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Original Research

Evaluation of Greek Post-Fire Erosion Mitigation Policy through Spatial Analysis

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Abstract

In the Mediterranean region severe wildfires occur mainly in summer and they are one of the main drivers of desertification in the region. Moreover, due to the speed and scale of climatic changes, it is likely that wildfires will hit this region more frequently. As a result, every year Mediterranean countries spend millions of euros on post-fire emergency watershed stabilization measures such as check dams in streams and erosion barriers on sensitive slopes. This study implements spatial analysis to evaluate the current Greek post-fire erosion mitigation policy and to support the decision made concerning the application of the most suitable response to post-fire erosion threat by fires. Applied to a case study area on the Kassandra peninsula, our spatial modeling approach of Kassandra post-fire treatment using Geographical Information Systems (GIS) has demonstrated the failure of the present policy and the need to adopt a new policy that will manage the inefficiency of the existing policy to mitigate post-fire erosion risks. Our results highlight the importance of incorporating more sophisticated and spatially detailed modelling approaches in order to achieve a more cost effective spatial targeting of land use policy interventions.

Keywords: policy evaluation, spatial analysis, wildland fires, rehabilitation treatment, GIS

Introduction

Mediterranean forests provide a variety of significant benefits and services to society that are more precious than traditional forest products. Their biological wealth makes their management and preservation a complex work [22]. One of the major threats of Mediterranean forests is wild land fire, which constitutes an intense and consistent problem for that area. During the last 20 years, an increased frequency of wild-land fires has been observed, despite the fact that great sums of public funds have been invested for their control.

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First and foremost, Mediterranean countries should consider the real causes that provoke this out-burst so as to make an effective use of the funds. These causes are related to a variety of socio-economic parameters and changes that take place in Mediterranean countries [24]. The occurrence of wild land fires in the Mediterranean region is a usual phenomenon and it appears that they contribute decisively to the formation of the Mediterranean landscape. However, the enormous rise in frequency of wild land fires during the last decades has resulted in the significant degradation and destruction of vegetation, accelerated soil erosion and provoked the occurrence of destructive floods [12, 24]. Moreover, the Mediterranean areas have been classified as the main cluster threatened by forest fires and droughts in Europe [6].

According to the average burnt area per fire, Greece faces the most severe forest fire problem (31.3 ha) compared to other affected EU countries like Spain (11.9 ha), Italy (11.6 ha) and Portugal (6.2 ha) [14]. The most immediate consequence of fire is the potential soil erosion and rapid response (erosion potential assessment and rehabilitation treatment) is necessary to mitigate this phenomenon. In Greece, the post-fire conservation practice is regulated by the forest service according to the directive 86783/7-12-92 of the Reforestation and Mountainous Hydrology Direction [19].

This paper aims to evaluate the efficiency of the current post-fire erosion mitigation policy (building of check dams and long erosion barriers) compared to the use of computational spatial models that allow a more accurate targeting of these interventions and reduce the restoration cost significantly.

Computational spatial models are commonly used by scientist all over the world in order to understand nature, acquire knowledge of spatial processes, predict future scenarios and support spatial decision making and environmental education [5]. These models are rarely used to evaluate a forest management policy [2, 27], but even then, they are oriented to multifunctional land use and water quality and are not concerned with the post-fire erosion mitigation policy that this paper discusses.

Geographic Information Systems (GIS) are a technology designed to store, manipulate and display spatial and non-spatial data [1]. Furthermore, they are able to contribute decisive changes and ameliorate a bad policy through their visualization and quantification capabilities.

Today, many models have been developed so as to describe and predict soil erosion and sediment transport [29]. In this paper, the integration of GIS and Gavrilovic model [10] has been applied for the classification of the post-fire erosion severity. The main reason that led to the selection of this erosion model instead of others is because it has been widely used in the Mediterranean region [11, 16, 28] and especially in Greece [4, 23], where it is well known by the Greek forest service.

The rest of the paper includes a review of the current Greek post-fire erosion mitigation policy, which is then followed by analysis of the proposed methodology. The comparison between the current policy practice and the sophisticated spatial modeling approach is elaborated in a case study of a recent wild-land fire in Northern Greece. Finally, the results of the analysis are demonstrated and discussed in separate sections, while the emerged conclusions are presented at the end.

The Current Policy Practice

On 7/12/1992, after the destructive fire of Parnassus (Athens Prefecture), the Reforestation and Mountainous Hydrology Division of the Greek Forest Service immediately prepared and initiated the directive 86783/7-12-1992. This directive concerns the technical specifications and guidelines for the application of post-fire conservation practice. Moreover, it divides the post-fire stabilization measures into two major categories. The first category concerns the erosion mitigation works that will be implemented at hillslopes of the watersheds, while the second one regards the works that will be constructed at the river channel. The objectives of the stabilization measures are to decrease erosion potential, maintain the soil on the slopes and trap the sediments in the tributary channels [8].

Fig. 1. LEBs constructed at the study area.

- Works at hillslopes.

According to the directive, the identification of the areas where post-fire erosion mitigation treatments are required is based on the slope magnitude. As a result, a series of log erosion barriers (LEBs) will be constructed on the hillslopes. LEBs aim to maintain the soil on the slope and hinder runoff by cutting and laying fire-killed trees on the ground parallel to slope contours (Fig. 1).

- On slopes between 0-30% LEBs should be constructed with a 20 m interval, 0.20 cm high and a target density of 370 m of LEBs per hectare.
- On slopes between 30-50% LEBs should be constructed with a 10 m interval, 0.20 cm high and a target density of 450 m of LEBs per hectare.
- On slopes greater than 50% no rehabilitation technique will be applied.
- In areas with scant vegetation, the necessary erosion barriers should be constructed by wooden boards according to the above-mentioned specification concerning the slope inclination and the land should be reforested.
- In agricultural land, no erosion control measures should be applied.

- Works at the river channel.

According to the above-mentioned directive a series of wooden check dams with 1m heights should be constructed at river channels of all mainstreams and tributaries except those that are characterized as order I (principal order) following the Horton's classification [13] of stream ordering. The appropriate locations for the establishment of the check dams will be chosen by the forest service staff, which will take into account several subjective field factors.

Such factors are stream morphology, the topography, the visual examination of the burnt area and the accessibility to transport building materials and staff.

Methodology

This section demonstrates a detailed methodology that elaborates sophisticated spatial models so as to identify the locations where post-fire erosion mitigation policy interventions (building of check dams and LEBs) are really required. The presented methodology follows the same segregation of the works between hillslopes and river channels as the current policy practice does in order to facilitate our quantitative comparison between the two approaches.

- Works at hillslopes.

The soil erosion model of Gavrilovic will be employed to map the post-fire erosion risk according to its intensity in order to identify the locations that require the installation of conservation practices. In the Gavrilovic model, mean annual soil loss is expressed by the following formulas:

$$W = T \cdot h \cdot \pi \cdot \sqrt{z^3} \cdot F \qquad (1)$$

$$T = \sqrt{\frac{t^0}{10} + 0.1} \qquad (2)$$

...where: W is annual average erosion (m^3/year), T is a coefficient of temperature, t is the annual average temperature (ºC), h is the mean annual rainfall (mm), F is the area of the watershed (km^2), and z is the erosion coefficient given by equation (3):

$$z = x \cdot y \cdot (\varphi + \sqrt{J}) \qquad (3)$$

...and x, y, φ are the coefficients dependent on vegetation, geology and the basin's erosive degree, respectively, and J is the average slope steepness of the watershed (%). The thematic maps for each coefficient (Fig. 2) of the Gavrilovic formula are prepared using the available datasets of the study area and then the model is implemented in the graphic environment of ArcGIS [7] by using simple GIS procedures [26].

The results of this procedure are the calculated value of annual average erosion for the study area and a thematic map in raster form for erosion coefficient z. Afterwards, this map is classified in categories [25] so as to represent the desirable erosion intensity map. Effective and appropriate decisions [17] can be made according to erosion risk classes in order to select the most suitable sites and install erosion control measures. The recommended measures according to the erosion risk classes are the following:

- Very Slight (z <0.19) or Slight (0.19< z <0.40) erosion: the application of any conservation practice is not necessary.
- Moderate erosion (0.41< z <0.70): LEBs should be constructed having a 60 m interval between them, a height of 0.20 cm and a target density of 180m of LEBs per hectare.
- Heavy erosion (0.71< z <1): LEBs should be constructed having a 20 m interval between them, a height of 0.20 cm and a target density of 370 m of LEBs per hectare.
- Severe erosion (z >1): LEBs should be constructed having a 10m interval between them, a height of 0.20 cm and a target density of 450 m of LEBs per hectare.
- In agricultural lands no erosion control measures should be applied.

- Works at the river channel.

The identification of the areas requiring the establishment of check dams is based on a series of criteria that can be easily modeled in a GIS environment and they are specified [21] as follows:

- channel gradients less than 56% [29],
- river channels close to moderate, heavy or severe erosion areas (proposed 150 m),
- river channels long enough to accommodate a series of check dams (proposed 100 m), and

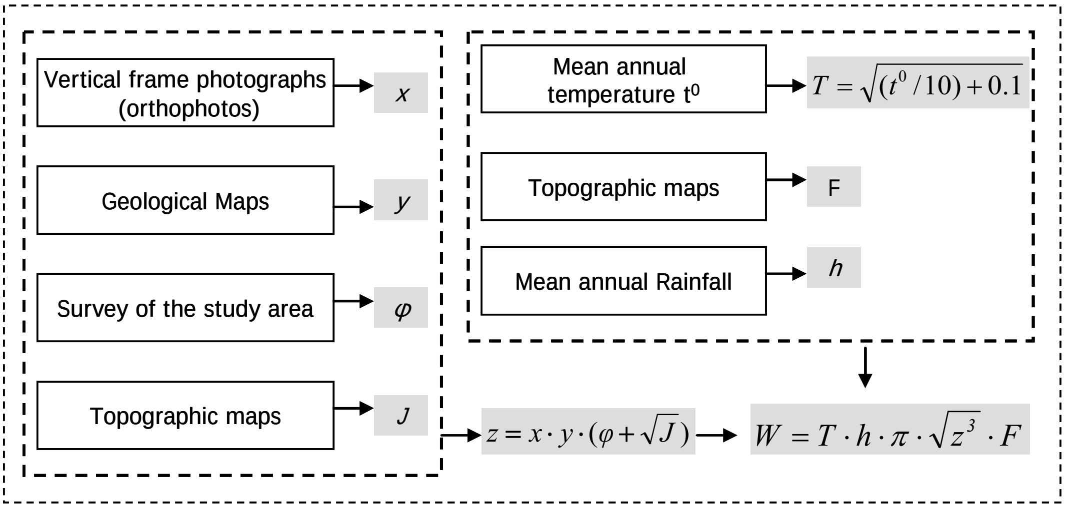

Fig. 2. Gavrilovic erosion potential methods workflow.

Table 1. Cost of rehabilitation treatments according to different modeling approaches.

Modeling approach	Area without conservation practices (ha)	LEBs 10 m, 450 m/ha (km)	LEBs 20 m, 370 m/ha (km)	LEBs 60 m, 170 m/ha (km)	Total length of LEBs (km)	Total Cost of Rehabilitation treatments (€)
Directive	2,351	193	1,796	-	1,989	6,970,000
Gavrilovic	3,563	426	357	281	1,064	3,550,000

- the spacing between the check dams that should be determined according to the following formula:

$$\text{Minimum spacing} = 2l = \frac{H}{\tan\theta - \tan\eta} \quad (4)$$

...where: H = height of dam (proposed 1m), θ = original channel gradient, η = backfilled channel gradient, l = length of potential downhill scour.

Case Study and Datasets

This study was conducted at the southern part of the Kassandra Peninsula in N. Greece (Fig. 3). On August 21st 2006, the outbreak of a large wildland fire completely burned 1/5 of the Peninsula (76.61 km^2) and destroyed a 30-year-old forest of *Pinus halepensis Mill.* (Aleppo Pine). Topographically, the study area is characterized by a hilly relief with moderate slopes and an average elevation height of 146 m. The prevailing climatic conditions are characterized by hot dry summers and mild rainy winters and thus can be considered typical of the Mediterranean climate. The major crops grown in the area are wheat and olives.

Topographical data (contour map and drainage network) have been produced by the digitization of 1:50,000 scaled topographical maps provided by the Hellenic Military Army Service. Precipitation and temperature data covering a period of 33 years were obtained from the local State Meteorological station. Vertical frame photographs (orthophotos) were captured immediately after the fire by the Greek Forest Service and they were used to extract the post-fire land-use map of the study area. The soil map (1:50,000) was obtained by the National Agricultural Research Foundation (NAGREF).

Results

The accomplishment of the necessary studies concerning the application of the post-fire conservation treatment in the burned area was assigned to private forest companies by the Greek Forest Service.

- Work on hillslopes.

Slope classes were derived by the digital elevation model (DTM). Then, the agricultural areas were excluded from the slope map based on the information of vertical frame photographs, and thus the appropriate conservation

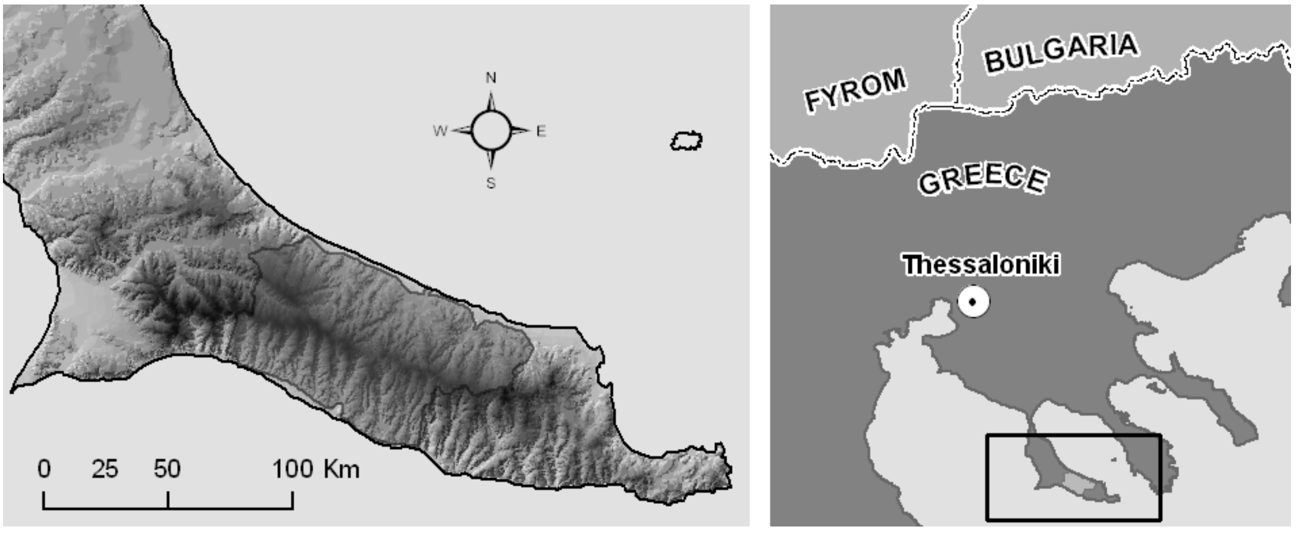

Fig. 3. Location map of the study area.

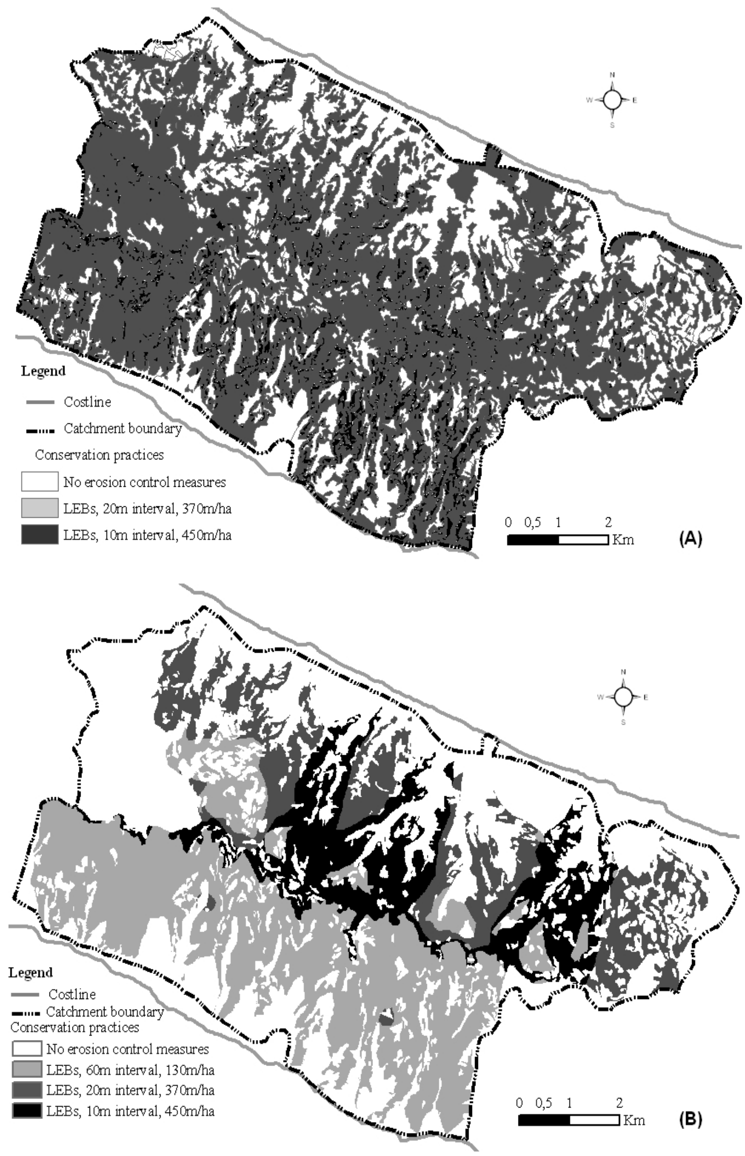

Fig. 4. Post-fire conservation practice according to (a) directive No. 86783 and (b) the Gavrilovic formula.

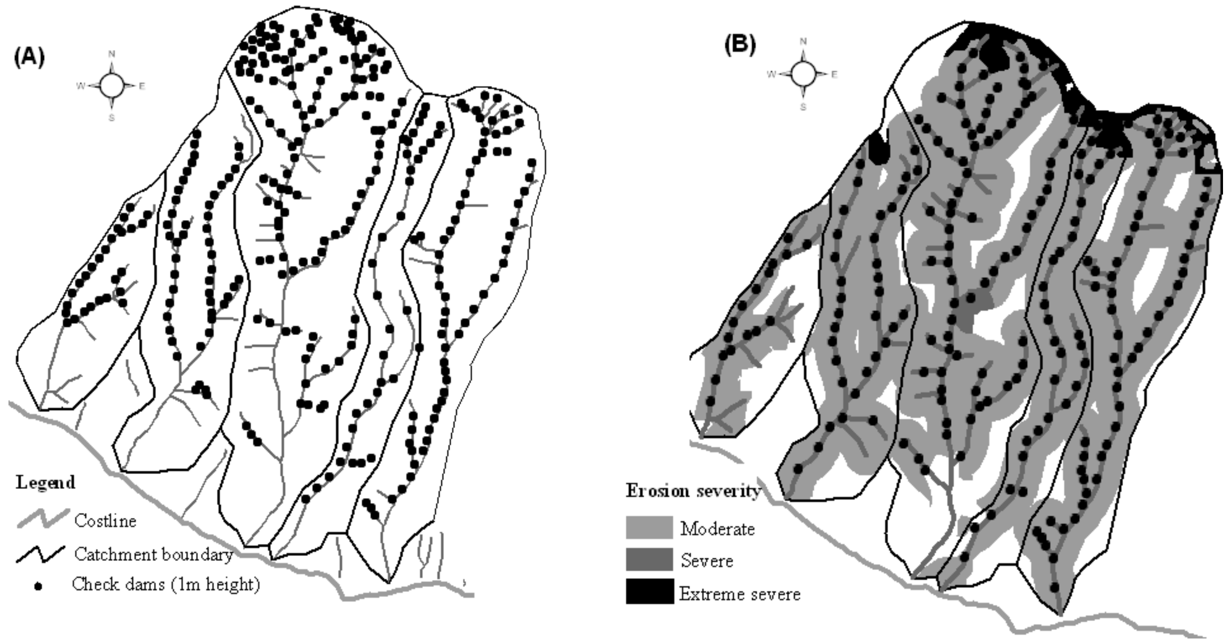

Fig. 5. Check dam locations according to (a) the aspect of forest service staff and (b) spatial modeling.

practices were applied according to the directive specifications (Fig. 4a). Afterwards, the annual erosion value of the burned area (253,580 m^3/year) and the spatial distribution of erosion coefficient were easily [4] computed by incorporating the Gavrilovic formula into ArcGIS software. As a result of the above, the appropriate erosion mitigation measures were applied according to the erosion risk classes derived from the reclassification of the erosion coefficient (Fig. 4b).

Furthermore, the length of the constructed LEBs according to the target density and the interspacing between LEBs for each slope class in the study area, was computed using the map of Fig. 4a. These results were validated based on the payments that the forest service has realized (Table 1). Additionally, the quantities of LEBs and the cost of the conservation practice, which would emerge in case the Gavrilovic formula was employed to identify the locations requiring the application of rehabilitation treatments, were calculated by using the map of Fig. 4b (Table 1).

Following the Gavrilovic modeling approach instead of the current policy practice, the implemented conservation practices could have been avoided for at least 1,212 ha of land, which corresponds to 53% of the land fitted out with LEBs under the current policy.

- Works at the river channel

The identification of the stream channel spots where check dams should be established under the current policy practice is based on forest service staff judgments and not on scientific criteria. The selected spots, which the forest service staff pointed out to us for the construction of the check dams, were mapped using an HTC P-3600. In Fig. 5a, a small part of these locations where 316 check dams are going to be built is displayed for better visualization. According to data provided by the forest service, 2,186 check dams are going to be constructed in the burned area at a total cost of 1,200,000€.

In the spatial modeling approach, the calculation of the slopes of all mainstream and tributaries is based on the digital elevation model [18] and the streams with channel gradients less than 56% and a minimum length of 100 m are extracted by using a simple query on stream database. Then, buffer zones of 150 m length are created using the erosion intensity map that derived from the classification of the Gavrilovic erosion coefficient in order to identify stream proximity to high, moderate or severe erosion areas. Finally, the locations for the construction of the necessary check dams are selected using the above-mentioned thematic layers and equation 4 (Fig, 5b).

By applying the spatial modeling approach, not only the number of the necessary check dams would be limited to 1,520 but also the total cost will be reduced to 835,000€ and, thus, there would be 31% saving of the public funds.

Discussion of Results

The two approaches differ in methods used to identify areas requiring LEBs. On the one hand, the directive is based only on slope factor, while on the other hand, the Gavrilovic model quantifies four factors for the same assessment. Additionally, it calculates the annual erosion value. Furthermore, when planning of stabilization tactics is based only on slope factor, it is possible to construct unnecessary LEBs that will impede regeneration and compact soils. A study conducted in Greece showed that LEBs were effective in trapping sediments on steep slopes (35-55%) but not on low (10-20%) or intermediate (20-35%) slopes [9]. In our case, the constructed LEBs at low and intermediate slopes consist of the 90% of the total number of LEBs.

The unnecessary engineering of LEBs on gentle slopes, which are not effective at trapping sediment, can be replaced by the installation of mulch that could reduce post-wildfire erosion rates by 50-94% [20]. Besides, this method is considered to be highly effective with a low risk of failure and low or moderate cost [15]. Furthermore, the combination of seeding and mulching has been found to reduce runoff and enhance infiltration, as do LEBs [3].

The implementation of the Gavrilovic model in the spatial planning of the LEBs takes into account three more factors compared to what the current practice does. Moreover, it focuses the interventions on sites that most need it and cuts the intervention cost in half.

As far as it concerns the establishment of the check dams on the river channels, our approach realizes this by using a series of scientific criteria that are incorporated in a GIS platform and it is not based on the arbitrary forest service staff practice (as in the current policy). The application of this method will lead to an accurate targeting of the positions that check dams should be constructed and a considerable saving on public funds would be achieved.

A more interdisciplinary approach would also require a series of measures such as:

a. Evaluation of the burned area using GIS and remote sensing (RS) tools and prescription of the suitable treatments.
b. Application of more practices on works at hillslopes (seeding, mulching, silt fences, fiber rolls, soil scarification, etc.) and on works at stream channel (grade stabilizers, stream channel armoring, channel deflectors, debris basins and others) so as to protect soil effectively.
c. A mechanism of continuous monitoring of implementation and effectiveness of conservation practices should be established so as to be able to intervene immediately in cases of failures.

Conclusions

The outbreak of a wildland fire in a region has very significant socio-economic, environmental, and aesthetic impacts. In particular, the accelerating soil erosion and the occurrence of floods are the most severe. Thus, in Greece – a country that is frequently affected by wildland fires during summer – it is necessary to establish a post-fire conservation plan and to construct the necessary works that will contribute to the more rapid ecological and hydrological rehabilitation of the burned area.

The current Greek policy for the application of post-fire conservation practice is old and ineffective and it mainly uses obsolete methods on the post-fire mapping of the erosion risk and planning of the stabilization tactics. Moreover, it does not take into account the substantial evolution of GIS and RS that could incorporate erosion models and offer us a rapid and inexpensive tool for locating the appropriate sites to apply conservation practices.

The drawbacks and the inadequacies of the current policy and the need for its reformation are revealed and visualized by means of spatial modeling. As a consequence of the above, unnecessary works were constructed on both hillslopes and river channels and they resulted in wasting funds, disrupting lands and obstructing regeneration. The presented methodology can be used to achieve a more precise localization of the post-fire planning of policy interventions, and it can become a valuable tool for environmental/land management researchers and practitioners.

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