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Abstract

Vegetation Regrowth in Gullies After a Wildfire: The Case Study of the Alva Basin (Centre of Portugal) †

Bruno Martins [1,2,*], Catarina de Almeida Pinheiro [3], Adélia Nunes [1,2], António Bento-Gonçalves [3] and Manuela Laranjeira [3]

1 CEGOT (Centre of Studies on Geography and Spatial Planning), Department of Geography and Tourism, University of Coimbra, 3004-530 Coimbra, Portugal; adeliajnnunes@gmail.com
2 RISCOS (Portuguese Association of Risks, Prevention and Security), University of Coimbra, 3004-530 Coimbra, Portugal
3 Communication and Society Research Centre, Department of Geography, University of Minho, 4710-057 Braga, Portugal; catarina-pinheiro@mail.com (C.d.A.P.); bento@geografia.uminho.pt (A.B.-G.); manuela.laranjeira@geografia.uminho.pt (M.L.)
* Correspondence: bmscmartins@gmail.com

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Abstract: The aim of this study is to identify and characterize gullies considering their morphological and topographical aspects and determine the factors that control vegetation regrowth (VR) in gullies in Alva Basin after the wildfire of 2017. The use of hierarchical clustering identified two groups of gullies. Multiple regression produced three models (R-Square = 81.3%) for gullies group 1, considering the explanatory factors mean width, slope, and burn severity. Group 2 also produced three models (R-Square = 71.8%) but considering the explanatory variables mean width, slope, and flow accumulation. VR mainly depends on post-fire recovery strategies for vegetation, the remaining soil, and site humidity.

Keywords: vegetation regrowth; gullies erosion; sustainability; mediterranean environment

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1. Introduction

Gullies contribute very effectively to soil loss and degradation in various areas around the world, e.g., [1]. They are especially effective in certain geomorphic units in arid and semiarid regions, examples of which include the Mediterranean environment. Several studies show that wildfires are responsible for burning extensive areas of scrubland and forests every year, contributing to physical soil erosion, soil degradation, and the presence and formation of gullies. Nevertheless, gullies are sometimes seen as productive hotspots of high biodiversity, playing an important role as an ecological corridor [2]. They are sometimes sediment containment areas, especially when occupied by vegetation. Knowledge of how vegetation recovers along gully channels is therefore particularly interesting, especially in Mediterranean regions that have suffered various forest fires that led to highly degraded soils. This research therefore aims to answer the following objectives (R):

R1: To identify and characterize gullies considering morphological and topographical aspects.

R2: To determine the factors that control vegetation growth, considering a substantial number of geo-environmental factors, including topographic, hydrological, and environmental ones. The stepwise multiple regression (SMR) was used.

2. Materials and Methods

2.1. Study Area

The study area is located in the municipality of Oliveira do Hospital (center of Portugal), more specifically on the right bank of the Alva River. From a lithological point of view, it is essentially composed of granitic rocks with a predominance of coarse-grained porphyroid granite of a calc-alkaline nature and sometimes with megacrystal orientation. The climate of the region is temperate with mild, dry summers and rainy winters. The municipality's area is often affected by forest fires, the most notable in the last decade being the great forest fire of 2017. It started on 15 October and burned an area of 7600 ha of woodland, and it was followed by storm Ana on 10 December 2017, which caused abundant heavy rainfall. According to DGT (2022) [3], the forest is formed mostly by pine trees (52% of the study area) and broadleaf trees (13% of the study area). The pine trees correspond to cultivated forests of Pinus pinaster. In addition, invasive forest species like Acacia dealbata, Ailanthus altissima, occupy 7% of the study area.

2.2. Data Collection

A digital elevation model (DEM) of the study area was created based on contour lines with an equidistance of 10 m. Then, the following topographic parameters were determined: altitude (A), slope (S), aspect (As), topographic ruggedness index (TRI), curvature (C), and flow accumulation (FA). The Normalized Difference Vegetation Index (NDVI) was derived to investigate the post-fire regrowth dynamics of vegetation. Burn severity (BSaf) was also computed. Before performing model processing, the variance inflation factor (VIF) was used for multicollinearity tests, which avoids model variables with the high correlation being simultaneously substituted into the model processing. Landsat 8 OLI/TIRS images with a spatial resolution of 30 m were used to characterize vegetation regeneration (VR) after the fire. Two images were acquired for the pre- and post-fire period, respectively, 28 September 2017 and 30 October 2017. Another five images were included (15 September 2018, 18 September 2019, 4 September 2020, 30 September 2021, and 26 September 2022). The Normalized Difference Vegetation Index (NDVI) was used to analyze VG and the Normalized Burn Ratio (NBR) was used to estimate fire severity (Bsaf). The gullies were identified based on the 2018 orthophotograph provided by the Directorate-General for Territory with a spatial resolution of 25 cm. Overall, 38 gullies were vectorized, and four elements of morphological characterization were calculated, namely total length (L), mean width (mW), maximum width (MaxW), and plan area (Pa).

2.3. Statistical Analysis

Hierarchical clustering (HC) was used to detect homogeneous groups for the 38 gullies identified. Stepwise multiple regression (SMR) was used to identify the determinants of VR in the fourth year after the fire based on 10 independent variables. The TRI variable was removed after applying the VIF. The other variables were integrated and progressively removed.

3. Results

HC identified two groups of gullies based on the five homogeneity parameters Pa, MaxW and mW, S and L. The most important morphological and topographical characteristics of GG1 and GG2 are given in Table 1.

Table 1. Descriptive morphological characteristics of GG1 and GG2.

	Pa (m^2)	MaxW (m)	mW (m)	S (^{0})	L (m)
GG1	1597.0	10.6	5.9	21.6	81
GG2	663.0	7.8	4.0	19.6	146.0

The vegetation in the gullies takes 4 years to reach NDVI values close to those recorded before the 2017 fire, although they are slightly lower (especially in GG2) (Figure 1).

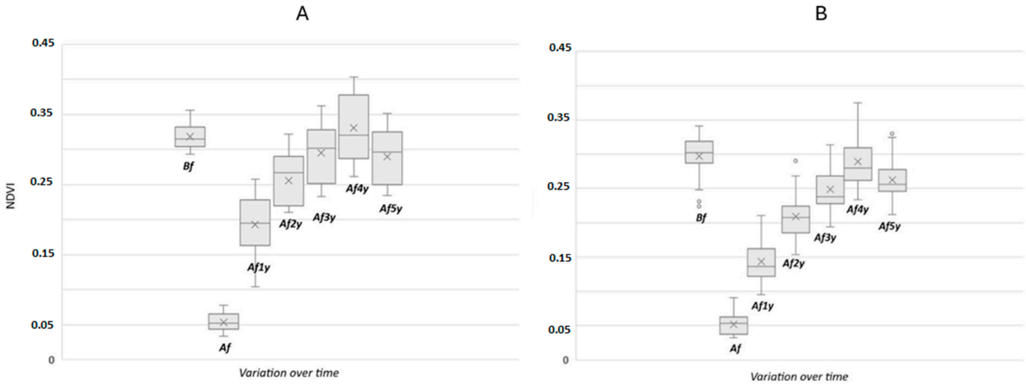

Figure 1. NDVI variation for GG1 (**A**) and GG2 (**B**) (adapt. [4]).

Considering the 11 variables, SMR produced a solution with three models to explain NDVI Af4y. Regarding GG1, the multiple regression produced three models with an R-square of 81.3%, considering the variables mW, S, and BSaf (Table 2).

Table 2. SMR for overall GG1 considering NDVI Af4y.

Model	Variables	Partial R-Square	Model R-Square	Unstandard	Standardized	t	*p*
1	mW	0.584	0.584	0.145	0.546	3.915	<0.001
2	mW	0.195	0.779	0.087	0.753	6.575	<0.001
	S			−0.061	−0.543	−4.867	<0.001
3	mW	0.034	0.813	0.081	0.705	2.705	<0.001
	S			−0.049	−0.439	−3.847	<0.001
	BSaf			−0.041	−0.252	2.321	0.026

Note: The following covariates were considered but not included: L, MaxW, Pa, Rd, A, As, FA, TRI and C. mW is mean width, S is slope and BSaf is burn severity after the fire.

Considering GG2, the multiple regression produced three models with an R-Square of 71.8% considering the variables mW, S and FA (Table 3).

Table 3. SMR for overall GG2 considering NDVI Af4y.

Model	Variables	Partial R-Square	Model R-Square	Unstandard	Standardized	t	*p*
1	mW	0.558	0.558	0.221	0.701	7.347	< 0.01
2	mW	0.117	0.675	0.042	0.685	7.397	< 0.01
	S			0.030	−0.203	−2.189	0.033
3	mW	0.043	0.718	0.400	0.400	3.945	< 0.01
	S			0.313	0.313	2.915	0.005
	FA			0.266	0.266	2.611	0.012

Note: The following covariates were considered but not included: L, MaxW, Pa, Rd, A, As, TRI, C and BSaf. mW is mean width, S is slope and FA is flow accumulation.

4. Discussion

Wildfires have a serious impact on the physical, chemical, and biological properties of soils, which is mainly because the soil is heated and secondarily because of the burning of plants. In the gullies, the NDVI takes 4 years to reach values of vegetation cover close to those recorded before the 2017 fire albeit they are slightly lower (especially in GG2). Other studies of post-fire VR estimated from spectral data in Mediterranean pine forests have recorded similar results. After a disturbance such as a wildfire, herbaceous, perennial, or evergreen plants are the first to become established [2]. This should explain the significant increase in NDVI in the first two years after the fire regardless of BSaf. The increase in NDVI from the third year after the wildfire may be associated with the expansion of Erica and Ulex, species that are particularly resistant to wildfires, with new shoots emerging from the rhizomes shortly afterwards. Overall, after 4 years, the highest VR values occur in the widest gullies (mW), which were distributed over lower altitudes (A) and with higher AF values. The area and greater water availability in these gullies are the main drivers of faster vegetation regrowth. This short-term VR will help to reduce soil erodibility [5] and increase the soil's organic carbon content, thereby improving aggregate stability [6]. Considering VR by gully group, it can be seen that in addition to area, S and BSaf are also important driving forces in GG1, which is made up of the largest gullies in the study area. The results indicate a significant negative relationship between VR and both S and BSaf, indicating that vegetation grows more in areas that are less steep and less affected by fire. In the case of the smallest gully group, GG2, in addition to mW, factors such as S and FA play an important role in VR. This suggests that VR occurs more quickly in gullies on steeper slopes, which favor a greater convergence of water into the gullies. These results once again reinforce the importance of greater water availability in VR.

In our work, although the results indicate NDVI values that are similar after four years to those recorded pre-fire, this does not mean that there have been no qualitative changes in the vegetation and soil.

5. Conclusions

The use of hierarchical clustering (HC) identified two groups of gullies. The first group (GG1) includes gullies with higher values of PA, MaxW, mW and S. The second group (GG2) includes gullies with higher values of L. The vegetation in the gully channel recovered mainly in the two years after the wildfire. In the following years, growth was at a slower rate until it reached similar values in 2021, which was four years after the wildfire that affected the entire study area, eliminating all vegetation. With regard to GG1, multiple regression produced three models with an R-Square of 81.3%, considering the explanatory factors mW, S, and BSaf. For GG2, multiple regression produced three models with an R-square of 71.8%, considering the explanatory variables mw, S, and FA. The results of the study are in line with the evidence that post-fire VR mainly depends on post-fire recovery strategies for vegetation, the remaining soil, and water availability.

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