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New Metropolitan Perspectives

Post COVID Dynamics: Green and Digital Transition, between Metropolitan and Return to Villages Perspectives

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Towards Quantifying Rural Environment Soil Erosion: RUSLE Model and Remote Sensing Based Approach in Basilicata (Southern Italy)

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Abstract. Land degradation is a phenomenon that describes the degradation of soil quality, the causes are multiple, some dynamics related to agriculture have particularly influenced the process of degradation. Specifically, agricultural over-exploitation with unsustainable practices and the abandonment of agricultural land can cause pedological alterations of the most superficial layers of the soil that with intense rainfall and trigger the process of soil erosion. The aim of this work is to evaluate the dynamics and relationships between erosion processes and land cover changes. The approach employed is based on GIS and remote sensing. An initial analysis involved the application of the Revised Universal Soil Loss Equation (RUSLE) model to calculate soil erosion on an annual basis. The resulting data were then processed through a Getis-Ord local autocorrelation index to produce a persistent erosion map. The resulting dataset was compared to land cover classes of arable and brownfield areas. Finally, an attempt was made to quantify and test the relationships between erosion rate and the period of abandonment. Models and survey techniques have been applied in a rural area of Basilicata Region (South Italy) using exclusively a GIS Free and Open-Source Software and remote sensing approach.

Keywords: Soil erosion · Remote sensing · Abandoned arable land

1 Introduction

Land degradation is a complex phenomenon that describes the degradation of soil quality due to which agricultural land in particular is unproductive as a consequence of the loss of ability to produce crops and biomass caused by multiple factors that limit or inhibit the productive, regulatory and utilitarian functions as well as eco-system services that a natural soil can offer can offer [1–4]. The causes are diverse, including some agricultural

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practices that have particularly influenced the degradation process. In particular, agricultural overexploitation with unsustainable practices and land abandonment are causing ecological alterations that require contextual analysis to assess medium- and long-term effects [5–8].

The United Nations Convention to Combat Desertification (UNCCD) [2] has developed a methodology for qualitative assessment using a combined approach of the following sub-areas provides for the combined use of the following sub-indicators: land use and land cover change, loss of productivity, loss of ecosystem services, fragmentation, firers, etc. A first step to analyze land degradation is to highlight which territorial and phenomenological aspects are closely linked to this phenomenon. One of the most important indicators in the definition of the phenomenon is certainly the change in land cover followed by loss of productivity [2]. In the end land degradation is the reduction in the capability of the land to produce benefits from a particular land use under a specified form of land management. Soil degradation is one aspect of land degradation; others are degradation of vegetation or water resources [9]. Oldeman, recognized two categories of soil degradation: the first is soil degradation due to displacement of soil material such as soil erosion by wind and water; the second is related to degradation due to chemical process like loss of nutrients and organic matter, salinization, etc. [10].

Current climate change processes have been recognized as important factors in land degradation, e.g., global warming can affect seasonality and precipitation amounts [11–13]. Short and intense rainfall affects soils without vegetation cover, the resulting runoff removes the surface layer rich in organic matter from the soil. Arid, semi-arid and sub-humid areas with sunny exposures are generally more at risk because they are often affected by this type of rainfall that triggers erosion processes [3, 4].

Agricultural overexploitation and abandonment of agricultural land are among the most cited causes to trigger phenomena of surface erosion, in particular some agricultural practices oriented towards mechanical processing and the use of chemicals can reduce soil quality and subsequent degradation. The abandonment of agricultural activities is also under the attention of the scientific community because the complete abandonment of soils, in addition to producing socio-economic and landscape impacts, can trigger a whole series of degradation phenomena. Soil erosion represent a most serious consequences of land degradation hazard in the Mediterranean Basin. It has an adverse influence on land degradation and agricultural productivity problems [14, 15]. Soil erosion consists in the detachment and transport of soil particles and also nutrients from the most superficial layers of the soil, decreasing the quality of the soil and reducing the productivity of the affected lands [16]. According to the Italian Institute for Environmental Protection and Research (ISPRA) about 10% of the national territory is at risk of soil degradation, and in particular in the Basilicata region the percentage of the territory affected by the phenomenon is about 25% [17]. The effects of soil erosion can be change in relation to territorial contexts and therefore depend on climatic factors, ecological, biological, pedological and topographical factors. Land abandonment, soil erosion and land degradation are closely linked and this connection is the subject of heated debates in the literature and needs in-depth methodological analysis and careful study of the dynamics and triggers that can often be divergent. The Basilicata Region (Southern Italy) is one of the Italian regions to have undergone over the years an intense process of exodus and demographic decline, which has led to intense agricultural abandonment with consequent land degradation and erosion processes [18]. In the literature, most of the studies of erosion of its are based on the use of RUSLE model, which takes into consideration several factors such as precipitation, soil erodibility factor, loss, to land cover and erosion control practices [19–21]. The present work concerned the estimation of the erosion rate by applying the RUSLE model in an area of Basilicata (Italy).

Starting from a study area located in Southern Italy (Basilicata Region) and affected by problems of agricultural abandonment, land degradation [3] and soil consumption [27], GIS and remote sensing techniques were used to perform a preliminary investigation to assess the relationship between land degradation and soil erosion. After an initial statistical survey, arable land and areas with post-crop vegetation potentially susceptible to land degradation were mapped based on erosion rates estimated using RUSLE methodology and grouped using autocorrelation techniques.

This work was based on the integration of remote sensing techniques and Geographic Information System (GIS) with the use of Free and Open-Source Software technologies and open datasets e freely available. The integration of the different datasets and the application of new models, represent an opportunity to study and monitor the evolution of the territory with a detailed temporal and spatial scale. The increasing efficiency of analysis models and the interoperability of the various data, represent a strength for the planner in terms of definition of plans and strategies consistent with real needs and environmental problems [22–24]. The purpose of this work is to quantify and identify areas at high risk of erosion and degradation, and then to compare erosion values with land cover classes, specifically in abandoned arable areas.

2 Materials and Methods

2.1 Study Area

The study area covered a portion of the Basilicata Region, made up of about 20 municipalities, located in the eastern part of the regional territory, bordering the Apulia Region. It is located in a territorial context particularly suited to agriculture and affected by the phenomenon of the abandonment of agricultural soils in recent decades, a territory, therefore, particularly vulnerable to soil erosion due to the combination of anthropogenic and natural factors. The climate is Mediterranean, with a pronounced bistagional regime characterized by hot, dry summers and wet, cold winters.

Agricultural areas of different types, such as arable land, permanent crops (olive groves, orchards, vineyards), permanent meadows, cover almost the entire study area (80% of the territory), the remainder is covered by natural areas (wooded areas, shrub and grassland) for about 18% [25] (Fig. 1, Table 1).

From a geomorphological point of view, it is possible to ideally divide the study area into two sub-areas: the western part characterized by a more complex and diversified morphology and the eastern part more heterogeneous. Geologically, the area considered falls almost entirely within the domain of the Bradanic Foredeep [26], which constitutes 43% of the entire Lucanian territory, and only in small part within the domain of the Apennine chain of hills [27].

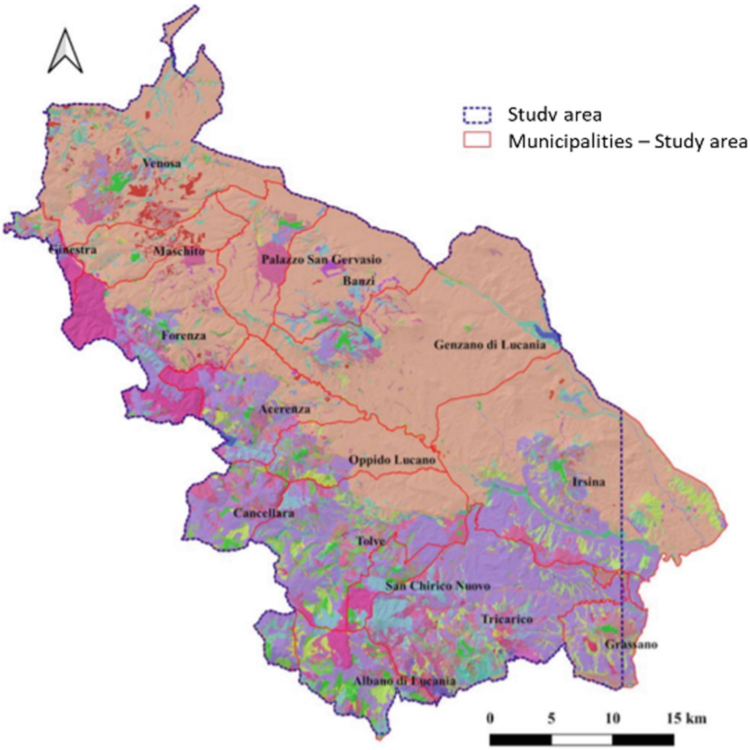

Fig. 1. Map of study area (dashed line) and related municipalities and land cover classes based on the 2013 Nature Map [25].

Table1. Land cover based on the 2013 Nature Map expressed in square kilometers (km^2) and percentage (%)

Level Nature Map 2013	Km^2	Percentage %
Agricultural areas	1266.19	81.45
Artificial areas	12.44	0.80
Forest and semi-natural areas	2271.40	17.46
Water	3.77	0.24
Wetlands	0.79	0.05

The eastern part presents gentle morphologies, engraved by the valleys of the main water courses streams, and that are connected with regularity to the plains, to the marine terraces, the prevalence of clay outcrops creates a landscape at times gully.

The territory under analysis is affected by landslide phenomena of different nature, which are differ according to the lithology of the outcropping soil. In the study area, 858 landslides were surveyed up to 2014 by the IFFI Project (Inventory of Landslide Phenomena in Italy) [28], distributed as in Fig. 2.

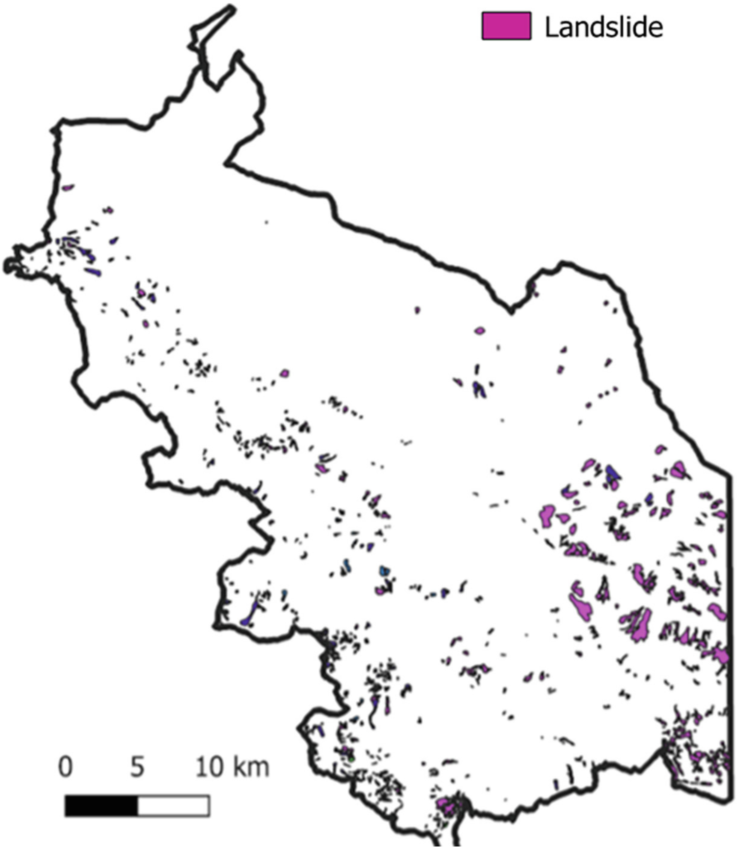

Fig. 2. Spatial distribution of landslides cataloged by the IFFI Project falling within the study area.

2.2 Methodology

The whole procedure has been realized with the open source software QGIS [29] and its plugins. The reference satellite data is represented by the Sentinel 2 medium-high resolution images provided by the Copernicus Mission [30] and the land cover classification was based on the 2013 Nature Map at scale 1:50.000 in a format freely available from the ISPRA website.

The first part of the work involved the implementation and application of useful models to estimate and map areas with high erosion rates.

Soil erosion was estimated using the RUSLE (Revised Universal Soil Loss Equation) [19], resampling all necessary parameters all necessary parameters to the spatial resolution of Sentinel 2A (10 m). The observation period of this work is from September

2019 to October 2020. The estimate of annual soil loss according to the RUSLE model is a function of five variables related to precipitation regime (R), soil characteristics (K), topography (LS), land crop cover and management (C), and conservation cropping practices (C), according to the following formula:

$$A = R * K * LS * C * P$$

The annual soil erosion assessment consisted of the following steps: geospatial data collection, estimation of soil loss with RUSLE for annual scenarios considering the changes recorded by K, LS and C factors.

The RUSLE values were first calculated monthly, through the implementation of specific model in QGIS to realize a batch processing in order to calculate the different parameters in a semi-automatic way. Then the monthly values were summed to have an annual RUSLE value.

The integration of remote sensing data and geostatistical analysis is an innovative approach for analysis and mapping based on factors influenced by the spatial and geographical component [4, 31]. The integration of remote sensing data and geostatistical analysis is an innovative approach for analysis and mapping based on factors influenced by the spatial and geographical component. By considering occurrences of a spatial variable (e.g., areas of persistent erosion), spatial autocorrelation measures the degree of dependence between events, considering their similarity and long-distance relationships [32, 33]. In particular, the issue of spatial autocorrelation is crucial to assess whether a particularly intense phenomenon in a specific area, implies the presence of the same in contiguous areas as well [34]. In the present work, autocorrelation indices were applied to erosion estimation maps derived from the application of the RUSLE model to produce an annual map of persistent erosion. Local indicators of spatial autocorrelation allowed us to locate clustered pixels by measuring the number of elements within the "fixed neighbor" file that are homogeneous. After several investigations, for this work we chose to use the local autocorrelation index Gi proposed by Ord and Getis [35]. Statistical interpretation of this index allows values to be grouped on the basis of a hot spot (pixel values above the mean) or cold spot (values below the mean).

The index was applied to the annual map of RUSLE values highlighting only pixels with positive autocorrelation. This allowed the development of a map highlighting areas with persistent erosion rates based on clusters of hot spots.

3 Results and Discussion

The purpose of this work was to relate erosion data to land cover in order to assess how this process may influence degradation phenomena and the relationship between the period of abandonment of agricultural activities with erosion rates.

Preliminary phase of the study was to identify on the basis of the Nature Map the abandoned agricultural areas and the areas under arable cultivation.

Next, a statistical investigation of the annual mean values of RUSLE was made with respect to cultivable areas and areas with post-crop vegetation (abandoned agricultural areas). The analysis on the annual values shows an erosion rate with the same order of magnitude in the two classes, but with a slightly higher value in the areas with post cultivation vegetation. In fact, the arable land areas show an erosion value of 22.92 (Mg-ha -1 -year -1), while the abandoned ones of (26.23 Mg-ha -1 -year -1). This small difference is extremely important to investigate because, generally, high values are noted in arable crops as they have long periods of the year with bare soil. The reason could be that areas with post-crop vegetation, have a cover type (expressed by the C-factor) and morphological context that could influence erosion.

Geostatistical operations carried out through the use of Getis & Ord.'s autocorrelation index, have made it possible to create a map of permanent erosion that takes into account the spatial and geographical relationship that may exist between contiguous areas [4]. These were compared to the Nature Map land cover classes to assess which classes were most affected in terms of surface area by permanent erosion. It emerged that, in percentage terms, the most representative classes are those related to arable land (22.48%) and areas with abandoned land (61.125) due to abandonment of agricultural activity. The results obtained from the statistical analyses were compared to the IFFI Project Landslide Map to assess which landslide type was affected by permanent erosion relative to the RUSLE data. The following histogram (Fig. 32) represents the result of the statistical analysis performed between the areas of the Landslide Map classified by activity status and type of movement compared with the Map of areas of permanent erosion identified to the spatial autocorrelation analysis performed by applying the Getis algorithm, what is inferred is that the areas identified as areas of permanent erosion are, for the majority, areas subject to surface and diffuse landslides, active and/or reactivated. The results obtained from the statistical analysis were compared with the Landslide Map of the IFFI Project, what inferred is that the areas identified as areas of permanent erosion are, for the majority, areas subject to surface and diffuse landslides, active and/or reactivated.

The map of permanently eroded areas was then compared to the areas affected by agricultural abandonment previously divided into decades (1990/2000, 2000/2010, 2010/2020). It was found that areas that were abandoned in the 1990s have RUSLE values of 22 (Mg-ha -1 -year -1) while those abandoned in the second and third decades have erosion values of 37 and 31. This first analysis shows that soils abandoned in the first decade present values of soil lost compared to the following decades, this probably because these areas have rinaturalized and stabilized over time. It is more difficult to discriminate and evaluate the abandonment from 2010 to the present, because these areas can be subject to vegetation rest. areas may be subject to vegetative rest and/or crop rotation, and therefore require further analysis. Subsequently, the average value of eroded soil for the agricultural areas, what can be deduced is that the average of the values of RUSLE in agricultural areas is about 19 (Mg-ha -1 -year -1), if the values of erosion for the arable land classes alone this amounts to about 17 (Mg-ha -1 -year -1) and about 33 (Mg-ha -1 -year -1) for extensive crops and complex agricultural systems.

4 Conclusion

The use of satellite data and GIS tools have provided useful data for estimating erosion risk, mapping and monitoring areas prone to degradation. These methods are mainly based on the use of indices obtained from the combination of different spectral bands, which emphasize and detect any change in the state of vegetation. Integration of soil erosion models (RUSLE model) with GIS and remote sensing have proven to be effective tools for mapping and quantifying areas and rates of soil erosion for the development of better conservation and monitoring plans for the land. In addition, the use of spatially explicit geostatistical surveys allows for a more accurate quantitative analysis of the various results obtained. In conclusion, it is possible to deduce from the analyses carried out that land cultivated with arable crops in the during the period considered present values of lost soil lower than that of the soils abandoned in the three decades analyzed.

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