Post-wildfire erosion rates and triggering of debris flows: a case study in Susa Valley (Bussoleno).

Giuseppe Mandrone[1*], *Damiano* Vacha[1], and *Jessica* Chicco[1]

[1]DIST – University of Torino, 10125 Viale Pier Andrea Mattioli, 39 Torino, ITALY

Abstract. Post-wildfires geological hazards are an emerging problem in many places, including areas not typically associated with these events such as the Alpine Region. Hazards connected with post-fire processes such as debris-flows and flood-type events threatens people, infrastructures, services and economical activities. Apart from a few examples, there is a lack of models available to quantify the increase in susceptibility as a result of the modification induced by the wildfires. In this work we test the application of a modified version of the RUSLE, on GIS, to quantify the post-fire erosive phenomena for a case study in the north-western Italian Alps. The results of its application, taking advantage of high-resolution rainfall series and data deriving from field surveys, highlight the marked increase (more than 20 times) in erosion rates, quantified by expressing both the EI (erodibility index), the A (monthly soil loss) and the SL (monthly sediment loss) rise. The months of April, May and June represents the larger share of the total quantities. This is a consequence of the noticeable increase of the Erodibility Index EI, which for the post-fire scenario is more than one order of magnitude higher than the pre-fire one.

1 Introduction

Recent estimates for the Alpine region, forecasting an increased impact of climate change effects, suggest wildfires and post-wildfire geological hazards to represent a looming issue soon [12-10-5]. Forest fires lead to new avalanche-prone slopes, and to a higher probability of rockfall, debris-flow, mudslides, soil erosion and water quality problems.

Amongst other hydrological hazards, debris-flow and flood-type events represents the most serious concern, as can be seen in the reports and the scientific literature of regions (USA, Australia) which are facing the problem nowadays [2]. Modifications of hydrological properties, due to litter and vegetation removal, ash deposition, alteration of physical properties of soil and rocks results in an increase of availability of easily erodible materials on hillslopes and of runoff rates [7].

Currently very few models are available to estimate the impacts of these phenomena. The USGS preliminary hazard assessment relies on empirical models to assess likelihood, volume and combined hazard of debris flows for selected watersheds in response to a design storm. These models rely on historical debris–flow occurrence and magnitude data, rainfall storm conditions, terrain and soils information, and burn–severity maps [8].

2 Study area

This study focus on the application and validation of a modified version of the RUSLE model (Revised Universal Soil Loss Equation) [11] to quantify the post-fire erosive phenomena for a case study in the north-western Italian Alps (fig. 1).

In this area (fig. 2), about 50 km W of Torino, in October 2017, ten wildfires occurred, burning a total area of 10,000 hectares of which 7,000 were forests; this value far exceeds the average regional forest burned area (600 ha/year between 2005 and 2013) [6]. These fires were favoured by exceptionally dry conditions, high temperatures and occurrence of several days with hot and dry winds. The largest and severe wildfire - almost 4,000 ha - occurred in Susa Valley, where many catchments on the left of the Dora Riparia River were involved [1]. Starting from late April 2018 until the early June several flow events originated from the burned catchments. Damages were recorded especially at the outlet of the Comba delle Foglie, a small drainage basin overhanging the Bussoleno municipality. Ground evidence highlighted a remarkable increase in erosion rates exerted by the surface runoff in many sectors within the fire perimeter, in agreement with literature findings [4].

3 Methods

The structure of the RUSLE model (Revised Universal Soil Loss Equation) [11] proved to be the most suitable framework to be adopted based on the assumption that these processes represent the key aspect governing the availability of sediments to be entrained during rainfalls and considering the available spatial data.

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[*] Corresponding author: giuseppe.mandrone@unito.it

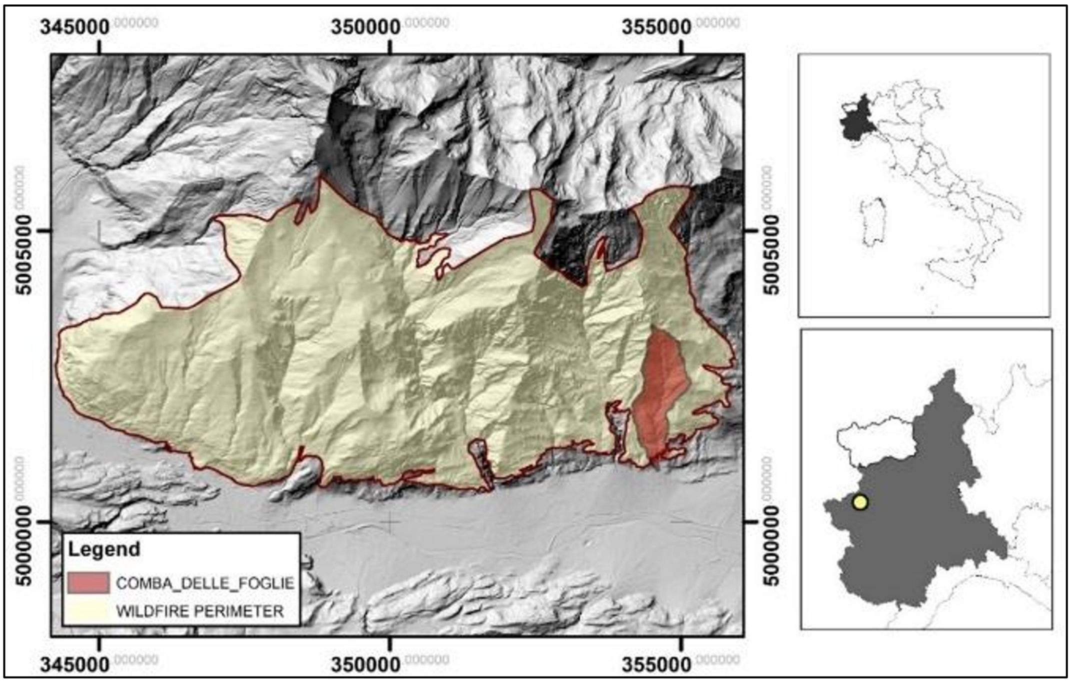

Fig. 1 Perimeter of the Susa Valley wildfire and location of the Comba delle Foglie watershed.

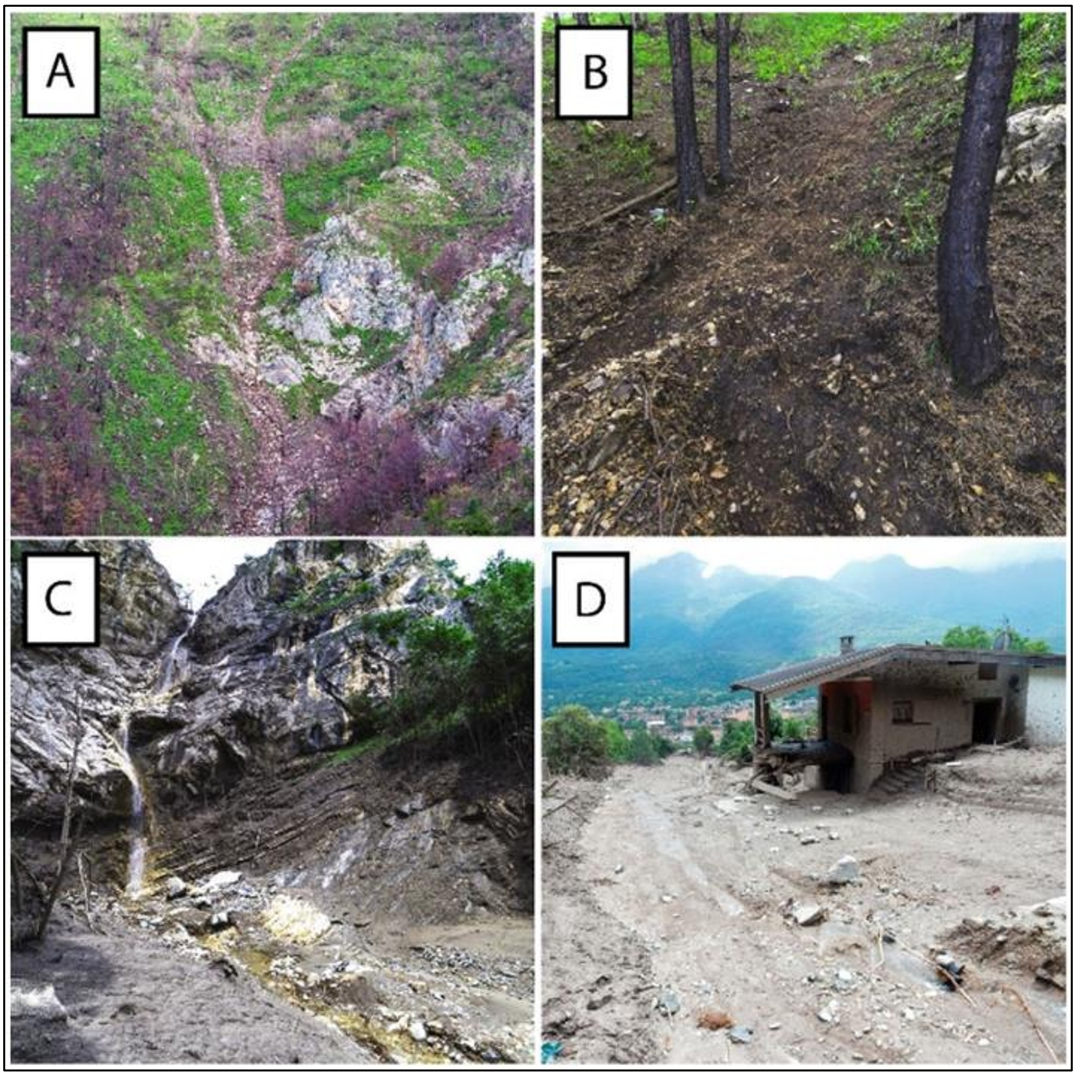

Fig. 2 Erosional features on low order drainage a), and open slopes b), bottom of the channel c). Deposition area and one of the evacuated houses d).

4 Methods

The structure of RUSLE model (Revised Universal Soil Loss Equation) [11] proved to be the most suitable framework to be adopted based on the assumption that these processes represent the key aspect governing the availability of sediments to be entrained during rainfalls and considering the available spatial data. RUSLE empirical model estimates the average annual soil loss caused by surface water erosion through the following equation: $A = R \cdot K \cdot L \cdot S \cdot C \cdot P$
where
A = mean soil loss per year [Mg ha-1 y-1],
R = rainfall erosivity factor [MJ mm h-1 ha-1 y-1],
K = soil erodibility factor [Mg MJ-1 mm-1 h],
LS = topographic factor or slope length factor [-],
C = soil coverage [-], and
P = erosion control practices factor [-].

RUSLE model is intended to quantify soil losses in the long term, so that processes such as gully and channel erosion and sediment transport cannot be modelled. Prediction accuracy for individual storm is very low, as controversial is the application on large spatial scale. Despite this, the model can be used as a solid framework to quantify high-risk erodible areas.

The approach used is deliberately simple, replicable, improvable and easy to implement in a GIS environment. The model has been applied and validated on the Comba delle Foglie catchment, for which a detailed temporal reconstruction of the processes and quantification of the volume of mobilized material has been carried out in a previous work [9].

The burn severity map of the Bussoleno and Mompantero Wildfire [6] was adopted in this work. This map was produced through satellite imagery and field surveys, following a methodology based on US FIREMON framework [3]. The analysis of spectral changes caused by 2017 wildfires was carried out using multispectral images acquired by the MultiSpectral Instrument (MSI) onboard Sentinel-2 A/B satellites (European Space Agency).

5 Results

The volume of coarser sediments coming from the watershed was estimated in 1300 m^3 (fig. 3). Volumes were calculated by difference between DEM available before the event (Piedmont Region data) and that reconstructed using a "structure from motion" approach through photogrammetric processing of ground and helicopter images after the event. By applying a simple rule of thumb, considering a bulk density of 1500 Kg/m^3, the 7 June flow mass can be estimated in 1950 Mg. Because other 4 minor events (1 debris/mud flow in April and 3 floods in May) happened before the 7 June, is reasonable to presume that the remnant part of the total sediment loss estimated by the model could be related to those events.

Some non-negligible aspects undermine the model robustness and accuracy: in fact, the 7 June event volume estimated via photogrammetrical modeling is different compared with the one proposed by Arpa Piemonte (2018b) which, after expeditive surveys, estimates a total event volume of about 20000 m^3.

Erodibility Index values for the pre-fire and post-fire situation (table 1) has been calculated and finally monthly mean soil loss A [Mg ha^{-1} m-1] and averaged monthly sediment loss SL [Mg m^{-1}] for the entire watershed have been computed for both burned and unburned condition. The post-fire mean Erodibility Index is more than one order of magnitude higher than the pre-fire one, having a pre-fire value of 4.63E-04 Mg MJ^{-1} mm^{-1} h and a post fire value of 1.21E-02 Mg MJ^{-1} mm^{-1} h. Also, the maximum values show a rise of about the same order.

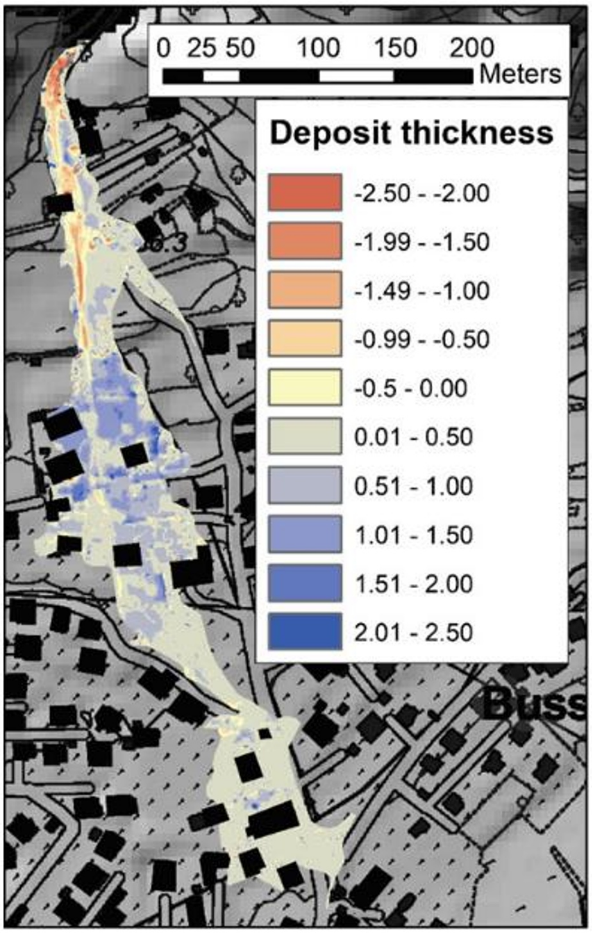

Fig. 3 Deposition area and deposit thickness reconstructed by photogrammetric modelling.

6 Conclusions

Piedmont region experienced an unusually severe wildfire season in 2017. Fires occurred in late autumn and, after a snowy winter, were followed by spring rains. Some of the catchments burned in the Susa Valley wildfire were interested in May and June 2018 by debris/mud flows and flood type events. The major debris-flow involved Comba delle Foglie catchment and struck the Bussoleno municipality. Based on field evidence it was found that the flows mobilized materials and sediments which was eroded from the burned hillslopes and subsequently deposited in the channels.

Table 1 Spatially averaged mean soil loss A and averaged monthly sediment loss SL comparison for the burned and unburned situation.

	Burned		Unburned	
Month-year	A [Mg/ha*m]	SL [Mg/m]	A [Mg/ha*m]	SL [Mg/m]
9-17	0.000	0.00	0.000	0.00
10-17	0.000	0.00	0.000	0.00
11-17	0.133	17.32	0.005	0.66
12-17	0.208	27.07	0.008	1.03
1-18	3.342	434.36	0.127	16.48
2-18	0.014	1.82	0.001	0.07
3-18	0.310	40.28	0.012	1.53
4-18	4.223	548.87	0.160	20.83
5-18	8.081	1050.28	0.307	39.86
6-18	2.371	308.14	0.090	11.69
7-18	0.981	127.55	0.037	4.84
8-18	1.014	131.75	0.038	5.00
TOT.	20.677	2687.45	0.785	101.98

A modified version of the RUSLE model was applied in that area to quantify the erosive processes on a monthly scale. The results of this application, incorporating high resolution rainfall series and data deriving from field surveys, made it possible to reproduce and highlight the marked increase in erosion rates, quantified by expressing both the EI (erodibility index), the A (monthly soil loss) and the SL (monthly sediment loss) rise. Overall, A and SL increased more than 20 times in post-fire scenario, the months of April, May and June representing the larger share of the total quantities. This is a consequence of the noticeable increase of the Erodibility Index EI, which for the post-fire scenario is more than one order of magnitude higher than the pre-fire one. The intrinsic uncertainties of the model are related to the fact that it does not consider the stream-flow erosion in the channels, it does not account for the material eroded by the debris-flow during its passage, and it does not incorporate the eroded volume of ash and combustion residues.

This methodology can provide a useful guidance to rank the post-fire debris-flow susceptibility and to establish intervention priorities. It can be applied everywhere on the regional territory because the model make use, for the most, on open-source spatialized data and thanks to its structure it can be easily implemented into a GIS for thematic map production.

Another aspect which should be considered when dealing with the model validation is the remarkable erosion exerted by the debris-flows along all their path, which may have increased their volume considerably. The results of the model are not suitable to predict streamflow erosion, so when the estimated value is compared to the available surveyed data, this aspect may also increase the uncertainty. Finally, the current model does not consider the ash and combustion residues which, for sure, contribute to the overall sediment availability to be entrained.

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