

Assessment of Post Fire Soil Erosion with ESA Sentinel-2 Data and RUSLE Method in Apulia Region (Southern Italy)

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Abstract. Fires are one of the main causes of environmental degradation as they have an impact on flora and fauna, can also strongly influence ecological and geomorphological processes and permanently compromise the functionality of the ecosystems and soils on which they impact. The severity of the fire event influences the superficial hydrological response and the consequent loss of soil. Precipitation on the basins recently affected by fires produces an increase in the outflow which commonly transports and deposits large volumes of sediment, both inside and downstream of the burned area. In the years following the fire, the loss of soil is very high and the degradation processes of the soils are much greater than in the pre-event. The aim of this study is to evaluate the potential annual loss due to post-fire erosion using remote sensing techniques, RUSLE (Revised Universal Soil Loss Equation) methodology and GIS tecniques in nine different event occurred in 2019 in the northern part of the Apulia Region (Southern Italy). Geographic Information System techniques and remote sensing data have been adopted to study the post-fire soil erosion risk. Satellite images are the most appropriate for environmental monitoring as they provide high resolution multispectral optical images, infact are able to monitor the development of vegetation by assessing the water content an changes in chlorophyll levels. This study can be useful to spatial planning authorities as a tool for assessing and monitoring eroded soil in areas affected by fires, representing a useful tool for land management.

Keywords: Soil erosion · RUSLE method · Geographic Information System

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1 Introduction

Since at least the second half of the 19th century, soil erosion has been recognized as one of the most significant environmental problems worldwide [1], particularly in areas having seasonally contrasted climate and a long history of human pressure.

Soil loss leads to a decrease of the water holding capacity, nutrient availability and organic matter content and to a reduction in the overall fertility of arable lands [5].

Fire represents one of the most important causes of degradation of Mediterranean area bringing important transformations at different temporal and spatial scales which affect ecosystems, landscapes and environments [9, 19].

Ongoing global climate changes are increasing the risk of fires, this risk is an effect of climate change but at the same time it is the cause. Fires cause a loss of the carbon contained in the vegetation and soils, against which it is important to evaluate the impact of the fire. Among the long-term effects of fires, which can also be found in the years following the event, there are profound alterations in the characteristics and structure of the soils.

Fire severity influences the hydrological response and soil loss [21–23]. In fact, a high severity of burned soil is generally associated with an increase in the water repellency of the soil [2, 8] and a decrease in infiltration [23]. Precipitation on recently burned areas produces a greater surface runoff which commonly transports and deposits large volumes of sediment, both inside and downstream of the burned area [2, 15, 20, 23, 24].

In the Mediterranean area, soil composition and structure have been generally strongly shaped by fires, which they tend to operate as an erosive force. The aim of this work is to understand the erosion of burned soil in Apulia Region (Southern Italy) in pre and post-fire conditions in nine different fire event occurred in 2019 in the northern part of the Region (Gargano Area). The analysis has been carried out by using satellite images derived from Sentinel 2A and Sentinel 2B satellite and geographical information systems (GIS). RUSLE (Revised Universal Soil Loss Equation) methodology has been applied to evaluate the pre-fire and post-fire soil erosion. The entire procedure was carried out with the open source QGIS software and related plugins.

This study confirm that Remote Sensing and GIS are effective tools in generating spatial and quantitative information on soil erosion studies and risk assessment mapping.

2 Material and Method

Soil erosion is one of most serious environmental problems in the Mediterranean area and is also the most intensively studied subjects in this European Region. This process is extremely variable due to the interaction with different factors such as geomorphological and geological features, type of climate and exogenous agents, fire occurrence, land use and management and type and density of vegetation cover. It includes the erosion of the washing of the slabs, the breakthrough, the trampling, the surface landslide and the development of large and active badlands both in the sub-humid and semi-arid areas [10].

Fires are a serious short-term risk of soil erosion, but can also result in land degradation and sometimes desertification over the long-term.

2.1 Study Area

The study areas are located in the northern part of Apulia Region, in Foggia Province (Fig. 1).

Foggia is one of the largest provinces in Italy, about 7000 km^2 and its dived in three areas characterized by different geomorphological and geological features: Gargano, Tavoliere of Apulia Region and Monti Dauni Area (Fig. 2).



Fig. 1. Geographical localization of study area in Apulia Region.

This area is characterized by a typically Mediterranean climate with mild and slightly rainy winters alternating with hot and dry summers. However there is a great climatic variability between the two areas, in fact the Gargano is characterized by a high rainfall while the Tavoliere plain has some of the highest temperatures in Italy.

This area lies in the northern sector of the Bradanic foredeep bounded to the west by the external sector of the southern Apennines chain ('Subappennino Dauno') and to the east by the Gargano Promontory (northern part of the Apulian foreland) (see Fig. 2) [4, 13, 21, 26].

The Tavoliere di Puglia is a large alluvial plain located in southern Italy (Foggia Province, Apulia Region) characterized by a series of low elevations, in fact large weakly inclined surfaces are well observable. From a geological perspective view, it represents the northern part of the Bradanic trough located between the southern Apennine Chain and the Apulian Foreland [9, 11, 12, 18, 19, 24, 26].

The outcrops are characterized by quaternary deposits mainly in facies alluvial and lake [10, 12, 13, 18].

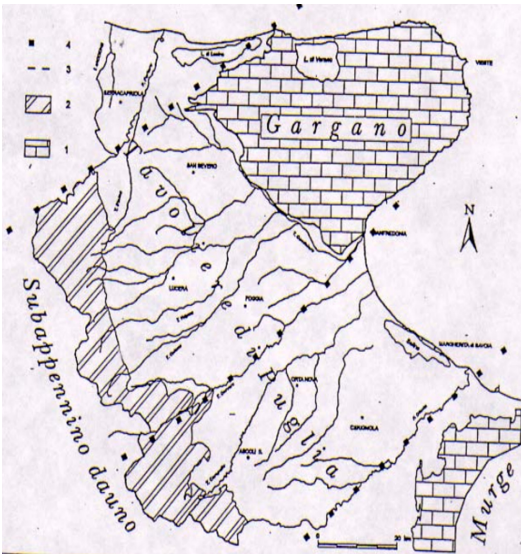

Fig. 2. Schematic geologic map of the chain-foredeep-foreland system of the southern Apennines and location of the Tavoliere di Puglia plain and Gargano horst: note that it represents the northern sector of the Bradanic trough. Rectangle 1 represents the carbonate units of the Apulian foreland. White part represents the terraced marine deposits of the Tavoliere and finally rectangle 2 represents the deposits belonging to the Appennine Chain of the Dauno Apennines [2, 4, 21, 26].

The Gargano Promontory is a carbonate horst and Monte Calvo (1056 m. asl) represents the highest part of the whole Gargano Area. Overall from geomorphological point of view, the entire territory is characterized by a succession of escarpments, isolated reliefs, depressions and small plains. Surface erosion forms are evident due to the action of morpho-climatic processes [4, 12].

To assess pre- and post-fire soil erosion we selected nine fire events that occurred in the 2019 into the study area. One of them (Lucera fire) is located within the morpho-geological unit of the Bradanic Trough. Geology of the territory is mainly constituited by Quaternary deposits like such as deposits of silty clays, sands and pebbles interspersed with clay sands [13].

The other eight fires are located in the municipalities of Ischitella, San Maro in Lamis, Carpino and Cagnano Varano, in the Gargano area. Deposits presents in this area are mainly costituited by different type of calcarenite and limestones [4, 23].

2.2 Data and Methodology

Multi-spectral and multi-temporal satellite data with medium and high spatial resolution are very appropriate to evaluate the burned soil erosion process and fire severity. In present work images of ESA (European Space Agency) Sentinel-2A and 2B satellite have been used (source: https://scihub.copernicus.eu/dhus/#/home). Sentinel 2 satellite

acquired images with 13 bands (Table 1), from infrared to thermal infrared wavelengths, characterized by a mid-high spatial and temporal resolution [32, 33].

Specifically, for the events considered, two Sentinel 2 L2A images were already downloaded correctly atmospheric, pre and post fire, in which all the bands were resampled with a 10 m spatial resolution. Fire severity was stimulated using sentinel bands 2 most sensitive to changes in the post-fire reflectance value [7, 19, 27–29] (Fig. 3).

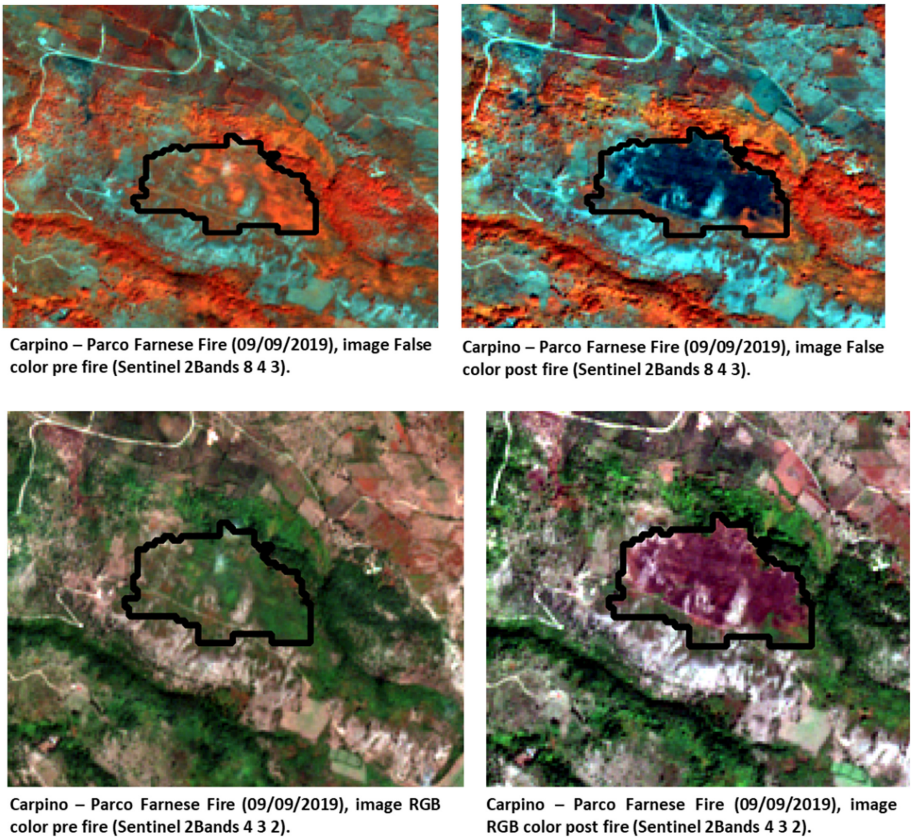

Fig. 3. Carpino – Parco Farnese fire. Sentinel 2 images before and after the fire (true colors, false colors) in black the perimeter of the polygon of the burned area.

In particular, the reflectance in the medium infrared band (band 12 - SWIR), sensitive to the knowledge content of the soil and growth, increased after the fire, while in the near infrared region (band 8A - NIR) occurs a decline in reflectance due to the demand for the chlorophyll content of the phytomass.

The Normalized Burn Ratio (NBR) index was created considering these characteristics [14, 15] and is widely used to evaluate the severity of fire [17].

Table 1. Sentinel 2A overview.

Satellite	Bands	Range wavelength (nm)	Resolution (m)
Sentinel 2	Band 1 –Coastal aereosol	443	60
	Band 2 – Blue	490	10
	Band 3 – Green	560	10
	Band 4 – Red	665	10
	Band 5 – Vegetation Red Edge	705	20
	Band 6 – Vegetation Red Edge	740	20
	Band 7 – Vegetation Red Edge	783	20
	Band 8 – NIR	842	10
	Band 8a –Vegetation Red Edge	865	20
	Band 9 – Water vapour	945	60
	Band 10 – SWIR – Cirrus	1375.3	60
	Band 11 – SWIR	1610.0	20
	Band 12 – SWIR	2190.0	20

In reference to Sentinel-2 images, the NBR is calculated as reported in Eq. 1:

$$\mathrm{NBR} = (\mathrm{Band\,8A} - \mathrm{Band\,12})/(\mathrm{Band\,8A} + \mathrm{Band\,12}) \quad (1)$$

In addition, in order to evaluate the difference between pre- and post-fire NBR, the dNBR index was calculated:

$$\mathrm{dNBR} = \mathrm{NBR\,pre\,fire} - \mathrm{NBR\,post\,fire} \quad (2)$$

The dNBR index, being linked to the variation of the NBR values calculated before and after the event, provides a measure of the effects of the fire and can therefore be used to characterize the degree of severity of the fire (Fig. 4).

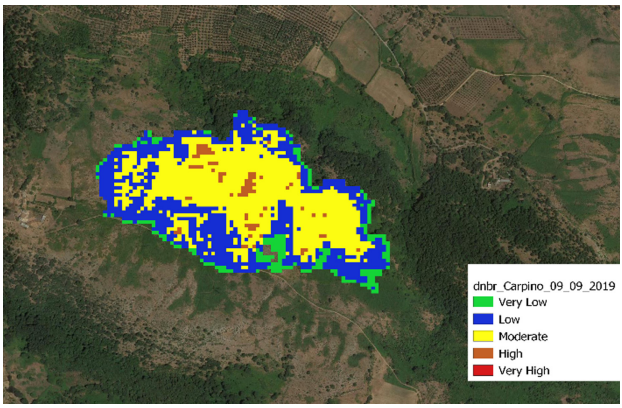

Fig. 4. dNBR Carpino – Parco Farnese fire (09/09/2019).

The QGIS software (www.qgis.org) is the tool used for all data processing and spatial analyzes. In particular, for the management of satellite images, the reference is the QGIS Semi-Automatic Classification Plugin (SCP) plugin. It allows you to download satellite images and to do their pre and post processing.

2.3 RUSLE Methodology

Several soil erosion models exist with varying degrees ofcomplexity. One of the most widely applied empirical models forassessing the sheet and rill erosion is the Universal Soil Loss Equation (USLE), developed by Wischmeier and Smith in 1965 [31, 38]. Agriculture Handbook 703 [30] is a guide to conservation planning with the RUSLE. With its revised (RUSLE) and modified (MUSLE) versions [35, 37, 38].

Pre- and post-fire soil loss have been calculated using the RUSLE (Revised Universal Soil Loss Equation) model [8, 20, 22, 23], developed from the previous USLE model [30] by resampling all parameters necessary for the spatial resolution of Sentinel 2A (10 m). The estimate of the annual loss of soil according to the RUSLE model (Eq. 3) is a function of five variables relating to the regime of rainfall, soil characteristics, topography, coverage and management of crops and crop conservation practices, according to the following formula:

$$A = R \times K \times LS \times C \times P \tag{3}$$

Where:

A = annual soil loss (Mg · ha −1 · year −1);
R = precipitation erosion factor (MJ · mm · ha −1 · h −1 · year −1);
K = soil erodibility factor (Mg · h · MJ −1 · mm −1);
LS = slope length factor and slope steepness (dimensionless);
C = crop and cover management factor (dimensionless);
P = cultivation or anti-erosion (dimensionless) practice factor.

The erosion factor of the outflow of rainfall R (MJ · mm · ha−1 · h−1 · year−1), constitutes a measure of the rain energy considered as the main erosive agent [25]. It is calculated on the basis of the average monthly cumulated rainfall and was determined using the following formula [35]

$$R = (1163,45 + 4,9 \times H - 35,2 \times NRE - 0.58 \times q) \tag{4}$$

where H is mean value of annual precipitation, q is the site elevation using 5mt DTM and NRE is the mean value of rainy events per year. K factor is obtained from the "Soil Erodibility in Europe High Resolution Dataset" provided by the JRC's European Soil Data Centre (ESDAC) [30]. LS topographic factor was calculated with the support of the QGIS software starting from the DTM with a grid size of 5 mt. For the calculation of the LS factor at a point r located along a hilly slope, the following equation was used [23].

$$\mathrm{LS(r)} = (\mu + 1)[a(r)/a0]\mu \times [\sin b(r)/b0]^{\mathrm{n}} \quad (5)$$

C factor reflects the effects of surface coverage and roofing management on soil erosion [16], where C is the cover management factor and a = 1.18.

$$\mathrm{C} = -\mathrm{a} \times \mathrm{SAVI} + 1 \quad (6)$$

For both the pre-fire and post-fire scenarios, the estimate of the factor C was carried out on the basis of the calculation of vegetation indices derived from satellite. In particular, the SAVI (Soil-Adjusted Vegetation Index) was used.

$$\mathrm{SAVI} = [(\mathrm{N\,IR} - \mathrm{RED}) \times (1 + \mathrm{L})]/(\mathrm{N\,IR} + \mathrm{RED} + \mathrm{L}) \quad (7)$$

where L is a correction factor and has been assumed equal to 0.5 while NIR and RED are the reflectance values in the near infrared and red bands. SAVI is calculated using the best Sentinel 2 images acquired pre and post-fire as close as possible, temporally, to the date of the fire.

The cultivation or anti-erosion practice factor (P) is an expression of the effects of agricultural management practices aimed at reducing water runoff and consequently soil loss [18]. A is the forecast of soil lost one year after the fire.

The assessment of soil erosion before and after the fire was divided into the following three phases: (1) collection of geospatial data relating to the areas covered by the fire; (2) development of RUSLE spatial factors for pre- and post-fire conditions; (3) estimate of soil loss with RUSLE for pre and post fire scenarios (QGIS Raster Calculator) considering the variations recorded by the factors K, LS and C, influenced by the fires [19, 24, 29].

3 Result and Discussion

Applying methodology described allowed us to map fire severity for our nine study sites, which were subsequently used as input for the RUSLE model parameters estimation.

Figure 5 shows the calculation of the pre-fire RUSLE index (image on the left) and of the post-fire (image on the right) in Lucera fire. It can be seen that the second image has much larger areas (red), which indicate an increase in soil loss on areas that previously showed a low erosion index.

The pre and post-fire RUSLE maps are compared for each study area, in Fig. 6 shows some example of the nine areas analyzed.

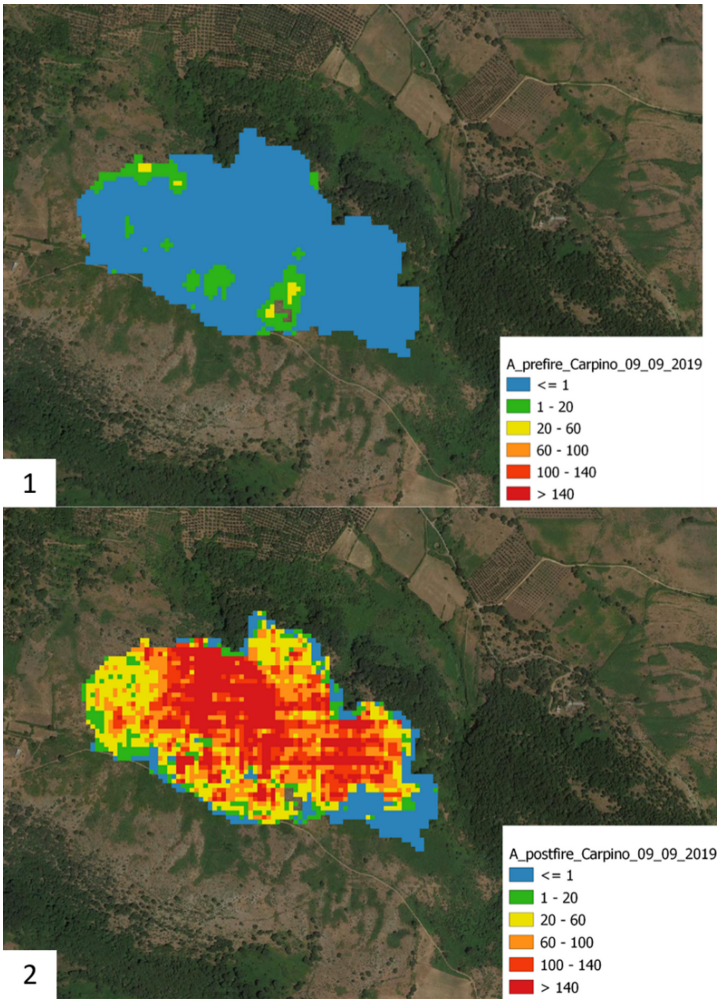

Fig. 5. Fire Lucera: RUSLE A pre and post fire factor. Annual post-fire soil erosion forecast. (Color figure online)

It is immediately evident that wildfire always increases the amount of soil loss, but there are also differences among the sites.

Thus, although the fire, according to the model, determines as expected, in all the analyzed cases, an increase in the potential soil loss, this increase shows different trends in the various sites. In relation to the high geological, geomorphological and vegetational variability, nine study sites were compared.

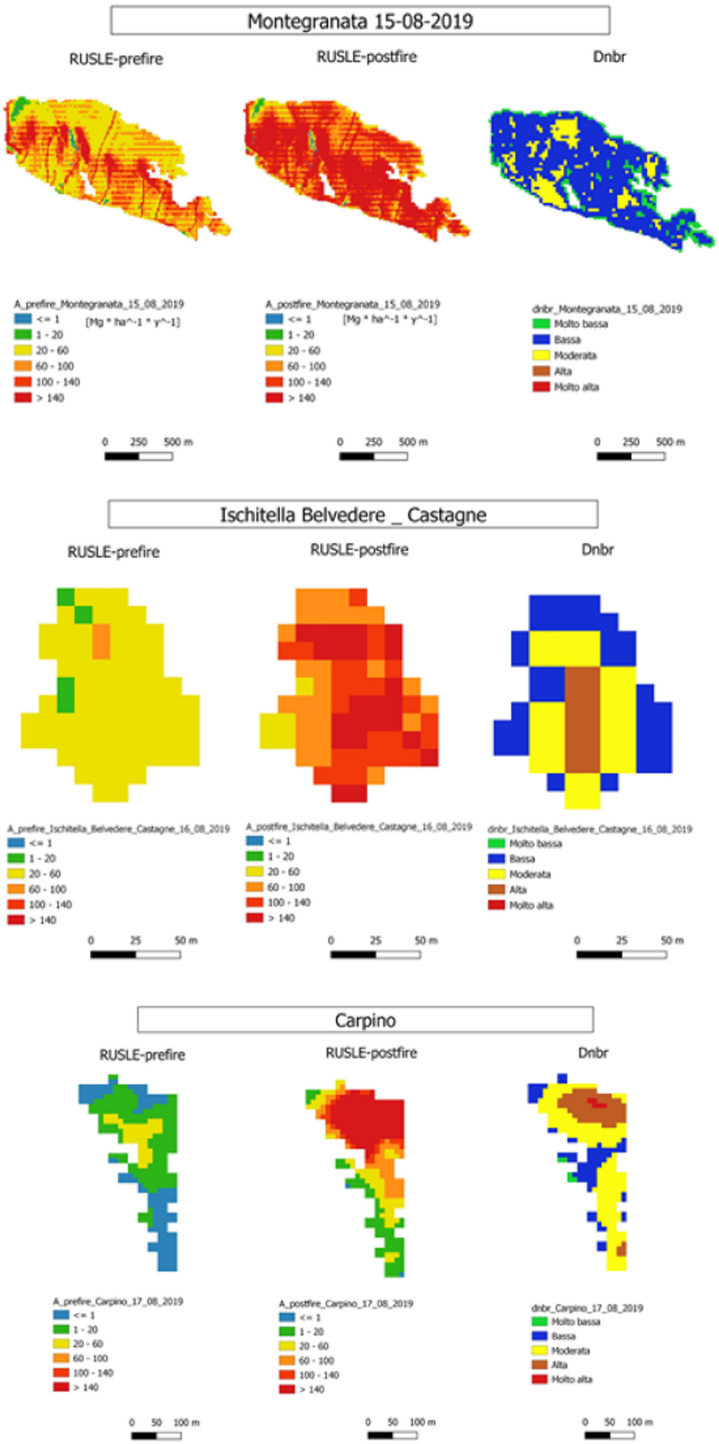

Fig. 6. Pre and post fire RUSLE and dNBR index: example of some analyzed areas.

Fire severity (estimated through the dNBR and SAVI satellite-derived indices) influences some RUSLE parameters. In the specific case, according to previous studies, the K and LS factors of RUSLE were modified using dNBR index, while the C factor was calculated as a function of the SAVI index.

4 Conclusion

Soil erosion is a serious problem in the Mediterranean area and is caused or aggravated by human activities, such as inadequate agricultural practices, industrial activities, fires or it urban and industrial development.

The result is less soil fertility and disruption of nutrient, this has direct repercussions on quality of ecosystem, biodiversity and climate change (European Commission, 2006).

This work provides a contribution to the study of the phenomenon of soil erosion caused by fires in the northern part of the Puglia Region, affected each year by incendiary phenomena.

The sites analyzed generally present themselves as areas very subject to erosive phenomena both for their geological and climatic characteristics, and for their high susceptibility to fire. In relation to the high to the geological, geomorphological and vegetational variability, nine study sites were compared.

Many authors have also investigated the relationships between fire severity and soil loss. In conclusion, it can be said that soil erosion risk maps have been created from the combination of many parameters interacting each others in a complex way generating the final quantitative RUSLE values.

The final results confirm that the loss of soil undergoes a significant increase following the fire, but also show that the intensity of this impact is different in relation to the specific properties of the nine site (from a geological, geomorphological and vegetational point of view).

This paper proved that the integration of soil erosion models with GIS and remote sensing is a simple and effective tool for mapping and quantifying areas and rates of soil erosion for the development of better soil conservation plans.

This study can be useful to spatial planning authorities as a tool for assessing and monitoring eroded soil in areas affected by fires, representing a useful tool for land management [18, 27, 28]. Future research will be aimed at validating the outputs of RUSLE and deepening the use of the parameters of the model and will explore the link between soil erosion monitoring and urban planning.

References

1. Bakker, M.M., Govers, G., Jones, R.A., Rounsevell, M.D.: The effect of soil erosion on Europe's crop yields. Ecosystems **10**(7), 1209–1219 (2007)
2. Caldara, M., Pennetta, L.: Lineamenti geografici della Provincia di Foggia. Bonifica **8**(3), 13–24 (1993)

3. Cannon, S.H., Gartner, J.E., Wilson, R.C., Bowers, J.C., Laber, J.L.: Storm rainfall conditions for floods and debris flows from recently burned areas in southwestern Colorado and southern California. Geomorphology **96**(3–4), 250–269 (2008)
4. Cremonini, G., Elmi, C., Selli, R.: Note illustrative della Carta geologica d'Italia alla scala 1: 100 000, foglio 156 S. Marco in Lamis (1971)
5. Csáfordi, P., Pődör, A., Bug, J., Gribovsyki, Z.: Soil erosion analysis in a small forested catchment supported by ArcGIS Model Builder. Acta Silvatica et Lignaria Hungarica **8**(1), 39–56 (2012)
6. Doerr, S.H., Woods, S.W., Martin, D.A., Casimiro, M.: 'Natural background' soil water repellency in conifer forests of the north-western USA: its prediction and relationship to wildfire occurrence. J. Hydrol. **371**(1–4), 12–21 (2009)
7. Elfadaly, A., Attia, W., Qelichi, M.M., Murgante, B., Lasaponara, R.: Management of cultural heritage sites using remote sensing indices and spatial analysis techniques. Surv. Geophys. **39**(6), 1347–1377 (2018). https://doi.org/10.1007/s10712-018-9489-8
8. Fox, D.M., Darboux, F., Carrega, P.: Effects of fire-induced water repellency on soil aggregate stability, splash erosion, and saturated hydraulic conductivity for different size fractions. Hydrol. Process. Int. J. **21**(17), 2377–2384 (2007)
9. Fu, B.J., et al.: Assessment of soil erosion at large watershed scale using RUSLE and GIS: a case study in the Loess Plateau of China. Land Degrad. Dev. **16**, 73–85 (2005). https://doi.org/10.1002/ldr.646
10. Gallicchio, S., Moretti, M., Spalluto, L., Angelini, S.: Geology of the middle and upper Pleistocene marine and continental terraces of the northern Tavoliere di Puglia plain (Apulia, southern Italy). J. Maps **10**(4), 569–575 (2014)
11. García-Ruiz, J.M., Nadal-Romero, E., Lana-Renault, N., Beguería, S.: Erosion in Mediterranean landscapes: changes and future challenges. Geomorphology **198**, 20–36 (2013)
12. Gioia, D., Gallicchio, S., Moretti, M., Tropeano, M.: STUDIO GEOLOGICO E GEOMORFOLOGICO DEL RETICOLO IDROGRAFICO DEL SETTORE PUGLIESE DEL SUBAPPENNINO
13. Jacobacci, A., Malatesta, A., Martelli, G., Stampanoni, G.: Note illustrative della Carta Geologica d'Italia. Foglio 163–Lucera (1967)
14. Key, C.H.: Landscape assessment (LA): sampling and analysis methods. In: Lutes, D.C., et al. (eds.) FIREMON: Fire Effects Monitoring and Inventory System. USDA Forest Service, Rocky Mountain Research Station. General Technical Report RMRS-GTR-164-CD, Fort Collins (2006)
15. Key, C.H., Benson, N.C.: Landscape assessment (LA) sampling and analysis methods. USDA Forest Service General Technical Report, RMRS-GTR-164-CD (2006)
16. Kuo, K.T., Sekiyama, A., Mihara, M.: Determining C factor of universal soil loss equation (USLE) based on remote sensing. Int. J. Environ. Rural Dev. **7**(2), 154–161 (2016)
17. Lanorte, A., Danese, M., Lasaponara, R., Murgante, B.: Multiscale mapping of burn area and severity using multisensor satellite data and spatial autocorrelation analysis. Int. J. Appl. Earth Obs. Geoinf. **20**, 42–51 (2013)
18. Las Casas, G., Murgante, B., Scorza, F.: Regional local development strategies benefiting from open data and open tools and an outlook on the renewable energy sources contribution. In: Papa, R., Fistola, R. (eds.) Smart Energy in the Smart City. GET, pp. 275–290. Springer, Cham (2016). https://doi.org/10.1007/978-3-319-31157-9_14
19. Lasaponara, R., et al.: Spatial open data for monitoring risks and preserving archaeological areas and landscape: case studies at Kom el Shoqafa, Egypt and Shush, Iran. Sustainability **9** (4), 572 (2017). https://doi.org/10.3390/su9040572

20. Lufafa, A., Tenywa, M.M., Isabirye, M., Majaliwa, M.J.G., Woomer, P.L.: Prediction of soil erosion in a Lake Victoria basin catchment using a GIS-based Universal Soil Loss model. Agric. Syst. **76**(3), 883–894 (2003)
21. Maggiore, M., Masciale, R., Massari, R., Pappagallo, G., Passarella, G., Vurro, M.: Caratteri idrostrutturali del Tavoliere di Puglia ed elaborazione di una carta geolitologica a finalità idrogeologiche. Geologi e Territorio-Periodico di Scienze della Terra dell'Ordine dei Geologi della Puglia **2**, 6–16 (2005)
22. Miller, J.D., Nyhan, J.W., Yool, S.R.: Modeling potential erosion due to the Cerro Grande Fire with a GIS-based implementation of the Revised Universal Soil Loss Equation. Int. J. Wildland Fire **12**(1), 85–100 (2003)
23. Mitasova, H., Hofierka, J., Zlocha, M., Iverson, L.R.: Modelling topographic potential for erosion and deposition using GIS. Int. J. Geogr. Inf. Syst. **10**(5), 629–641 (1996)
24. Moody, J.A., Martin, D.A.: Initial hydrologic and geomorphic response following a wildfire in the Colorado Front Range. Earth Surface Process. Landforms J. Br. Geomorphol. Res. Group **26**(10), 1049–1070 (2001)
25. Moody, J.A., Shakesby, R.A., Robichaud, P.R., Cannon, S.H., Martin, D.A.: Current research issues related to post-wildfire runoff and erosion processes. Earth Sci. Rev. **122**, 10–37 (2013)
26. Moretti, M., Gallicchio, S., Spalluto, L., Ciaranfi, N., Pieri, P.: Evoluzione geologica del settore settentrionale del Tavoliere di Puglia (Italia meridionale) nel Pleistocene medio e superiore. Il Quaternario **23**(2), 181–198 (2010)
27. Murgante, B., Borruso, G., Lapucci, A.: Sustainable development: concepts and methods for its application in urban and environmental planning. In: Murgante, B., Borruso, G., Lapucci, A. (eds.) Geocomputation, Sustainability and Environmental Planning. Studies in Computational Intelligence, vol. 348, pp. 1–15. Springer, Heidelberg (2011). https://doi.org/10.1007/978-3-642-19733-8_1
28. Murgante, B., Borruso, G., Balletto, G., Castiglia, P., Dettori, M.: Why Italy first? Health, geographical and planning aspects of the COVID-19 outbreak. Sustainability **12**, 5064 (2020)
29. Nolè, G., Lasaponara, R., Lanorte, A., Murgante, B.: Quantifying urban sprawl with spatial autocorrelation techniques using multi-temporal satellite data. Int. J. Agric. Environ. Inf. Syst. **5**(2), 20–38 (2014). https://doi.org/10.4018/ijaeis.2014040102
30. Nyman, P., Sheridan, G.J., Smith, H.G., Lane, P.N.: Evidence of debris flow occurrence after wildfire in upland catchments of south-east Australia. Geomorphology **125**(3), 383–401 (2011)
31. Panagos, P., Meusburger, K., Ballabio, C., Borrelli, P., Alewell, C.: Soil erodibility in Europe: a high-resolution dataset based on LUCAS. Sci. Total Environ. **479**, 189–200 (2014)
32. Pascale, S., et al.: Landslide susceptibility mapping using artificial neural network in the urban area of Senise and San Costantino Albanese (Basilicata, Southern Italy). In: Murgante, B., et al. (eds.) ICCSA 2013. LNCS, vol. 7974, pp. 473–488. Springer, Heidelberg (2013). https://doi.org/10.1007/978-3-642-39649-6_34
33. Renard, K.G.: Predicting Soil Erosion By Water: A Guide to Conservation Planning with the Revised Universal Soil Loss Equation (RUSLE). United States Government Printing (1997)
34. Riley, K.L., Bendick, R., Hyde, K.D., Gabet, E.J.: Frequency–magnitude distribution of debris flows compiled from global data, and comparison with post-fire debris flows in the western US. Geomorphology **191**, 118–128 (2013)
35. Robichaud, P.R.: Evaluating the effectiveness of postfire rehabilitation treatments (No. 63). US Department of Agriculture, Forest Service, Rocky Mountain Research Station (2000)

36. Santarsiero, V., Nolè, G., Lanorte, A., Tucci, B., Baldantoni, P., Murgante, B.: Evolution of soil consumption in the municipality of Melfi (Southern Italy) in relation to renewable energy. In: Misra, S., et al. (eds.) ICCSA 2019. LNCS, vol. 11621, pp. 675–682. Springer, Cham (2019). https://doi.org/10.1007/978-3-030-24302-9_48
37. Santi, P.M., Morandi, L.: Comparison of debris-flow volumes from burned and unburned areas. Landslides **10**(6), 757–769 (2012). https://doi.org/10.1007/s10346-012-0354-4
38. Terranova, O., Antronico, L., Coscarelli, R., Iaquinta, P.: Soil erosion risk scenarios in the Mediterranean environment using RUSLE and GIS: an application model for Calabria (southern Italy). Geomorphology **112**(3–4), 228–245 (2009)
39. Van Remortel, R.D., Hamilton, M.E., Hickey, R.J.: Estimating the LS factor for RUSLE through iterative slope length processing of digital elevation data within Arclnfo grid. Cartography **30**(1), 27–35 (2001)
40. Wischmeier, W.H., Smith, D.D.: Predicting rainfall erosion losses - a guide for conservation planning. U.S. Department of Agriculture, Hyattsville, Agriculture Handbook No 537, p. 58 (1978)
41. Wischmeier, W.H., Smith, D.D.: Predicting rainfall-erosion losses from cropland east of the Rocky Mountains: Guide for selection of practices for soil and water conservation (No. 282). US Department of Agriculture (1965)