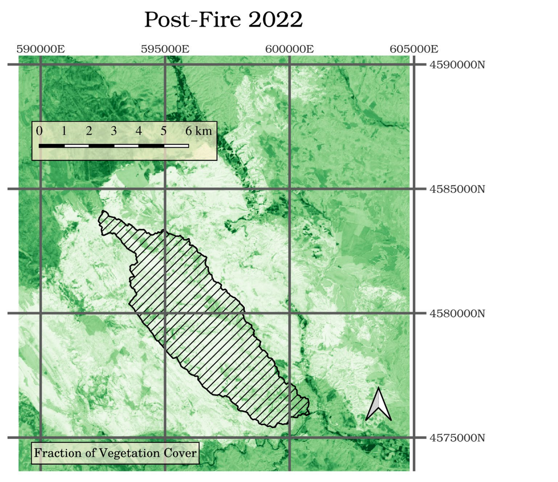



## Application to post-wildfire Erosion estimation

**To include the wildfire effects into our hydro-erosive model, we utilize the Fractional Vegetation Cover (FVC) as it is closely related to the severity of the burn.**

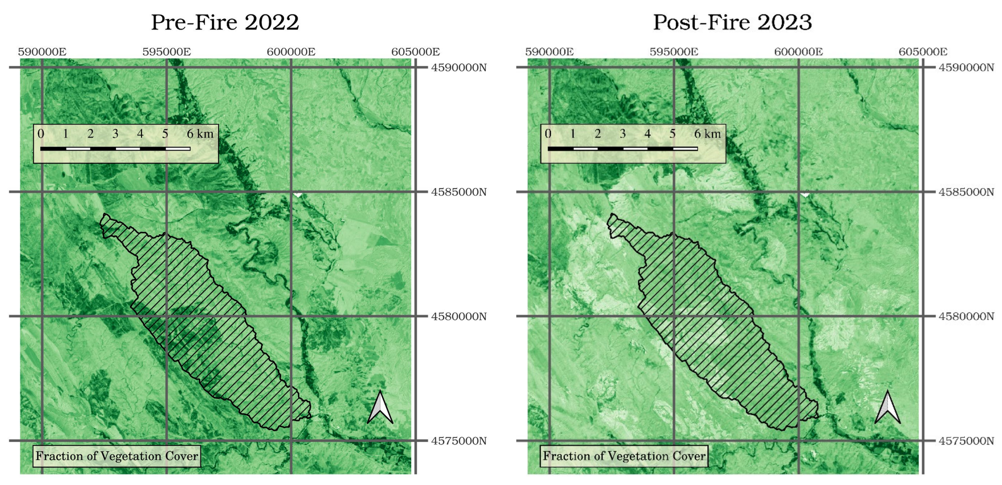
**The following images depict the changes in vegetation before, immediately after, and one year following the wildfire event.**



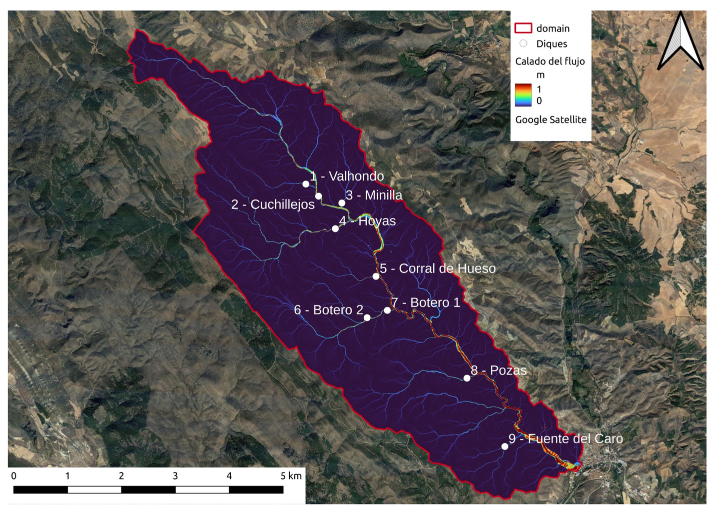

**Land use maps (LU), obtained from the CORINE EU maps.**

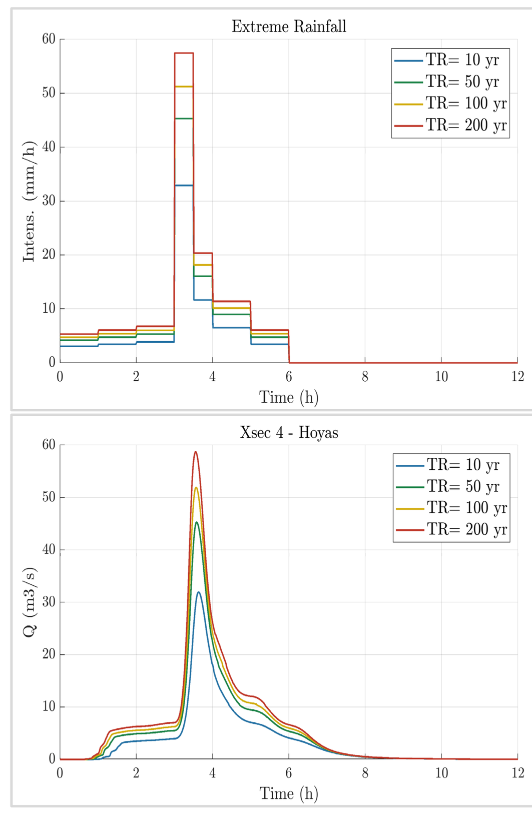
**high-resolution digital terrain model (DTM) with a resolution of 2x2 meters.**

**Manning maps, can be derived from geographical products.**



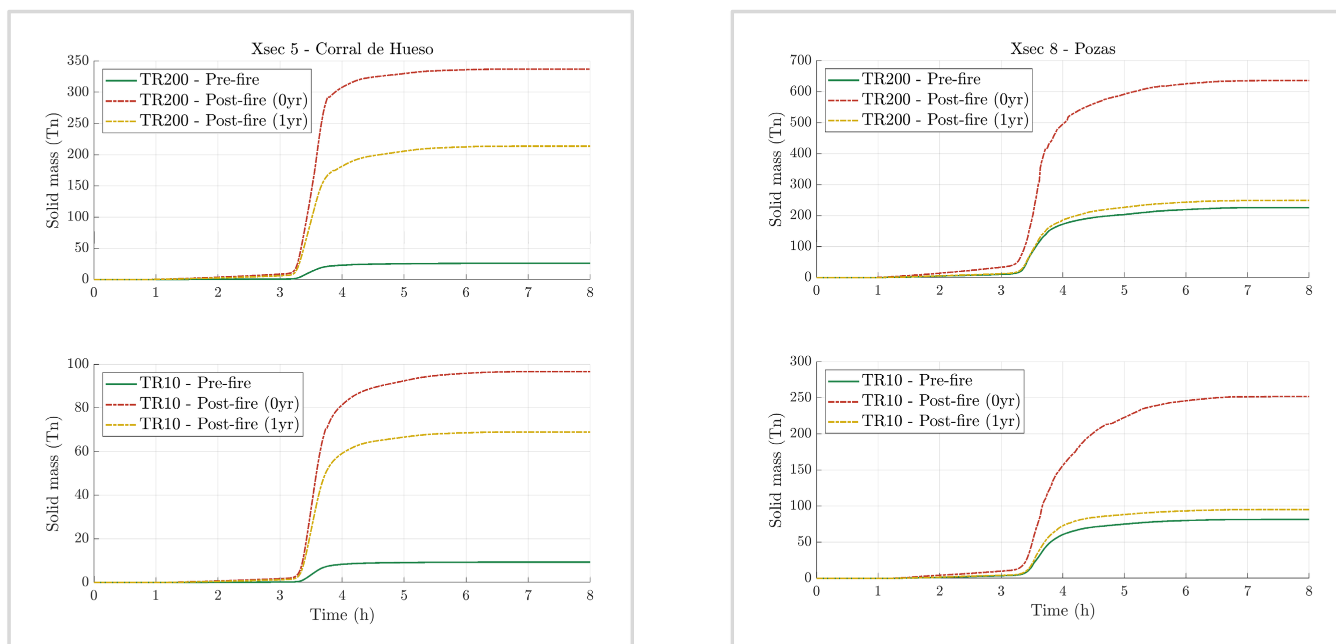

- Simulation using a set of design storms: with return periods (TR10, TR50, TR100 and TR200).
- The discharge is recorded at the exits of the main gullies.






**Soil loss (erosion-deposition patterns) and sediment concentration in the flow are calculated at each spatial cell along the rainfall duration.**

- 4 extreme storms for each scenario: Pre-Fire, Post-Fire, and 1 Year After (recovery in process).




**We can observe some shared tendencies in the plots:**

- just after the wildfire, there is a significant increase in
- The following year, there is a notable decrease in erosion due to vegetation recovery.
- Additionally, higher rainfall events result in higher Soil Losses.
- The influence of specific terrain factors (such as FVC, DTM) yields changes in the amount of generated sediment in the following year differ depending on the zone.

## Discussion and Future works

- **"The developed Soil Loss model has demonstrated its ability to account for changes in soil loss following a wildfire using Sentinel-2 images.**
- **Design storms also allow us to simulate and assess risks associated with climate change scenarios.**
- **Furthermore, our observations indicate that vegetation regeneration plays a crucial role in reducing soil erosion.**

Future work will involve fine-tuning model parameters and conducting comparisons with experimental data to further validate our findings and improve model accuracy, an introduction in the model of a Burn Index as BAIS2 or NBR can also improve the model taking into account the wildfire severity.

### References


**[1] Caviedes-Voullième, D., Morales-Hernández, M., Norman, M. R., & Özgen-Xian, I. (2023). SERGHEI (SERGHEI-SWE) v1. 0: a performance-portable high-performance parallel-computing shallow-water solver for hydrology and environmental hydraulics. Geoscientific Model Development, 16(3), 977-1008.**
**[2] Martínez-Aranda S, Murillo J, García-Navarro P, 2019. Adv. in Water Res. 130, pp. 91-112.**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