

# The influence of rural fires in surface water quality

## A influencia dos incêndios rurais na qualidade de águas superficiais

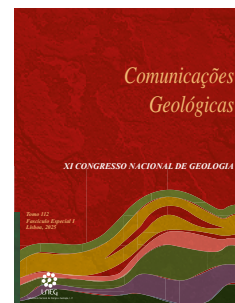
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**Abstract:** This study focuses on the impact of rural fires on water quality in the Mondego River basin in Portugal. An analysis of water quality was conducted to assess the interaction between fires, land use, geology, and precipitation. Data from a monitoring program conducted over two hydrological years were statistically analyzed and compared to a geochemical background. The results reveal substantial increases in the concentrations of Ca, K, Mg, NO<sub>3</sub>, SO<sub>4</sub>, and As in surface waters after the fires. These changes are accompanied by an increase in electrical conductivity. While some parameters returned to normal concentrations in the following months, As kept with elevated grades in some sites, which appear to reflect complex interactions between post-fire processes and geology.

**Keywords:** Rural fires, land use, surface water quality, physical chemical parameters, geochemical background.

**Resumo:** Este estudo está focado no impacto dos incêndios rurais na qualidade da água na bacia do rio Mondego em Portugal. Foi realizada uma análise de qualidade da água na interação entre os incêndios, o uso do solo, a geologia e a precipitação. Os dados de um programa de monitorização realizada durante dois anos hidrológicos foram analisados estatisticamente e contrastados com um fundo geoquímico. Os resultados revelam aumentos substanciais nas concentrações de Ca, K, Mg, NO<sub>3</sub>, SO<sub>4</sub> e As nas águas superficiais após os incêndios. Essas alterações são acompanhadas por um aumento na condutividade elétrica. Embora alguns parâmetros tenham regressado às concentrações normais nos meses seguintes, o As manteve-se com teores elevados em alguns locais, que parecem refletir interações complexas entre os processos pós-incêndio e a geologia.

**Palavras-chave:** Fogos rurais, uso do solo, qualidade de água superficial, parâmetros físico-químicos, fundo geoquímico.

### 1. Introduction

There has been a growing concern regarding the quality of surface waters due to their importance as a resource for domestic, industrial and agricultural purposes, as well as their integral role in hydrological and biogeochemical cycles (Anderson *et al.*, 2019). From the multitude of factors that impact water quality (Chen *et al.*, 2018), fires have emerged as a significant contributor to water quality deterioration, exhibiting pronounced effects across spatial and temporal scales (Smith *et al.*, 2011), and gathered attention as an environmental issue within watersheds (Mansilha *et al.*, 2019; Ré *et al.*, 2021). While water quality is the result of complex interactions among multiple factors, fires should be singled out as a major source of pressure, and be treated as an interacting factor. Consequently, this study aims to delve into the influence of fires and their interplay with other anthropogenic and natural factors affecting water quality.

### 2. Study Area

The study area, part of Portugal's Mondego river basin, lies within the Central Iberian Zone. It includes Precambrian flysch sequences with schist and greywackes, overlaid by Ordovician quartzites, along with areas dominated by granitoids. Some catchments exhibit Cretaceous to Cenozoic successions (Figura 1a). The region displays varied geomorphology, from flat upstream areas to steep valleys in the south (Dinis *et al.*, 2020). Land use in the study area primarily consists of forests and semi-natural areas, with some upstream catchments dedicated to agriculture (Figura 1b). After the 2017 fires, several catchments experienced significant deforestation, loss of agricultural land and even destruction of urban area (Figura 1c).

The region experiences a Csb Köppen-Geiger climate, marked by warm, dry summers and winter precipitation (IPMA, 2013). In 2016/2017, an exceptionally dry hydrological year resulted in widespread drought and subsequent fires by October 2017 (IPMA, 2017). The following year, 2017/2018, witnessed atypical precipitation patterns, including a shift in the peak rainfall period to March.

### 3. Methodology

To discern water characteristics influenced by fires from those influenced by other factors, such as geogenic processes, land use, and dilution, a comprehensive approach was employed. The study design

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encompassed a three-stage data methodology, comprising: 1) data collection, including surface water monitoring, spatial analysis of catchments, and precipitation data collection; 2) statistical analysis, involving data processing, selection of independent variables through Pearson correlation, and regression analysis to distinguish fire effects from other factors; and 3) quantification of disturbances caused by fires, achieved by comparing with a geochemical background of parameters influenced by fires as determined by the regression analysis.

The physical and chemical properties of water were treated as dependent variables, and the data was collected during monitoring campaigns spanning two hydrological years in catchments of the Mondego Hydrological Basin (Figura 1). In the first hydrological year (2017-2018), following the October 2017 fires, surface water monitoring occurred on a monthly basis, starting in November and concluding in June. In the second year, two campaigns were conducted, one during the rainy season (April) and the other during the dry season (September). In each campaign, water parameters such as electrical conductivity (EC), pH, turbidity (Trb), and alkalinity (Alk) were measured in situ (Sequeira *et al.*, 2020). Additionally, water samples were collected for the assessment of major and minor ions (Br, Cl, NO<sub>3</sub>, PO<sub>4</sub>, SO<sub>4</sub>, Ca, K, Mg, and Na), as well as metals and metalloids (Al, As, Ba, Fe, Mn, Ni, Pb and Zn).

To understand the influence of catchment characteristics and precipitation on water properties, these factors were considered independent variables. Catchment characteristics were determined using spatial analysis in ArcGIS software, version 10.7.1. This involved calculating the average slope (AvSlp) using altimetry data and categorizing geological features into clastic sedimentary (SClt), carbonate sedimentary (SCrb), igneous (Ign), and metamorphic (Mtm) categories. Land use data

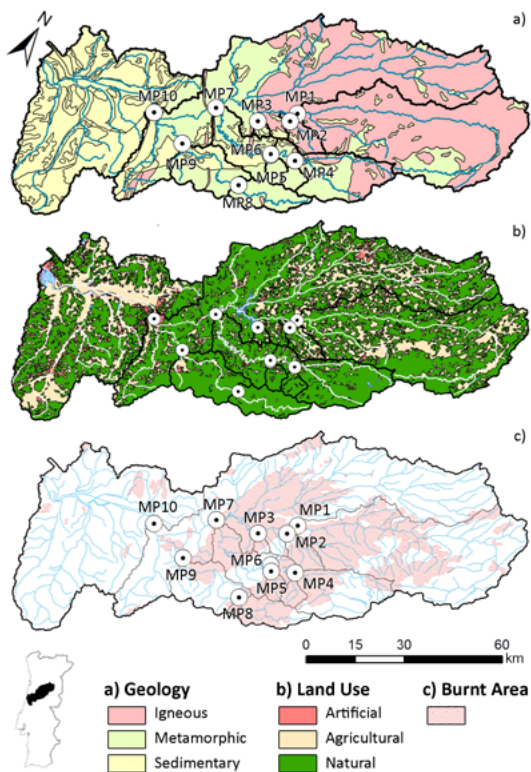


Figure 1. The monitored catchments, and respective a) geology, b) land use, and c) fire-affected area located within the Mondego Hydrological Basin.

Figura 1. As bacias de captação monitorizadas e respetiva a) geologia, b) uso do solo e c) área afetada pelo fogo localizada na Bacia Hidrológica do Mondego.

were categorized as artificial (Art), agricultural (Agr), forest (For), and shrub/herbaceous vegetation (Shv). The land use data was overlaid with fire-affected areas (A) to assess the impact of each land cover type.

For statistical analysis, IBM SPSS Statistics version 26 was utilized. Before conducting further tests, an examination of outliers and skewness in all variables was performed. Pearson correlation was employed to identify statistically significant relationships between the independent variables and water parameters. Subsequently, a regression analysis model was constructed using only the significant independent variables to quantify their influence on water parameters. A stepwise regression method was applied to remove less significant independent variables, considering tolerance and variance inflation factor to ensure their independence.

As the creation of control points for comparison was infeasible due to the widespread nature of the study, monitoring points were compared with historical data. Using a comparison range based on 30 years of datasets (1992-2022) from the same catchments obtained from network stations of the Portuguese Environmental Agency, a geochemical background (GB) was calculated using the ‘MAD’ method (Mean Absolute Deviation) (Reimann *et al.*, 2005). Subsequently, an analysis was conducted to determine the number of MAD values outside the GB range for parameters affected by fires and to assess the resulting magnitude of exposure to this pressure.

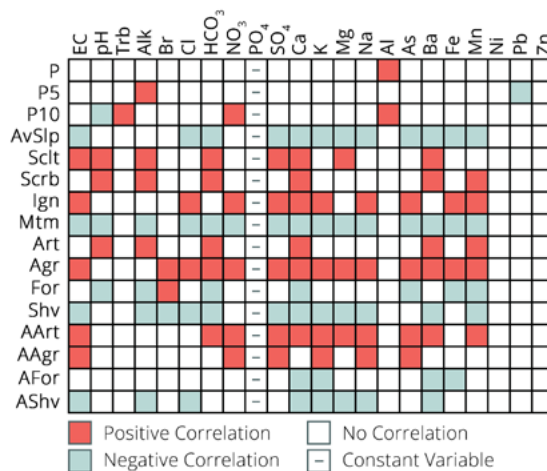


Figure 2. Schematic of the Pearson correlation analysis.  
 Figura 2. Esquema da análise de correlação de Pearson.

### 4. Results and Discussion

Following data processing, the PO<sub>4</sub> values remained unchanging (Table 1). Consequently, it was impossible to identify any correlations associated with this parameter. Furthermore, there were no discernible correlations between Ni and Zn with the dependent variables, leading to the exclusion of these elements from the regression analysis (Figura 2). Due to their lack of correlation with the fire-affected areas, variables such as pH, Trb, Br, Al, and Pb were also omitted from the regression analysis.

The regression analysis allowed the identification of the water parameters potentially affected by the fires, including EC, NO<sub>3</sub>, SO<sub>4</sub>, Ca, K, Mg, and As (Table 2). Additionally, it revealed other independent variables which also serve as an influence (Table 2).

In comparison to the GB, it is evident that the EC of most surface water samples exceeded the background levels during the initial three months subsequent to the fires, reaching a peak of 14 times the MAD above the GB (Figura 3). This rise in EC can be attributed to an increase in the concentration of dissolved ions in the water (Rusydi, 2018).

However, it is noteworthy to mention that a subset of the monitored water bodies exhibited EC levels persistently exceeding the background during the second year of monitoring, with values ranging from 1 to 3 times the MAD above the GB. Which can be attributed to other independent variables, such as agricultural activities within the catchments (Ngoye and Machiwa, 2004).

It appears that as a consequence of the release to surface water of the byproducts of the combustion of organic materials, either present in the soil or in vegetal matter (Smith *et al.*, 2011),  $\text{SO}_4$  concentrations escalated to 12 times the MAD above the GB, one month after the fires (Figura

Table 1. Statistics from the results of monitoring campaign after removing the outliers.

Tabela 1. Estatísticas dos resultados das campanhas de monitorização após remoção dos outliers.

	Units	Min.	Max.	Mean	S.Dev.	Skw.	Kurt.
EC	$\mu\text{S}/\text{cm}$	36.9	134.9	80.8	26.5	0.49	-0.70
pH	-	6.3	7.3	6.8	0.2	0.10	-0.86
Turb	NTU	0.3	14.8	5.1	3.6	1.13	0.51
Alk	mg/l	4.4	17.2	10.2	3.6	-0.07	-1.01
Br	mg/l	0.02	0.06	0.04	0.01	0.32	-0.32
Cl	mg/l	4.40	13.00	7.87	1.85	0.28	-0.26
NO3	mg/l	0.70	5.00	2.66	1.22	0.38	-0.87
PO4	mg/l	0.05	0.05	0.05	0.00	1.02	-2.06
SO4	mg/l	2.10	10.00	5.46	2.03	0.14	-0.82
Ca	mg/l	0.97	4.70	2.51	0.95	0.51	-0.23
K	mg/l	0.33	1.70	0.92	0.36	0.48	-0.65
Mg	mg/l	1.10	3.40	2.20	0.61	0.10	-0.87
Na	mg/l	3.80	11.00	7.05	1.92	0.23	-0.68
Al	$\mu\text{g}/\text{l}$	1.0	46.0	21.4	11.1	0.39	-0.62
As	$\mu\text{g}/\text{l}$	0.2	2.2	1.0	0.5	0.36	-0.38
Ba	$\mu\text{g}/\text{l}$	0.5	7.2	3.2	1.9	0.39	-1.06
Fe	$\mu\text{g}/\text{l}$	5.3	108.5	52.1	29.2	0.07	-1.20
Mn	$\mu\text{g}/\text{l}$	0.5	22.8	7.7	6.0	0.56	-0.54
Ni	$\mu\text{g}/\text{l}$	0.1	0.7	0.3	0.2	0.12	-1.19
Pb	$\mu\text{g}/\text{l}$	0.1	1.3	0.4	0.4	0.90	-0.57
Zn	$\mu\text{g}/\text{l}$	1.0	7.8	2.6	1.9	1.39	1.35

Min. minimum; Max. maximum; S.Dev. standart deviation; Skw. Skewness; Kurt. Kutosis.

3), while  $\text{NO}_3$  concentrations were 1 to 8 times the MAD above the GB from 2 to 5 months following the fires. In the case of  $\text{NO}_3$ , the highest concentrations also coincide with one of the highest rainfall periods on March of 2018. While the regression analysis also points that, although to a minor extent, long term precipitation (P10) seems to be partially responsible for the increases in  $\text{NO}_3$ . Subsequently,  $\text{NO}_3$  concentrations remained within the GB for the rest of the monitoring period, as rainfall contributes to increased of water availability improving conditions for dilution of surface water concentrations. It is worth mentioning that in the statistical analysis, no independent variable was considered to factor in any combustion products that might still have been present in the soil following the fires. Consequently, it is not possible to ascertain when these products were exhausted by runoff. Differently from  $\text{NO}_3$ , the monitoring points registered  $\text{SO}_4$  concentrations close to the typical range of the pre-fire conditions eighth month post-fire.

It was observed that a sampling point presented K concentrations that exceeded the GB by 2 times the MAD within the first month after the fire. Furthermore, certain watercourses sampled within two months after the fires displayed elevated levels of both Ca and Mg in surface water. These concentrations exceeded the GB by 9 and 5 times the MAD, respectively. However, it's important to note that these elevated concentrations of Ca and Mg did not last, as four months later, the concentrations returned to within the GB. Previous studies have shown that K, Ca and Mg are heavily found within ash (Gabet and Bookter, 2011; Pereira *et al.*, 2014). Additionally, it appears that agricultural activities, such as the use of fertilizers (*i.e.* KCl) play a role in elevating K levels in surface water. This is particularly pronounced in cases where there is excessive soil remobilization and irrigation (Reimann and Caritat, 1998).

It was observed a specific pattern in the concentrations of As in two specific monitoring points where igneous rocks are abundant (MP1 and MP2) following the fires (Figura 3). Within the first two months As concentrations surged to levels that were 25 times higher than the MAD above the GB. This initial post-fire period saw a significant spike in As levels, which seems to indicate an impact of the fires on the surface water. Subsequently, over the following two years, while the As concentrations were not as pronounced as in the immediate aftermath of the fires, concentrations were between 4 to 8 times the MAD above the GB at the same sampling points. By the end of the study period, during the summer, As concentrations increased again to 18 times the MAD above the GB. The high extent of igneous geology in these two catchments seems to contribute to the high concentration of As in surface water. The regression analysis also points the igneous geology as a contribution of As to surface

Table 2. Results from the regression analysis | Tabela 2. Resultados da análise de regressão

DV	Regression	R	R <sup>2</sup>	p
EC	$\text{EC} = 40.3 + 15.0 \text{ AArt} + 1.85 \text{ Agr} + 0.5 \text{ SClT}$	0.683	0.467	<0.001
Alk	$\text{Alk} = 11.59 + 0.29 \text{ SCbr} + 0.12 \text{ P5} - 0.04 \text{ Mtm}$	0.584	0.341	<0.001
Cl	$\text{Cl} = 2.93 + 0.35 \text{ Agr}$	0.642	0.412	<0.001
HCO3	$\text{HCO3} = 21.12 + 0.33 \text{ SCbr} - 0.09 \text{ Mtm}$	0.463	0.215	<0.001
NO3	$\text{NO3} = 3.33 + 1.50 \text{ AArt} + 0.01 \text{ P10} - 0.01 \text{ Mtm}$	0.704	0.495	<0.001
SO4	$\text{SO4} = 8.15 + 1.34 \text{ AArt} - 0.04 \text{ Mtm}$	0.575	0.331	<0.001
Ca	$\text{Ca} = 1.61 + 0.87 \text{ AArt} + 0.09 \text{ SCbr} + 0.05 \text{ SClT} + 0.03 \text{ Ign}$	0.764	0.584	<0.001
K	$\text{K} = 0.97 + 0.30 \text{ AArt} + 0.03 \text{ Agr} - 0.01 \text{ Mtm}$	0.775	0.601	<0.001
Mg	$\text{Mg} = 2.43 + 0.32 \text{ AArt} + 0.02 \text{ SClT} - 0.01 \text{ Shv}$	0.524	0.274	<0.001
Na	$\text{Na} = 3.84 + 0.23 \text{ Agr}$	0.626	0.392	<0.001
As	$\text{As} = 1.446 + 0.724 \text{ AArt} + 0.034 \text{ Ign} - 0.016 \text{ For}$	0.877	0.769	<0.001
Ba	$\text{Ba} = 6.804 - 0.046 \text{ Shv} + 0.032 \text{ SClT} - 0.027 \text{ Mtm}$	0.667	0.445	<0.001
Fe	$\text{Fe} = 123.876 - 3.995 \text{ AvSlp} - 1.934 \text{ Agr} + 0.633 \text{ Ign}$	0.430	0.185	<0.005
Mn	$\text{Mn} = 18.687 + 0.466 \text{ SCbr} - 0.115 \text{ Mtm}$	0.485	0.235	<0.001

DV. Dependent variable; R. Correlation coefficient; R<sup>2</sup>. Coefficient of determination; p. Significance

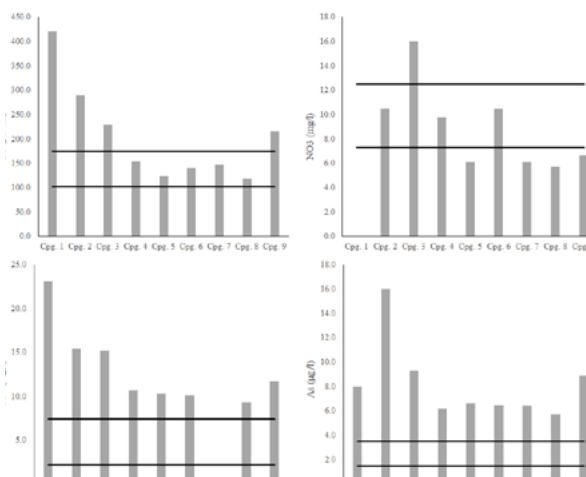


Figure 3. Comparison of the EC, NO<sub>3</sub><sup>-</sup>, SO<sub>4</sub><sup>2-</sup> and As data with their respectively GB range in the MP2.

Figura 3. Comparação dos dados de EC, NO<sub>3</sub><sup>-</sup>, SO<sub>4</sub><sup>2-</sup> e As com seus respectivos intervalos de GB no MP2.

water chemistry, as As can originate from various minerals commonly found in granitoids (Reimann and Caritat, 1998). However, it is important to note that the influence of the geology on As concentrations did not appear to be as strong as expected. One possible explanation for this weaker influence is the relatively low environmental movement of As (Smith *et al.*, 2003). As may not move as readily through the environment as other elements, which could limit its release from geological sources. However, if the role of fires in influencing Arsenic availability in the environment is considered, it raises the possibility that the fires themselves may be a significant factor contributing to the elevated As concentrations observed. As fires can potentially release As through atmospheric deposition (Nriagu and Pacyna, 1988; Smith *et al.*, 2011). This hypothesis also fits with the regression analysis, which suggested that fires might have a more substantial influence on As concentrations than the underlying geology. However, it is essential to highlight that further research is needed to confirm whether fires indeed play a more dominant role in elevating As levels than geological factors, and the exact mechanisms and interactions between geology, fires and As requires further research.

## 5. Conclusions

This study aimed to investigate the influence of rural fires, in conjunction with various land-use and natural variables, on water quality within the Mondego river basin in Portugal. To address this objective a holistic approach was adopted, using an analysis of surface water parameters in conjunction with various anthropic and natural variables.

Following the devastating fires of October of 2017, it was observed significant alterations in water quality parameters. Namely, major increases in surface water concentrations of Ca, K, Mg, NO<sub>3</sub><sup>-</sup>, SO<sub>4</sub><sup>2-</sup> and As, and consequently increases in the surface water's EC. The temporal dynamics were diverse, as Ca, Mg and NO<sub>3</sub><sup>-</sup> returned to normal concentrations within 6 months, and SO<sub>4</sub><sup>2-</sup> concentrations around 8 months after the fires, while As seems to exhibited longer-lasting effects. This last parameter underlines the complex interplay of multiple factors, including post-fire processes, geology and land use.

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