Impacts of Wildfires on Surface Runoff and Erosion: The Case Study of a Fire Event in Pelion Area, Greece

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Abstract. Wildfires can trigger dramatic increases in surface runoff and erosion, because of the burned vegetation and the appearance of a condition of soil-water repellence. Fire-enhanced surface runoff generation and soil erosion constitute adverse effects of high concern for a long-term future period after a fire event occurrence. The current study investigates the increase on peak surface runoff and sediment loss as a result of a fire event that occurred in Pelion area in Greece on June 27th, 2007. The boundaries of the burned area were determined using satellite images, and the total burned area was found to be almost 60km^2. The land cover of the area prior to fire event, mainly included forest, seminatural and agricultural areas as determined by the raster datasets produced by the Copernicus land cover program. The change of peak surface runoff discharge pre- and post-fire event was estimated using the Natural Resources Conservation Service – CN (NRCS-CN) method, while the sediment loss was also estimated. The fire event was found to significantly increased peak surface runoff, which may cause the occurrence of flood events in the downstream area.

Keywords: Wildfires; Land use change; Surface runoff; NRCS-CN method; Sediment loss

1. Introduction

Woodlands are characterized by their high infiltration rates, low overland runoff volume and low sediment loss (Wu et al., 2021). This behavior of forested areas is mainly regulated by plant roots which improve soil structure and increase macropores, providing preferential flow paths and increasing water holding capacity. Vegetation determines the surface roughness which is strongly related to overland flow resistance which constitutes the most important parameters in hydrology and erosion models (Psilovikos, 2010; Stoof et al., 2015). Land use and climate change is expected to increase the magnitude and frequency of fires in many wildland environments, including the European region (Psilovikos, 2020; Wu et al., 2021).Wildfires are of particular concern since they promote the reduction or elimination of ground cover and alteration of soil characteristics, exposing the mineral soil to raindrop impact and significantly affecting hydrological processes, including surface runoff and soil erosion (Wand et al., 2020).The runoff increase following wildfires is commonly ascribed to the development of a water-repellent layer on the soil surface, restricting infiltration and inducing surface runoff. Increase of fire intensity results to greater litter and soil organic matter consumption such is humus (González-Pérez et al., 2004), which is the organic component of soil, formed by the decomposition of leaves and other plant material by soil microorganisms, and increase of the site susceptibility to soil loss, runoff and flooding. Hydrologic regime modification and soil degradation promotion depend on several factors such as pre-fire land cover, soil properties, soil water repellency, slope, rainfall intensity and amount, and the spatial distribution of the burned areas (Wilson et al., 2021). Increased rainfall intensity and fire spatial extent may result in greater overland flow and larger sediment transport amounts.

The negative post-fire consequences cover not only the on-fire sites but also the downstream flood zone area and the associated human infrastructures. In the Mediterranean climate type, impacts of wildfires depend on ecological conditions, management practices and fire history of each area. Fire-enhanced generation of runoff and soil erosion are maximal immediately after the fire event while the necessary time period for the situation to become similar to pre-fire one could be difficulty quantified since it depends on fire severity and post-fire climatic conditions.

The relationship between post-fire soil erosion and runoff under natural rainfall has not widely studied (Prats et al., 2016) despite the recent focus on causes of post-fire erosion. In addition, the magnitude of wildfire effects is most commonly decided subjectively (Bart et al., 2020), although the decisions could be assisted by remote sensing and land surveys. The objectives of this study are to: (1) determine the burned area using satellite images; and (2)compare peak runoff volumes and sediment yields before and after the fire event in order to better understand the adverse effects of wildfires on hydrologic regime.

2. Methods and Results

2.1. Site description

Mountain Pelion is located in Magnesia Prefecture of Thessaly Region, between the Aegean Sea to the northeast and the Pagasetic Gulf to the southwest, in Central Greece (Figure 1). The Regions is inhabited by almost 730 thousand residents and more than 22% of the workforce is engaged in agricultural and livestock activities. The region is of major ecological value with a wide range of biotopes while having a unique natural beauty due to the harmonization of the natural environment with the traditional local building style.

The climate in the study area is hot-summer Mediterranean (Csa, Köppen classification system) with moderate temperatures, changeable rainy weather, and hot and dry summers. The average annual rainfall is 885.40 mm/year, with the average rainfall of wet (October to March) and dry (April to September) periods equal to 553.77 mm/ 6 months and 331.61 mm/6 months, respectively. The rainfall amount that Mountain Pelion receives is enough to support abundant vegetation with a plenty of different plant species. The average monthly temperature is 13.61 °C, with the average temperature of cold (October to March) and hot (April to September) periods equal to 8,35 °C and 18,87 °C, respectively.

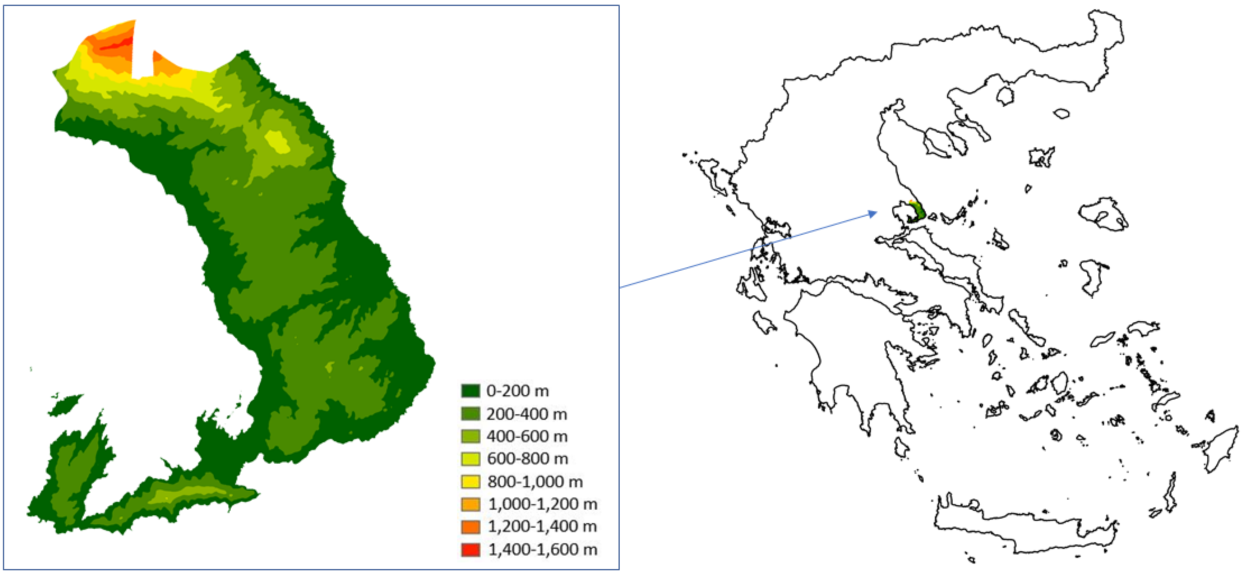

Figure 1. Pelion area and its situation in Central Greece.

2.2. Determination of the burned area

The total burned area was delineated, using the appropriate satellite images, and analyzed using Esri ArcGIS pro software. Eventually, it was found that the burned area is situated between 23°11'08" – 23° 17'15" E longitude and 39°21' 09" – 39°14' 15" N latitude, and it covers a total area of 58.11 km^2.The soil in the whole study area has very high runoff potential and low infiltration rates (Greek National Water Committee, 2014).

The surface of the study area was represented by the Digital Elevation Model developed by the Greek National Cadastre S.A. with a spatial resolution of 5x5 m. The DEM was utilized in the framework of the surface hydrological analysis of the study area which includes the surface water flow direction and accumulation, resulting in the delineation of the boundaries of 6 catchments (Figure 2). The main geographical characteristics of the 6 catchments are presented in Table 1.

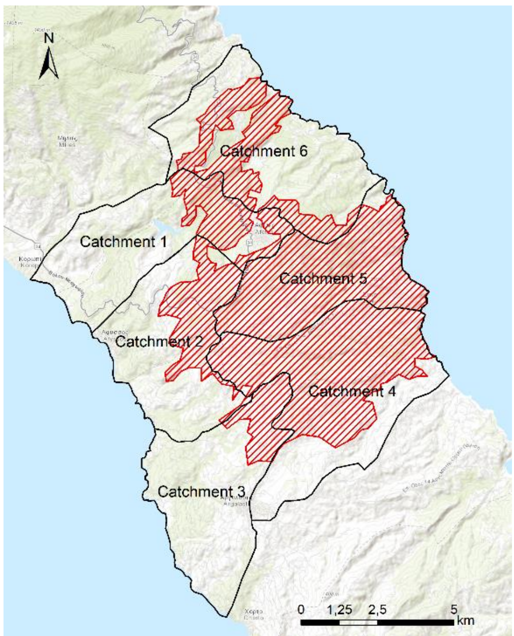

Figure 2. Catchments affected by the fire event.

Table 1. Geographical characteristics of the catchments affected by the fire event.

Catchments name	Area (km^2)	Maximum elevation (m)	Mean elevation (m)	Mean slope (%)	Main channel length (km)
Catchment 1	19.77	625.64	235.38	14.06	9.49
Catchment 2	19.64	419.45	224.15	9.45	5.49
Catchment 3	19.36	340.12	177.72	7.73	6.05
Catchment 4	27.82	392.85	238.45	7.43	8.65
Catchment 5	17.33	624.12	315.54	14.99	6.44
Catchment 6	23.80	701.32	400.51	14.35	3.86

In terms of land cover in the pre-fire area, this included mainly forest and agricultural areas, as determined by the raster datasets generated by the Copernicus land cover program (Figure 2). After the wildfire, the form of the total area revealed an area that has lost vegetation as a whole, and exposed its soil to the risk of erosion. The total and post-fire area per each catchment and land cover are presented in Table 2.

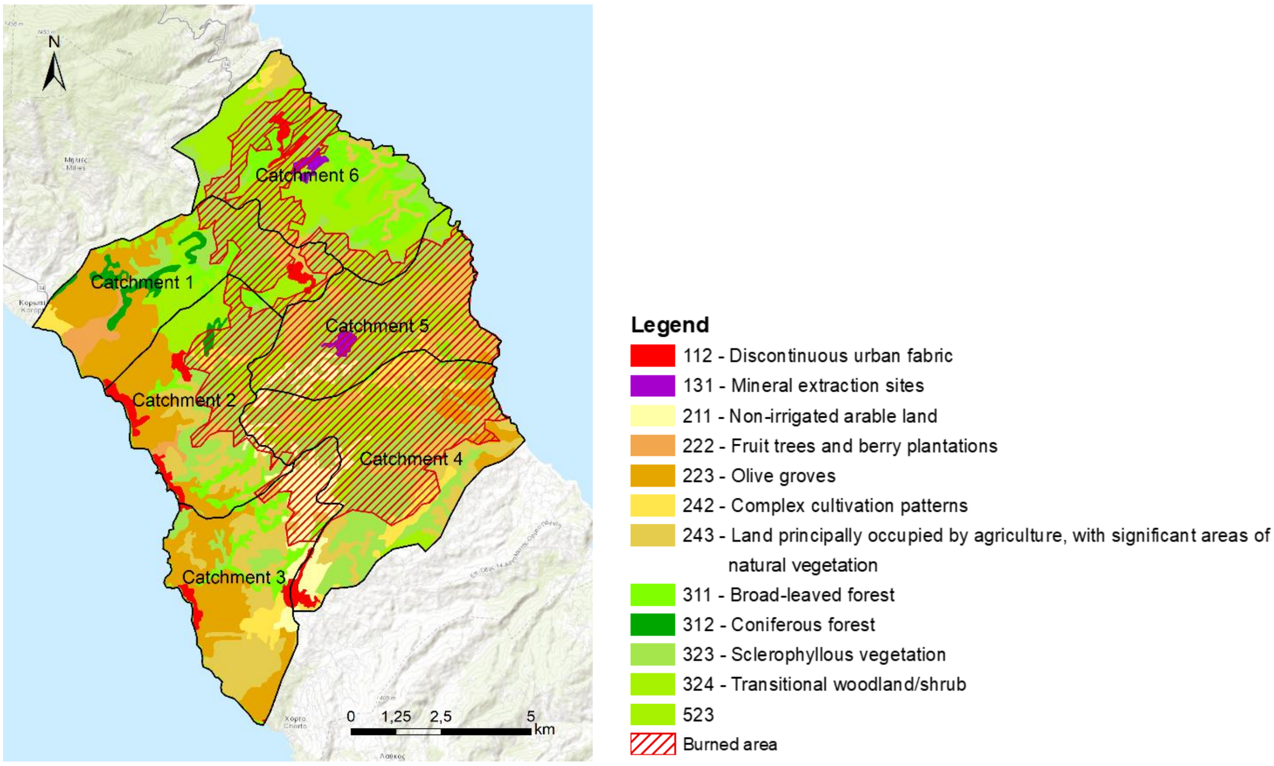

Figure 2. Land cover of the study area and the extent of the burned area.

Table 2. Total and post-fire area per each catchment and land cover.

Land cover code	Catchment 1		Catchment 2		Catchment 3		Catchment 4		Catchment 5		Catchment 6	
	Total area (km^2)	Fire area (km^2)	Total area (km^2)	Fire area (km^2)	Total area (km^2)	Fire area (km^2)	Total area (km^2)	Fire area (km^2)	Total area (km^2)	Fire area (km^2)	Total area (km^2)	Fire area (km^2)
112	0.38	0.05	1.03	0.02	0.53	0.00	0.40	0.00	0.00	0.00	0.45	0.25
131	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.36	0.35	0.43	0.17
211	0.00	0.00	0.33	0.17	2.82	2.12	1.85	1.11	0.84	0.84	0.00	0.00
222	1.12	0.00	0.27	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
223	5.98	0.00	4.02	0.00	6.02	0.00	1.97	1.39	0.10	0.09	0.00	0.00
242	0.45	0.00	0.50	0.49	0.92	0.00	2.43	1.59	0.19	0.19	0.25	0.00
243	0.96	0.75	3.37	0.57	5.85	0.43	6.36	3.58	4.13	4.11	2.38	0.43
311	1.75	1.03	1.96	0.44	1.68	0.14	0.25	0.25	0.20	0.20	5.02	0.93
312	1.45	0.00	0.28	0.17	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
323	3.32	2.13	4.66	2.93	1.55	0.55	9.23	6.13	5.86	5.65	4.27	2.36
324	4.36	1.16	3.22	1.43	0.00	0.00	5.32	4.91	5.66	5.31	11.00	3.82
Total	19.77	5.12	19.64	6.21	19.36	3.24	27.82	18.96	17.33	16.75	23.80	7.97

2.3. Impacts of fire event on runoff and sediment yield

The Natural Resources Conservation Service Curve Number (NRCS-CN) method (SCS, 1972) along with theStiny – Herheulidze method (Kotoulas, 1997) were used for the calculation of surface runoff and sediment yields, respectively.

The runoff is mainly based on the Curve Number (CN) parameter which is related to soil type and land use.Considering the high severity of the fire event (Mpouras, 2009),the post-fire CN values are taken equal to 95 for the artificial surfaces, and 92 for the agricultural, forest and seminatural areas (Livingston et al., 2005). The CN parameter was calculated equal to 82.16,82.81,85.72,84.28,84.75 and82.99for the pre-fire conditions, and was found to increase at85.00 (+3.46%),86.12 (+4.00%), 86.37 (+0.76%),89.95 (+6.73%),92.47 (+9.11%) and 86.50 (+4.23%) for the post-fire ones, for the catchments numbered as 1, 2, 3, 4, 5 and 6, respectively.

The calculated 50-years peak runoff volume and the relevant sediment yield are presented in Table 3 and 4, respectively.

Table 3. 50-years peak runoff volume for pre- and post-fire conditions.

Catchment	Runoff volume (m^3/s)	
	Pre-fire	**Post-fire**
1	112.18	130.14 (+16.01%)
2	149.29	174.52 (+16.90%)
3	138.40	142.68 (+3.09%)
4	144.74	197.15 (+36.21%)
5	93.46	131.83 (+41.05%)
6	146.12	167.29 (+14.49%)

Table 4. 50-years sediment yield for pre- and post-fire conditions.

Catchment	Sediment yield (m^3/s)	
	Pre-fire	**Post-fire**
1	12.75	14.79 (+16.00%)
2	16.96	19.83 (+16.92%)
3	15.73	16.21 (+3.05%)
4	16.45	22.40 (+36.17%)
5	10.62	14.98 (+41.05%)
6	16.60	19.01 (+14.52%)

3. Discussion

The results of the current study demonstrated that fire-induced alterations to the soil structure as reflected by the increase of the Curve Number parameter, cause an increase in runoff volume and sediment yield. Post-fire runoff and soil losses calculation constitutes a crucial procedure for the better adaptation of burned areas to post-fire flood events.

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