Science of the Total Environment 592 (2017) 262–276

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

Observational evidence on the effects of mega-fires on the frequency of hydrogeomorphic hazards. The case of the Peloponnese fires of 2007 in Greece

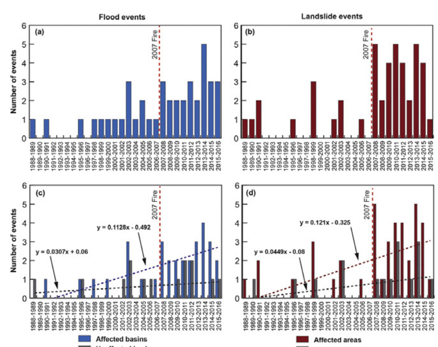
Diakakis M. [a,*], Nikolopoulos E.I. [b], Mavroulis S. [a], Vassilakis E. [a], Korakaki E. [c]

[a] Faculty of Geology and Geoenvironment, National & Kapodistrian University of Athens, Panepistimioupoli, Zografou GR15784, Greece
[b] Department of Civil and Environmental Engineering, University of Connecticut, Storrs, CT, USA
[c] WWF Greece, 21 Lembessi St., 117 43 Athens, Greece

HIGHLIGHTS

- The mega fire of 2007 in Greece and its effects of hydrogeomorphic events are studied.
- The frequency of such events over the period 1989–2016 is examined.
- Results show an increase in floods by 3.3 times and mass movement events by 5.6.
- Increase in frequency of such events is steeper in affected areas than unaffected.
- Increases are found even in months that record a decrease in extreme rainfall.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 6 January 2017
Received in revised form 7 March 2017
Accepted 8 March 2017
Available online xxxx

Editor: D. Barcelo

Keywords:
Forest fires
Megafires
Floods
Landslides
Geomorphology
Hydrogeomorphic

ABSTRACT

Even though rare, mega-fires raging during very dry and windy conditions, record catastrophic impacts on infrastructure, the environment and human life, as well as extremely high suppression and rehabilitation costs. Apart from the direct consequences, mega-fires induce long-term effects in the geomorphological and hydrological processes, influencing environmental factors that in turn can affect the occurrence of other natural hazards, such as floods and mass movement phenomena. This work focuses on the forest fire of 2007 in Peloponnese, Greece that to date corresponds to the largest fire in the country's record that burnt 1773 km^2, causing 78 fatalities and very significant damages in property and infrastructure. Specifically, this work examines the occurrence of flood and mass movement phenomena, before and after this mega-fire and analyses different influencing factors to investigate the degree to which the 2007 fire and/or other parameters have affected their frequency.
Observational evidence based on several data sources collected during the period 1989–2016 show that the 2007 fire has contributed to an increase of average flood and mass movement events frequency by approximately 3.3 and 5.6 times respectively. Fire affected areas record a substantial increase in the occurrence of both phenomena, presenting a noticeably stronger increase compared to neighbouring areas that have not been affected. Examination of the monthly occurrence of events showed an increase even in months of the year were rainfall intensity presented decreasing trends. Although no major land use changes has been identified and chlorophyll is shown to recover 2 years after the fire incident, differences on the type of vegetation as tall forest has been substituted

* Corresponding author.
E-mail address: diakakism@geol.uoa.gr (M. Diakakis).

http://dx.doi.org/10.1016/j.scitotenv.2017.03.070

with lower vegetation are considered significant drivers for the observed increase in flood and mass movement frequency in the fire affected areas.

1. Introduction

Although forest fires are an integral part of Mediterranean forest ecosystems (Arianoutsou, 1998; Naveh, 1994; Pausas and Vallejo, 1999) they constitute one of the most threatening natural hazard, as human presence expands into forested land. Modern societies are profoundly affected by fire disasters, inducing significant economic losses (Calkin et al., 2005; Crompton et al., 2010) and an important number of human casualties (Blanchi et al., 2014; Diakakis et al., 2016; Haynes et al., 2010; Mangan, 2007) as well as various adverse effects on hydrologic and geomorphologic processes (Lavee et al., 1995; Neary and Leonard, 2016; Shakesby and Doerr, 2006; Shakesby, 2011).

Fires have been found, among other effects, to directly influence rock weathering rates (Allison and Bristow, 1999; Allison and Goudie, 1994; Goudie et al., 1992; Dorn, 2003), reduce interception and storage capacity of the surface layer through removal of litter (Diaz-Fierros et al., 1994), change the chemical structure and hydrological properties of soil due to extreme heating (Giovannini et al., 1988; Scott et al., 1998) and affects its water repellency (DeBano, 2000; Doerr et al., 2004, 2005; Vieira et al., 2015). Due to these impacts, forest fires induce a series of indirect hydrological and geomorphological effects that can last up to several years (Shakesby and Doerr, 2006). These effects include reduction of infiltration (Wondzell and King, 2003), increase in annual runoff volumes (Lavabre et al., 1993; Helvey, 1980), increase of overland flow (Cerda and Doerr, 2005; Scott et al., 1998) and increase in erosion rates (Cerda and Doerr, 2005), especially due to the influence of ash that intensifies splash erosion and runoff rates (Bodí et al., 2014; Jordán et al., 2016). These effects lead directly to alteration of hydrological response of burned catchments (Scott, 1993) that usually manifest as increasing peak flows and reduced concentration times during storm events (Moody and Martin, 2001; Smith et al., 2011). In terms of geomorphological response, forest fires lead to a temporary intensification of erosion rates (Vega and Diaz-Fierros, 1987; White and Wells, 1982; Shakesby and Doerr, 2006) and occurrence of mass movement processes including debris flows and shallow landslides (Campbell, 1975; Cannon and Reneau, 2000; Cannon and Gartner, 2005; Cannon et al., 1998, 2001; Dragovich and Morris, 2002; Meyer et al., 2001; Swanson, 1981; Wells et al., 1979).

The duration of fire's impact on the hydrogeomorphic behaviour of an area vary considerably. Previous works have shown that this period commences immediately after the fire (Shakesby and Doerr, 2006) and lasts from a few months up to several years as vegetation recovers (Brown, 1972; Mayor et al., 2007; Morris and Moses, 1987; Prosser and Williams, 1998; Shakesby et al., 1994; Shakesby and Doerr, 2006). In fact, fire-induced increased water repellency, intensified by vegetation removal and the role of ash (Shakesby and Doerr, 2006; Jordán et al., 2016) is a key process regarding the increased runoff volumes and has been reported to last from months up to 6 years (DeBano et al., 1976; Dyrness, 1976; Doerr et al., 2000; Ebel et al., 2016). Prosser and Williams (1998) reported a period of 7 years until resistance to erosion returns to pre-fire levels. Legleiter et al. (2003) and DeBano et al. (1996) indicate that the period of disturbance can last up to 13 or 14 years respectively. Wittenberg and Inbar (2009) and Keesstra et al. (2017) state that the window of disturbance can be lengthened and the "baseflow" level of sediment yield was raised with each successive forest fire. Shakesby (2011) suggests that under circumstances there could be a permanent increase of 'background' sediment yield, indicating a more enduring footprint of the fire in geomorphological processes. González-De Vega et al. (2016) found correlation between fire severity and the recovery time for tall vegetation (pine forests), which indicates different duration of disturbance in parts of the burnt area (Vieira et al., 2016).

Even though the influence of forest fires in hydrologic and geomorphic processes is well established, and the increase in peak runoff as well as in the occurrence of debris flows is recorded (Bart, 2016; Mahat et al., 2016; Riley et al., 2013; Van Eck et al., 2016; Wondzell and King, 2003), there is limited documentation on the quantification of changes on the frequency of flood and mass movement events, before and after a fire. Candela et al. (2005) identified probability increases of 5-year and 10-year floods of approximately 1.5 times, by comparing simulated flood frequency curves between pre- and post-fire conditions. Nalbantis and Lymperopoulos (2012) calculated the same figures at approximately 3.5 and 2.5 respectively. Laurance (2007) suggested that removing of a 10% of existing forest cover could lead to an increase in flood frequency between 4%–28%. However, all the above works estimate changes on the basis of simulated results. Observational evidence of changes in flood and mass movement frequency of occurrence before and after a fire incidence are virtually absent from existing literature.

Among all forest fires the damages and the costs induced by mega-fires are by far the most extensive and serious, defining them as disasters of an entirely different scale in terms of impacts than the rest of the incidents (Williams et al., 2011). Mega-fires expand during extremely dry, hot and windy weather conditions and are fuelled by dense vegetation and unmanaged forest fuels (Williams et al., 2011). Most of the times mega-fires overwhelm the most advanced firefighting systems and organizations with consequences reaching beyond damages to property and infrastructure requiring a large commitment of financial and other resources (Omi, 2005). Recent mega-fires caused long lasting indeterminable impacts on the environment and local or even regional economies and societies (Ferreira-Leite et al., 2015; Williams et al., 2011). In addition, there is evidence of their growing frequency since 1990 (Ferreira-Leite et al., 2015) suggesting that within a changing climate it is likely that we will be dealing with such events more frequently.

Within the context of impact of fire on hydrogeomorphic response, the effects of mega-fires on hydrogeomorphology and the occurrence of related disasters is scarcely quantified, especially using long-term observational evidence. Quantifying these effects at a regional scale is particularly important for understanding and estimating the potential extend of the impact of future forest fires, not only in terms of alterations in hydrogeomorphic processes but also in terms of decision making for civil pretection (e.g. selection of post-fire protection measures and risk mitigation efforts).

This study is in line with this objective and presents an observation-based analysis regarding the regional impact of a mega-fire on the frequency of occurrence of hydrogeomorphic hazards. Particularly, this work builds upon the development and analysis of a complete catalogue of flood and mass movement events in the period 1989–2016 in the western part of Peloponnese in Greece, an area that was affected by a mega-fire in 2007, specifically aims to:

i. Identify possible changes, patterns or trends in the frequency of flood and mass movement events before and after the fire incident.
ii. Examine possible influencing factors (drivers) of the above changes
iii. Estimate quantitative (e.g. magnitude) and qualitative (spatial distribution, seasonality) characteristics of changes in occurrence.