Science of the Total Environment 526 (2015) 1–13

Contents lists available at ScienceDirect

Science of the Total Environment

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

Water resources planning for a river basin with recurrent wildfires

R.M.B. Santos [a], L.F. Sanches Fernandes [a,d], M.G. Pereira [a,b,e], R.M.V. Cortes [a,f], F.A.L. Pacheco [c,g,*]

[a] Centre for the Research and Technology of Agro-Environment and Biological Sciences, Vila Real, Portugal
[b] Dom Luiz Institute, University of Lisbon, Campo Grande, 1749-016 Lisbon, Portugal
[c] Chemistry Research Centre, Vila Real, Portugal
[d] Department of Engineering, University of Trás-os-Montes and Alto Douro (UTAD), Ap. 1013, 5001-801 Vila Real, Portugal
[e] Department of Physics, UTAD, Portugal
[f] Department of Forestry Sciences and Landscape Architecture, UTAD, Portugal
[g] Department of Geology, UTAD, Portugal

HIGHLIGHTS

- Wildfire impact on river water quality
- Relationship between wildfire frequency and fire risk
- Modeling phosphorus concentration in water after wildfire
- Forest management designed for reduction of wildfire risk

ARTICLE INFO

Article history:
Received 21 February 2015
Received in revised form 12 April 2015
Accepted 15 April 2015
Available online 26 April 2015

Editor: D. Barcelo

Keywords:
Wildfire
Fire risk
Land use
Hydrology
Phosphorus
Mike Hydro Basin

ABSTRACT

Situated in the north of Portugal, the Beça River basin is subject to recurrent wildfires, which produce serious consequences on soil erosion and nutrient exports, namely by deteriorating the water quality in the basin. In the present study, the ECO Lab tool embedded in the Mike Hydro Basin software was used for the evaluation of river water quality, in particular the dissolved concentration of phosphorus in the period 1990–2013. The phosphorus concentrations are influenced by the burned area and the river flow discharge, but the hydrologic conditions prevail: in a wet year (2000, 16.3 km^2 of burned area) with an average flow of 16.4 $m^3 \cdot s^{-1}$ the maximum phosphorus concentration was as low as 0.02 $mg \cdot L^{-1}$, while in a dry year (2005, 24.4 km^2 of burned area) with an average flow of 2 $m^3 \cdot s^{-1}$ the maximum concentration was as high as 0.57 $mg \cdot L^{-1}$. Phosphorus concentrations in the water bodies exceeded the bounds of good ecological status in 2005 and between 2009 and 2012, water for human consumption in 2009 and water for multiple uses in 2010. The River Covas, a right margin tributary of Beça River, is the most appropriate stream as regards the use of water for human consumption, because it presents the biggest water potential with the best water quality. Since wildfires in the basin result essentially from natural causes and climate change forecasts indicate an increase in their frequency and intensity in the near future, forestry measures are proposed to include as a priority the conversion of stands of maritime pine in mixed stands of conifer and hardwood species.

1. Introduction

In the Mediterranean region, summer is generally characterized by a combination of high temperatures and low air humidity which results in a very low moisture content of flammable materials (Giorgi and Lionello, 2008; Pausas, 2004). Under these conditions, the frequency of wildfires tends to increase, being further enhanced by high wind speeds and heat waves also predominant in that season (Fernandes, 2013; Shakesby, 2011). Aided by general warming and drying trends, the wildfires increased intensely in frequency and extent from the second half of the 20th century onwards (Shakesby, 2011). Apart from climate change, this increase was motivated principally by socio-economic changes, including rural depopulation, land abandonment and afforestation with flammable species (Fernandes, 2013; Moreira et al., 2011). Fire adaptations of many endemic plant species indicate an even longer fire history in the Mediterranean region (Pausas et al., 2008).

Wildfires are a major driving force in the shaping of vegetation dynamics (Ferreira et al., 2005a,b; Trabaud, 2002), but are also frequently regarded as a major agent of soil erosion and water quality degradation (Shakesby, 2011). Wildfires may cause very substantial changes to soil

* Corresponding author at: Chemistry Research Centre, Vila Real, Portugal.
E-mail address: fpacheco@utad.pt (F.A.L. Pacheco).

http://dx.doi.org/10.1016/j.scitotenv.2015.04.058

nitrogen (N) and phosphorus (P) (Baird et al., 1999; Chambers and Attiwill, 1994; Lane et al., 2008) that may affect post-fire nutrient exports and concentrations of these constituents in runoff and streams (Blake et al., 2010; Gimeno-García et al., 2000; Smith et al., 2011). Murphy et al. (2006a,b) reported a high reduction of N (92%) and P (76%) storages in forest floor surface organic material (O horizon) due to combustion and volatilization, with smaller reductions (31–51% in N) recorded under lower intensity fires. Blake et al. (2010) mentioned an increase of up to 20% in the concentration of particulate P in burned soil. The increase of available P and N after a fire has implications for water quality and potential eutrophication of water bodies (Smith et al., 2011). The high concentration of these nutrients gives rise to the growth of aquatic plants, algae and cyanobacteria. This growth triggers a decrease of oxygen in the water causing the death of fish and other animals and the formation of toxic gases. In the sequel, the toxins may contaminate the water intended for human consumption (Smith et al., 2011). Apart from the consequences for human health, it is worth noting the potential impacts of toxic blooms on esthetics (taste, odor and color) and aquatic ecosystem function (Drewry et al., 2006). In general, the differences registered in the exports of N and P from forested ground reflect differences in burn area and severity of fire, soil and forest vegetation types, erosion processes, pre-fire atmospheric deposition and extent of delivery to streams (Mast and Clow, 2008; Shakesby, 2011; Smith et al., 2011). Regardless of the cause, any aquatic ecosystem subject to eutrophication faces not only the loss of biodiversity but also the invasion of other species as a result of habitat changes.

It has been reported that forested catchments are an important source of potable water to communities around the planet (Dudley and Stolton, 2003; Neary et al., 2009; Smith et al., 2011). The impacts of forest fires at this scale are not limited to water quality degradation but bear many other facets. According to Hyde et al. (2007), wildfires alter substantially the hydrologic and geomorphic response of a catchment, which in turn promotes severe erosion during rainfall events. The decrease of infiltration rates and increase of available loose sediment after a wildfire is a consequence from the destruction of vegetation and changes in physical and hydrologic properties of the soil (Ferreira et al., 2005b, 2008). These changes can significantly increase the amounts of sediment, nutrients and other constituents delivered to streams, lakes and reservoirs throughout the watershed (Moody and Martin, 2009; Smith et al., 2011; Wilkinson et al., 2009). Smith et al. (2011) claimed that very high nutrient concentrations following wildfires are generally short-lived, but elevated concentrations may persist for some time after post-fire rainfall events. According to White et al. (2006), a scenario of recurrent river or reservoir water contamination by the leaching of nutrients from burned areas in a forested catchment may result in supplies that are unfit for human consumption. In those cases, the contamination of a supply source in the course of wildfire events, even if appellant for short periods of time may constitute a serious management problem for the authorities delivering drinking water to the population. This problem may become particularly serious when the capacity of water treatment has proved inadequate in the face of high concentrations and volumes to treat or when the population relies on a single water source that has been contaminated.

Although recognized as major cause of water quality degradation, wildfire recurrence has barely been considered in plans for the management of water resources at the basin scale. This study contributes to this issue because it addresses the impact on water quality and the implications for water resources management of recurrent wildfires in a forested watershed of a humid Mediterranean region (Temperate Mediterranean with continental influences): the Beça River basin, Northern Portugal. In this context, the main objectives of this study are: (i) to verify if the concentration of phosphorus in river water is an indicator of wildfire frequency, and (ii) to model the concentrations of phosphorus in stream water at the basin and sub-basin scales.

2. Materials and methods

2.1. Study area

The Beça River is located in northern Portugal (Fig. 1), extending its main water course along 55.2 km and draining a catchment of approximately 345 km^2. The watershed is shaped on a mountainous region where the altitudes vary within 190–1270 m and the average hillside inclinations approach $11.7 \pm 7.6°$. Pertaining to the period 1978–2006, the average temperature was 10.5 °C, with an interval of 9.5 °C–11.9 °C, while the average precipitation was 1440 $mm \cdot yr^{-1}$ with a range of 650–2400 mm yr^{-1}. Discarding the anomalous years of 2000 and 2001, the temperature and precipitation records indicate overall heating and drying trends of $+0.78$ $°C \cdot decade^{-1}$ and -300 $mm \cdot decade^{-1}$, respectively. Precipitation varies widely within the watershed, increasing towards the Southwest and ranging from 900 (in the NE edge) to 1500 mm yr^{-1} (in the SW edge) in a dry year and from 1000 to 2400 mm yr^{-1} in a wet year (Santos et al., 2014a).

In the Regional Plan for Forest Management (Machado and Bento, 2006; Portuguese Regulate Decree no. 3/2007, published in 17 January 2007), the Beça River basin occupies sectors of the Barroso and Tâmega homogeneous sub-regions, which are included in the Barroso and Padrela region (Fig. 1). The strategic objectives of that plan, to be accomplished until 2045, are: to reduce the risk of wildfire occurrence; and to adjust the proportions of resinous and deciduous species based on the application of correct forest management models. Another important goal is to assure the connectivity among isolated communities of fauna and flora, through the construction and maintenance of ecological corridors. According to the Corine Land Cover map available at http://www.eea.europa.eu or http://www.dgterritorio.pt, the land uses and occupations in the Beça River basin are dominated by semi-natural areas mostly composed of shrub lands, agricultural areas and forests (Fig. 1). The semi-natural areas are dispersed throughout the basin while the agricultural areas are mainly located in the headwaters and middle sector of the catchment. The forested areas are found predominantly in the downstream sector, being represented by large and continuous spots of *Pinus pinaster Ait* forests used for wood production. In the last two decades (period 1990–2006), the areas used for agriculture did not change significantly, preserving an occupation around 32% of the basin. In contrast, the forested areas increased from 19.4% to 23.5% in the period 1990–2000 and decreased to 15.2% in the period 2000–2006, while the shrub land areas evidenced a reverse trend: they decreased from 48% to 43.8% in the period 1990–2000 and increased to 52% afterwards (compare Fig. 1a–c).

Farmers in the Beça River basin area still use farmyard manures as the main source for supplying nutrients to fields or pastures, while dressings of commercial fertilizers on agricultural land remain low (Pacheco et al., 1999). The chemical composition of average-matured cow manure is characterized by high percentages of water (70%) and organic matter (26%) and by moderate propositions of nitrogen (3.14%) and potassium (0.74%), while phosphorus is virtually absent (Portela et al., 1993).

2.1.1. Forest fires

The Institute for the Conservation of Nature and Forests (http://www.icnf.pt) published a cartography of burned areas, covering the period 1990–2013 (Fig. 2a), and a cartography of wildfire risk assessed in 2011 (Fig. 2b). The risk of wildfire occurrence was estimated by a multi-criteria analysis involving biophysical and socio-economic parameters with variable relative importance (given in percentage): cover vegetation (59%), hillside slope (21%) and aspect (6%), road network (9%) and population density (5%). As regards the last parameter, irrespective of its presumed low contribution to the risk, it is consensual that wildfires in Portugal increased in recent decades mostly because rural areas became progressively deserted leading to an invasion of shrub land towards former farmlands and concurrently to a reduction of forest biomass