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LNCS 13376

Computational Science and Its Applications – ICCSA 2022

22nd International Conference
Malaga, Spain, July 4–7, 2022
Proceedings, Part II

2 Part II

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Abandoned Agricultural Areas: From Quantification to Qualification by Integration of GIS and Remote Sensing

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Abstract. The agricultural areas abandonment has become one of phenomena that is most influencing the land transformation. This has been evident for some decades already, especially in inland mountainous and hilly areas of the Mediterranean where some types of agricultural activities have been abandoned as less profitable. The effects of this abandonment are not yet very clear but above all vary greatly in relation to morphological, geological and microclimatic characteristics of territory. The drivers of abandonment are also linked to these territorial characteristics with the addition of socio-economic factors. Therefore, studying this process from a spatial and geographical point of view is crucial. To do this, the integration of GIS and remote sensing in an open source environment represents a key approach as it allows to address the issues in a multi-temporal and multi-disciplinary way in an accurate way. In this paper, a case study of Southern Italy (Alto Bradano area - Basilicata region) has been chosen to quantify and qualify abandoned agricultural areas. First, a methodology for quantification of abandoned agricultural areas has been implemented through the time series analysis of spectral indices obtained starting from freely available satellite imagery, then a qualitative analysis has been carried out by relating abandoned agricultural areas to some spatial variables. In this way, we want to better define the drivers of change and contextualize them with respect to the local geography in order to have an overall view of the phenomenon of agricultural abandonment.

Keywords: Land changes · Agricultural abandonment · GIS · Remote sensing · FoSS · Basilicata region

1 Introduction

In the last decades, the territory of the most disadvantaged rural areas from a morphological and socio-economic point of view is undergoing significant transformations in

O. Gervasi et al. (Eds.): ICCSA 2022, LNCS 13376, pp. 354–363, 2022.
https://doi.org/10.1007/978-3-031-10450-3_30

its landscape and environmental pattern [1]. This is mainly due to the abandonment of traditional agricultural activities (pastoralism and small-scale agriculture). It is a very common phenomenon in the inland areas of many Mediterranean regions [2]. However, in recent years, also due to climatic transformations, this process of abandonment is affecting also areas with high agricultural profitability [3].

Land transformation due to agricultural abandonment is very complex to evaluate and analyse because there are many biophysical, political and socio-economic variables that determine the development and intensity. Indeed, the drivers of abandonment of agricultural activities differs according to both the territorial and geographical context [4]. Even the impacts are complex to assess because they can be positive or negative in relation to the territorial context [5, 6]. Therefore, it is necessary to deepen both the causes of abandonment and the effects on the basis of methodologies that are as multidisciplinary as possible [7]. In view of the transformations taking place in the environmental, agricultural and social policies of the European community, these abandoned areas are also at the attention of the European Green Deal [8].

The first step for a more in-depth study of this phenomenon is linked to the quantification and qualification of agricultural areas that are abandoned. This mapping, however, must not be based on single years, but should be based on the trend of agricultural land over time, also because from a planning point of view the Common Agricultural Policy considers cultivated fields abandoned only after a certain number of years [9]. For this reason, the quantification of abandoned agricultural areas must be based on the use of time series realized by exploiting the different types of geodata available. One of the classical approaches is based on the use of historical cartography, aerial photos and orthophotos processed manually or semi-automatically in a GIS environment [10]. The use of historical cartography and aerial photos, although with some problems related to the accuracy of the estimate, is one of the fundamental methodologies for the assessment of agricultural abandonment as they allow to go back in time even more than a century [11]. However, one of the most used approaches is the one based on satellite images from different missions. This is because they allow to standardize the analysis for continuous and well-defined periods in order to create time series comparable over time [12].

Moreover, more and more often, in the literature it is possible to find case studies where integration between different remote sensing data is used. Among the commonly used satellite images there are Moderate Resolution Imaging Spectroradiometer (MODIS), Visible Infrared Imaging Radiometer Suite (VIIRS), or SPOT VEGETATION which, given their spatial resolution, allow a quantification mainly at geographical scale [13]. However, among the most used for investigations at small spatial scale are the images provided by the Landsat and Sentinel-2 missions. Indeed, there are many works that use different classification algorithms to evaluate land use and land cover transformations useful to estimate land abandonment rates [14]. In this type of classification algorithms in most cases are based on the use of vegetation indices that are able to perceive the photosynthetic changes or water content of the vegetation and thus assess its health and phonological status [15].

Increasingly common is the use of these techniques and methodologies in open source GIS environment since, in addition to the ease of use of the most common classification techniques, they also allow for more complex spatial analysis based on other

types of geodata [16]. This is fundamental in multidisciplinary researches such as those related to the qualification of abandoned agricultural areas. Indeed, qualifying patterns of abandonment is one of the preliminary analyses that follows quantification as it allows to make initial assessments of the drivers and impacts of agricultural abandonment [17].

This work is part of this context, as integrated techniques between free and open source software (FoSS) GIS and remote sensing are applied in a rural landscape typical of Southern Italy and with significant problems of land take and land degradation [16] (Basilicata Region - Alto Bradano area) to quantify and qualify the abandonment of agricultural areas in a period ranging from 1990 to 2020. In particular, the mapping of abandoned agricultural areas was based on the use of time series of NDVI (Normalized Difference Vegetation Index) extrapolated from images of Landsat missions. These were then correlated with some variables (altitude, slope and exposure) in order to qualify the abandoned areas from a biophysical point of view and thus make an initial assessment of the process of abandonment. These two steps are preliminary but fundamental for all phases of land-use planning as they are at the base of the compression of the abandonment problem.

2 Material and Methods

2.1 Study Area

The study covered an area of approximately 155.000 hectares within the Basilicata Region (Southern Italy) (Fig. 1), including 17 municipalities and in part corresponds to the landscape area delimited by the high and medium Bradano rivers. The study area does not include some municipalities in their totality because those used in a previous study based on a single Sentinel-2 tile were used as boundaries [18]. This scenario corresponds to an agricultural landscape in which the vast cereal cultivations mixed with arboreal pastures and forages extend on the hills up to the Bradano river, interspersed, in the steepest slopes, with oak woods and wooded spots. Close to the inhabited centres, the agrarian mosaic changes and thickens in olive groves, orchards, vineyards and specialized crops. The cultivations, often interspersed by the presence of natural elements; hedges, trees and small bushes or minor roads, are fragmented into smaller plots until they reach the slopes of the settlements.

The population is concentrated almost exclusively in the population centres and there is little or no settlement in the surrounding area. The demographic dynamics of the context record, as in all the smaller municipalities of the region, a trend and a negative migration balance and, consequently, a consequent and worrying index of aging. The degree of "dispersion" of settlements and the poor infrastructure of the area represent the main constraints to the development potential of the area.

This social problem and the morphological conditions represent the main themes for the planning strategies that are being implemented to reduce the abandonment and degradation of the territory.

2.2 Abandoned Agricultural Areas Quantification

The quantification of abandoned agricultural areas was based on the reconstruction of the NDVI time series from 1990 to 2020 already implemented in a previous study [18].

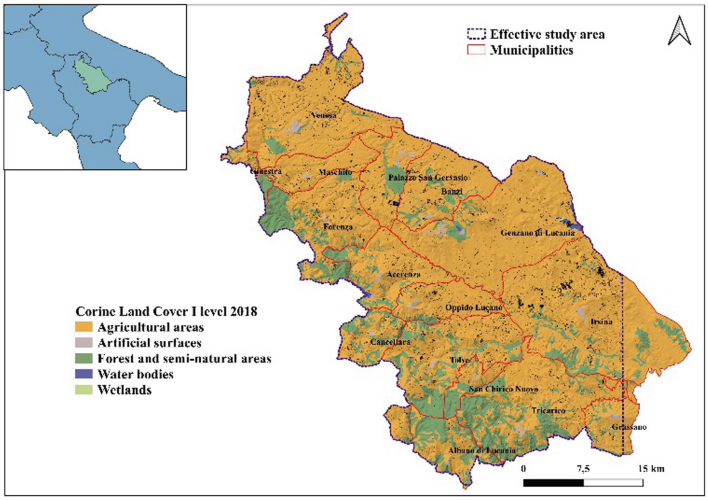

Fig. 1. Localization of the study area within Southern Italy and the Basilicata Region with a detail on land cover according to the 2018 Corine Land Cover I level.

The NDVI index is the most widely used remote sensing indicator to assess the health of vegetation (natural or cultivated) based on leaf reflectance. Indeed, it is the most accurate in estimating plant biomass because it is related to photosynthetic activity. It is based (Eq. 1) on the difference in leaf reflectance at different wavelengths. The value varies from -1 to $+1$ a lot but in general the higher it is, the better the vegetation is in a health state.

$$NDVI = \frac{NIR - RED}{NIR + RED} \tag{1}$$

Given the characteristics of this index, it is possible to use NDVI to evaluate over a one-year time frame how the vegetation status varies [20]. This is very useful to discriminate even one type of vegetation from another on the basis of a phenological curve and in particular to differentiate cereal crops from natural grasslands [19]. Effectively, the two land covers differ because cereal crops have an annual cycle that shows maximum NDVI values in spring (between March and April) and a minimum in autumn. In the same period, if we compare with natural meadows (where there is no more agricultural activity) we can see that in the autumn period the NDVI value is much higher and in the first part of spring the opposite. This is summarized in the example in Fig. 2 and can be explained by the differences in the phenological cycle between cereal crops and wild herbaceous species.

After the NDVI 1990–2020 time series was created, the difference between fall and spring for each year was calculated through change detections analyses. Finally, with subsequent spatial analyses as presented in a previous work [18], abandoned agricultural areas were identified. At the end of this phase, informed layers related to the abandoned agricultural areas between 1990 and 2020 were made. The satellite images used refer

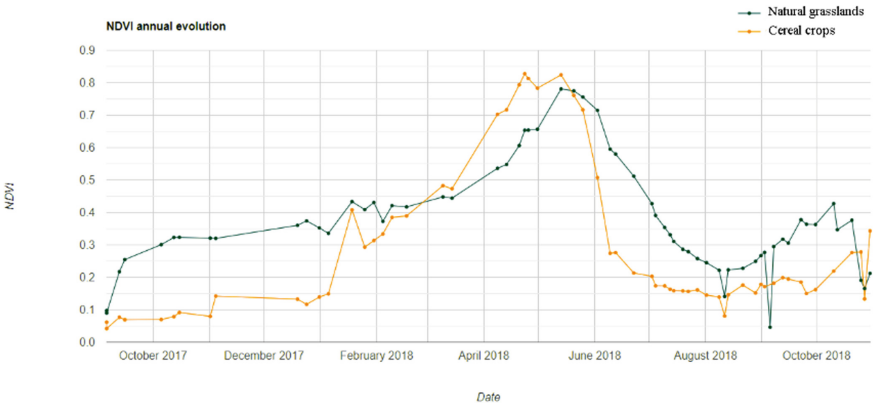

Fig. 2. Example of a phenology curve calculated on a historical NDVI time series from October 2017 to October 2018 for an agricultural area with cereal crops and a natural grassland (abandoned agricultural area). For this example, the time series was calculatedin Google Earth Engine platform based on Sentinel-2 L2A imageries.

to the Landsat 4/5 TM and Landsat 8 OLI mission. All operations were performed with the open source software QGIS.

2.3 Abandoned Agricultural Areas Qualification

Following the quantification, a preliminary assessment of the abandoned areas was made based on three indicators commonly used in studies involving land transformation [21]. Therefore, the information layer elaborated in the first part of the study, was related to altitude (meters above sea level), slope (in degrees) and aspect (in degrees). This procedure was carried out through a zonal spatial analysis with the altitude, slope and exposure raster processed from the digital terrain model provided by the geoportal of the Basilicata region [22]. The modules within QGIS allow to export the information in tabular format in order to better interpret them (Fig. 3). In fact, these data were exported in Comma Separated Value (.csv) format and processed within RStudio for the realization of box plots for the statistical interpretation of the data which is useful to start a process of more precise understanding of the process of abandoned agricultural areas.

3 Results and Discussions

The realization of the NDVI time series from 1990–2020 and the subsequent evaluation of the differences (ΔNDVI) allowed to map the areas that in this period of time have undergone a process of agricultural abandonment as they present several consecutive years with absence of cereal crops (Fig. 4).

The total number of abandoned hectares is about 4033, distributed mainly in patches of the same size as the single pixel (0.09 ha), demonstrating that the analyses must be integrated with subsequent spatial analyses to better determine abandonment. Through a random validation through a visual interpretation with orthophotos (1988 and 2020)

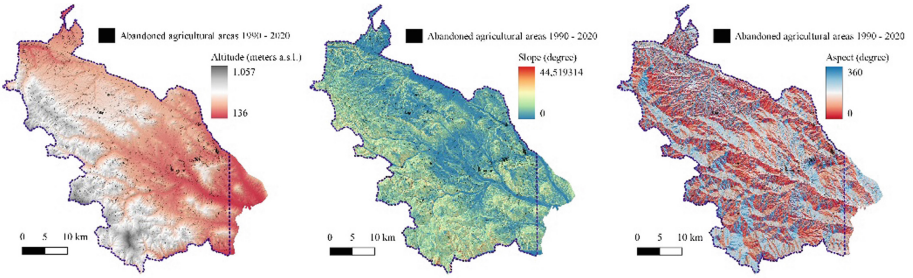

Fig. 3. Elevation, slope, and aspect maps for the study area.

the general accuracy of the identified areas has been verified (Fig. 5). The procedure, which will be improved in the next steps of the work, shows that time series and change detection represent the reference for this type of investigation and that NDVI is certainly sensitive but must be integrated with other spectral indices.

A problem is due to the temporal resolution of the Landsat missions which has a return time on the same area of 16 days and this leads to gaps in the time series when the cloud cover is high. In the future, the use of Sentinel-2, even if it allows to realize time series from 2015, will be fundamental because the return time is reduced up to 5 days in some cases.

Regarding the qualitative analysis of the abandoned agricultural areas identified with respect to some morphological variables (altitude, slope and aspect), the result has been statistically evaluated by making three different box plots (Fig. 6).

This preliminary analysis shows that the areas in which abandonment is most concentrated are at an average altitude of about 400 m above sea level and at a slope of about 7°. In both cases there is a concentration of values around a narrow range. Instead for what concerns the aspect, the values are more concentrated around a very wide range that goes from about 70° to 250 (from East to West) but that however represent the portions of the territory more sunny. This demonstrates that the phenomenon of agricultural abandonment should be analyzed and studied even at the local level because the complexity and the variables that determine it are diversified even within the same geographical area.

This was also confirmed by basic statistics calculated directly on the information layer in QGIS (Table 1).

The ease with which QGIS manages statistical databases makes it possible to quickly calculate all types of descriptive statistics accurately within the same work environment.

In the following steps of the study, further biophysical variables will be included and, above all, they will be related to planning and infrastructural variables such as the distance from roads and inhabited centres. This qualitative analysis, although preliminary, gives us an indication of a very important aspect, namely that in this study area the abandonment (from a topographical point of view) was not concentrated at the highest altitudes and steepest slopes, which are those considered at greater risk [23, 24]. Obviously the analysis is much simplified but the fact that it can be replicated in series within QGIS for all the layers and the possibility of replicating the scripts of RStudio directly within the same

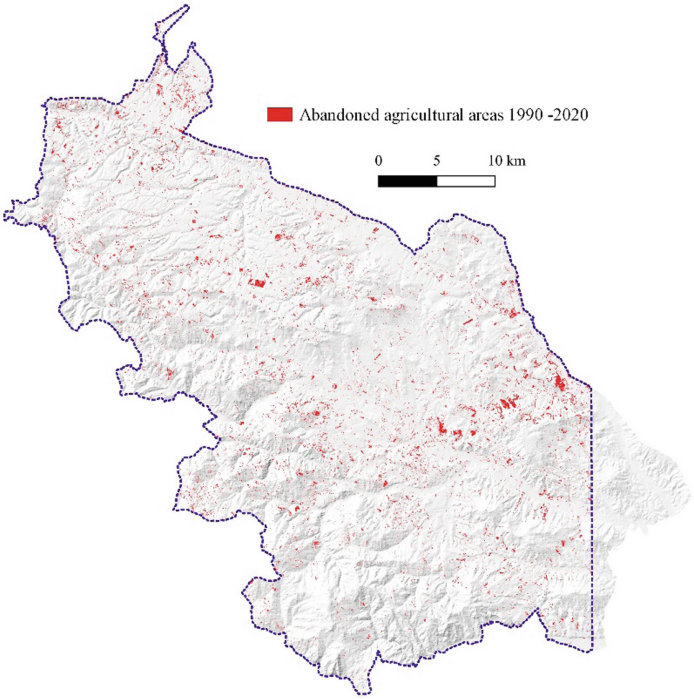

Fig. 4. Mapping abandoned farmland between 1990 and 2020.

Fig. 5. Example of abandoned agricultural area where the difference between abandoned agricultural area and agricultural area with cereal crops is clear.

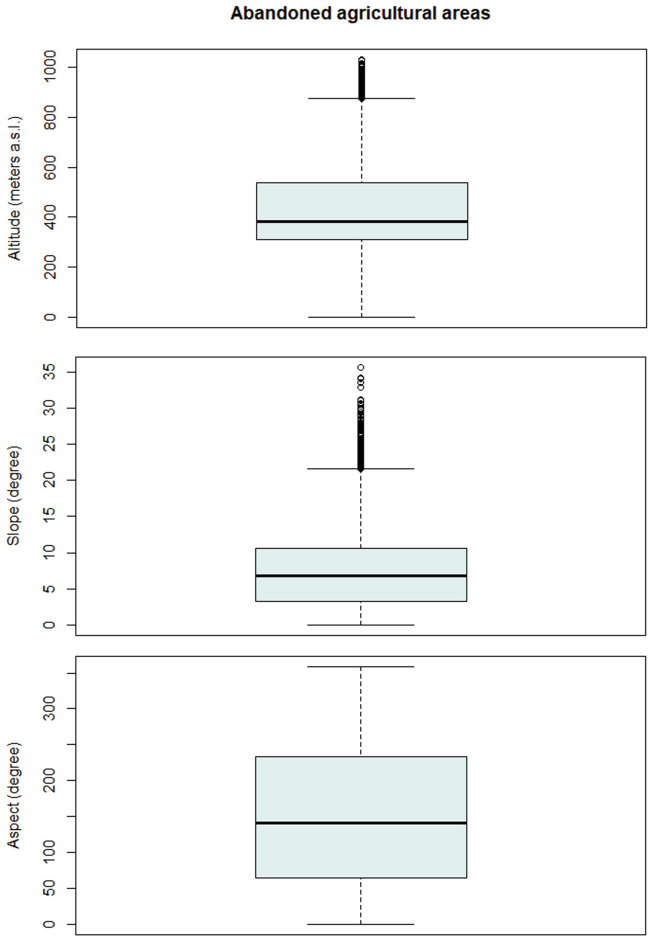

Fig. 6. Relative box plots of relationships between abandoned agricultural area and morphological variables (elevation, slope and aspect). Outliers (circles), median value (line inside the box), first quartile (bottom of the box), third quartile (top of the box) and variability beyond the quartiles (whiskers) are indicated.

Table 1. Average, minimum, maximum and standard deviation of morphological variables

Morphological variabiles	Avarage	Minimum	Maximum	Standard deviation
Altitude (meters)	434.99	160.06	1030.5	165.33
Slope (degree)	7.33	0	35.67	4.91
Aspect (degree)	153.90	0	358.53	98.55

software, provide a speed of operations that do not create computational problems by increasing the number of variables to be considered.

4 Conclusions

The abandonment of hill and mountain agriculture has paved the way for a massive return of nature, with the forest area doubling in the last hundred years and the number of trees growing by 4.7% between 2012 and 2017. But this, while positive it may seem in ecological terms, has had negative consequences in some cases especially in economic and social terms, with marginal areas and its few inhabitants increasingly left to their own devices. So the sustainable use and management of rural land through integrated planning could mitigate this ongoing process and especially avoid the negative impacts. In order for planning to be functional, it is necessary to implement replicable and updatable techniques and methodologies to quantify and analyze with the highest possible level of detail the abandonment of agricultural activities. This is necessary because the analysis at regional or large scale do not take into account the different local contexts that may present different differences even a few kilometres away.

Surely, the integrated free and open source approach based on GIS and remote sensing represents the key tool to address this issue. In fact, the various satellite missions in orbit, the developed indices, the increasingly widespread open data and the new techniques of spatial analysis and geostatistics can be combined within the same GIS work environment to speed up the operations and make them available to those who deal with spatial planning outside of academia.

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