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Land Use Change Evaluation in an Open-Source GIS Environment: A Case Study of the Basilicata Region (Southern Italy)

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Abstract. Soil is an essential, non-renewable natural resource that provides vital goods and services for ecosystems, human life, and the production of crops and fuels. The phenomena of land consumption and land use change have a considerable impact on ecosystems. In addition, the poor and confusing regulatory framework contributes to the spread of processes related to soil sealing, such as the wild installation of wind farms, resulting in an increasing fragmentation of the territory with related phenomena of soil degradation.

The research work has proposed an innovative methodological approach on issues related to land consumption and land use change, based on a robust territorial and landscape study. The whole research has been focused on the use and integration between geographic information systems and remote sensing techniques for the study of the territory. The increasing availability of cartographic data and the evolution of satellite data is the basis of a system that provides a continuous phase of analysis of the phenomenon. The work defines the picture of the phenomenon in Basilicata, investigating various aspects of land consumption, going into specific detail of some sample areas. The objective was the application of remote sensing techniques and change detection analysis for the qualitative and quantitative estimation of land take related to degradation phenomena. The methodologies and data developed in this work, could be the basis for the creation of a regional database on soil consumption, which could be made up of a robust infrastructure of spatial data and could provide a service and a system of data collection and collect data and reports from citizens, companies, institutions, research organizations, would support public bodies in the definition of policies, strategies and actions aimed at the containment of the phenomenon and would implement, in addition, measures of limitation, prevention, monitoring and mitigation of the same.

Keywords: Land use change · Remote sensing · GIS

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1 Introduction

Land take and land degradation represent the most dramatic consequences of the loss of the natural characteristics and functions of soils, due to an increase in artificial land cover, linked to settlement and infrastructural dynamics [1, 2]. The increase in land take is a very important indicator of land management policies, both for the assessment of settlement processes, and for the protection and enhancement policies of the agricultural, rural and natural areas of the territory [3–6]. Land degradation is the main cause of soil degradation in Europe, triggering an increase in environmental risks, urban fragmentation and all related problems [7]. This has led to the definition of standards with the aim of regulating and stemming the phenomenon [8, 9]. Over time, land take has been linked to different phenomena, such as urban/industrial expansion, the construction of infrastructures, the productive exploitation of specific natural and mineral resources etc. [10, 11]. These degradation processes involve different types of environmental risks such as hydrogeological instability, soil erosion, salinization, loss of organic matter [7, 12–15].

The innovative approach of this research was based on the construction of methodologies that allowed a detailed and accurate historical analysis on the issues of land consumption, land use change and land degradation based on a robust spatial study [16, 17].

The whole work has been based on the use and integration between geographic information systems and remote sensing techniques for the study of the territory.

In particular, the study of areas subject to land consumption and land degradation, was conducted with the use of innovative tools, models and techniques, using mainly satellite data. In fact, the methodological framework put in place is robust to monitoring the dynamics of land consumption and land use change over time. The research conducted defines the framework of Land Use Change (LCC) in Basilicata, investigating the various aspects, analyzing in detail some specific areas. The work has been articulated, therefore, analyzing and articulating the different aspects of LCC in different workpages (Land take, LCC, Land Degradation related to soil erosion), described in the following sections.

2 Material and Method

2.1 Definition of Land Take Monitoring System

The first part of the research was aimed at creating a land use classification model that would allow for expeditious monitoring of impermealized areas. The work was divided into two phases, the first involved the use of an experimental model for the classification and historical analysis of land take based primarily on Landsat satellite data (analysis of historical land consumption trends) [16–20].

Particular emphasis has been placed on the identification and classification of land use changes due to the installation of renewable energy sources to quantify the consumption of land take in the period 2010, 2014, 2018 [18].

In fact, subsequently, with the use of Sentinel 2 data, which has a higher spatial resolution than the Landsat data, it was possible to further improve the methodology created by increasing the degree of detail in the classification process. The use of Sentinel

2 data has allowed to study and estimate the land take due to the installation of renewable energy sources. Both methodologies developed saw the use of Support Vector Machine (SVM) algorithms for classification [18, 21, 22].

2.2 Analysis of Land Use and Land Cover Change

The objective of this analysis was the creation of a database of land use maps based on historical analysis of past trends, analyzed by land cover change detection through the use of satellite data. Specifically, the work was divided into two parts [21–23]. In the first, a regional scale approach was used in which land cover maps were created.

Maps of land cover, land cover changes were made 1990/2018 and mapping of some dynamics related to specific cover classes (grasslands) using MODIS satellite data. In the second part, a local scale approach was used based on innovative methodologies of satellite image classification. The local scale approach has allowed to determine with greater detail the dynamics that occur on the territory, to improve the methodology and to develop more prudent land-use planning strategies. Specifically, in this phase a case study (Regional Park of Gallipoli Cognato Piccole Dolomiti Lucane) and a supervised classification methodology for the land cover of the Basilicata Region.

One of the objectives of this part of the work was to improve knowledge and techniques related to the creation of land cover databases and analysis of the dynamics of transformation in such a way as to be used at different levels. The work carried out in the first part has allowed to highlight a trend of abandonment of agricultural areas and subsequent agricultural areas and subsequent renaturalization that is not very clear and detailed (especially in the case of the Land Monitoring Service) and(especially in the case of the Land Monitoring Service) and that instead has emerged with greater clarity in the second part thanks to a local scale approach and a very accurate preliminary methodology of identification of the accurate preliminary methodology for identifying land cover changes.

2.3 Assessment and Monitoring of Soil Erosion Risk and Land Degradation

This part of the work aimed at applying remote sensing techniques and change detection analysis for the qualitative and quantitative estimation of land consumption related to land degradation phenomena and spatial dynamics related to land use changes.

The analyses applied in this work page have allowed to evaluate, first of all, the existing link between the erosion phenomena and degradation in agricultural areas. Erosion in fact occurs more in areas that have areas that have undergone a change of land use and/or abandonment, while in stable agricultural areas the stable agricultural areas the phenomenon has less impact. The analysis techniques developed have made it possible to highlight the areas in degradation with respect to changes in the rate of erosion, developing maps of vulnerability to land degradation of areas that are currently arable land and post-crop vegetation. The relationships between spatial dynamics related to land use change and erosion were investigated. In addition, it was possible to estimate any existing connections between the age of agricultural abandonment of arable land and current erosion rates [15, 16, 24].

2.4 Methodology

The research was based on the integration between remote sensing techniques and Geographic Information Systems (GIS), using different datasets of open spatial data, this offers the possibility to study and monitor the evolution of the territory at a wide temporal and spatial scale, allowing to adopt the same techniques and models of analysis in different territorial contexts. Satellite data provide detailed information and insight into landscape characteristics and changes in urban and rural areas. Land cover changes are among the main fields of application of remote sensing [24–26]. The reference satellite data used are the Sentinel 2 products of the Copernicus Mission, data from the Landsat constellation and Modis satellite data.

The use of satellite data and GIS tools can provide useful data for estimating land use land degradation, erosion risk, and for mapping and monitoring degraded areas.

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. In the present work, the integration of the soil erosion model (RUSLE model) with GIS and remote sensing were found to be effective tools to map and quantify areas and rates of soil erosion for the development of better conservation plans and land monitoring. In addition, the use of spatially explicit geostatistical surveys allowed for a more accurate quantitative analysis of the various results obtained.

In order to provide a more fluent understanding of the methodologies, techniques, and analyses performed, the following are listed:

1. Supervised classification, through the use of the SVM algorithm, with the integration of ancillary data (orthophotos, ground truth data), of the historical trend (1994–2014) to create land cover maps subsequently used as input for estimating land take. In order to produce a synthetic map of land take, the Sentinel-2 images were classified using a supervised classification. Using Map Algebra, the 10-m rasterized information layers, or subsets thereof, were inserted on the previous classification map, replacing the corresponding pixels. A first map of land take was obtained divided the area characterized by urbanization from the area with the presence of the renewable energy sources. Eolic class have been reclassified discriminate the relevant street from the turbine pad and subdivided into other subclasses referred to the power wind turbines, in order to quantify the land take related to each one;
2. Estimation of land transformations in terms of land cover and land use through a comparison of differences in quantitative surface area Surface area associated with each land cover category. A quantitative spatial diachronic analysis of Land Use Land Cover (LULC) data has been carried out in order to identify and evaluate in detail the trends of changes within each class.
3. Calculation of the Revised Universal Soil Loss Equation (RUSLE) for estimating monthly erosion and overall annual erosion (October 2019 - September 2020);
4. General statistical investigation between land cover classes and monthly and annual RUSLE values;
5. Clustering of RUSLE, through Getis & Ord. autocorrelation algorithm, in order to highlight areas that, month after month, show a continuous erosion phenomenon;
6. Survey of Normalized Difference Vegetation Index (NDVI) time series for the period 1990–2020 in order to create a database on the transition dynamics of land cover;

7. Susceptibility to land degradation of areas classified as arable land and areas with post-crop vegetation on the basis of deviations from the average values of RUSLE and mapping of Areas of vegetation degradation, related to arable land, through statistical correlation with the vegetation factor C.

3 Results and Discussion

3.1 Definition of Land Take Monitoring System

In this study, a new method of classification of Landsat and Sentinel satellite data was proposed to perform a multi-temporal analysis to identify changes in LCC and subsequently quantify the change in impermeabilized areas. Moreover, within the defined model, the use of the Geotopographic Database (GTDB) spatial information layers was fundamental for the detailed definition of land take. The application of the proposed method allowed us to quickly extract detailed maps of land take with an overall accuracy greater than 90%, reducing the cost and the processing time [21].

Analyzed the land take due to urban expansion and renewable energy is evident how in the first case the trend is constantly growing, while in the latter trend shows a strongly increment starting from 2014 caused by the development of small and large Eolic stations.

3.2 Analysis of Land Use and Land Cover Change

Change detection has allowed us to highlight the areas in which changes in agricultural land use have occurred agricultural land use changes occurred. In most cases there has been a reduction of agricultural areas (e.g. sometimes fields close to others have been abandoned) and in other cases a new land use has been established. Statistical data indicate a value of class 4 (agricultural) equal to about 421000 ha in 1985 which have decreased to about 365000 ha in 2011, recording a loss of about 55000 ha. The transformations that have taken place show differences depending on the local contexts. In some cases, agricultural land has given way to shrub land, in others to wooded land, etc. In general, statistics on the entire region give a prevalence of new land use (which in 1985 was agricultural) of areas with shrubs (about 70%).

The analysis at a smaller scale, even if it requires more time and more knowledge of the territory, certainly guarantee a better accuracy and specificity of the data. So doing so, it is possible to use these techniques (generally used only for scientific purposes) also to support decision-making and planning activities of the various bodies.

Moreover, given the increasing number of open techniques and tools, it is possible to automate or make more accessible the however, make more accessible methodologies of land classification. In fact, using an analysis at the regional scale but with more specific techniques and with a knowledge of the territory allows to have a higher level of accuracy than that present in datasets than that present in the Corinne Land Cover (CLC) datasets. In fact, with the methodology applied it is recorded that, in a comparable but not identical period of reference, there has been a reduction in the agricultural areas and not an increase as reported in the CLC datasets.

In addition, the ability to access ancillary data of different types to implement supervised classifications is critical to improving and detailing the classes of land cover. Certainly, the main challenge in this field of research is to understand the methods for extracting useful information from the data, as well as properly interpreting signals of the time series, so that we can understand both slow variations, caused by gradual changes in the ecosystem, as well as faster variations due to external disturbances or other events.

3.3 Assessment and Monitoring of Soil Erosion Risk and Land Degradation

The results of this work page have allowed to realize preliminary maps of susceptibility to land degradation related to the spatial dynamics of land use changes. The mapping of the results allows, in general, to identify areas or large clusters that must be focused on both for further study and from a planning point of view as they are precisely those planning point of view as they are precisely those areas that may be subject to land degradation. The normalized values allow the subdivision into equal classes which in this preliminary investigation have been classified only by following an algebraic logic and without taking into account further aspects. The analyses applied in this work have allowed to evaluate the relationships existing between agricultural land use changes and land degradation phenomena, as erosion phenomena are more evident in areas that have undergone land degradation. erosive phenomena are more evident in areas which have undergone land use change and/or abandonment, while in stable agricultural areas the phenomenon has less impact. With the methodologies applied in this study, it was possible to create different datasets, both tabular and in the form of maps, for an assessment of the process of land degradation related to the dynamics of land use and land cover. The transition phase of these areas towards low-density urbanization has a marginal impact on the marginal compared to the phenomena of abandonment and/or agricultural transition (moving from one type of cultivation to arable farming to another type of cultivation) on the phenomenon of degradation. Starting with the application of the RUSLE model, soil erosion for the period October 2019/September 2020 was preliminarily estimated, based on which basic statistics were performed to evaluate the contribution of the various factors and investigations with respect to each land cover class. This allowed for the evaluation of land cover classes that had high erosion values over the period. In addition, for a general assessment, a preliminary and detailed survey was carried out on the state of arable land and areas defined as post-crop, which represent two classes of cover whose dynamics most influence the processes of land degradation in the region. Subsequently, models have been developed to specifically understand the relationship between land cover, erosion and land degradation. In addition, at this stage of the work, we began to analyze the cause-effect relationship between degradation and erosion. This allowed us to highlight the areas in degradation simply with respect to changes in erosion rates, producing maps of vulnerability to land degradation of areas that are currently arable land and post-crop vegetation.

Taking advantage of the link between lack of soil productivity and degradation, vulnerable areas were identified by correlating vegetation cover and erosion.

The two approaches, allow to systematically monitor the areas that present erosion problems and that are vulnerable to degradation. The outputs are represented by indications in the form of maps of the areas to be monitored and by data (in different formats) useful to support public decision-makers in the various activities of agro-forestry planning.

4 Conclusion

Land take and land use change have a considerable impact on the territory and on the ecosystems. The importance of biodiversity is recognized globally for its key role in maintaining key role in maintaining ecosystem services. Appropriate LCC data play a key role in several areas of land use planning. The problem of land transformation is one of those research fields that needs up-to-date LCC geodata that allow for standardized and repeated surveying over time.

The work currently carried out defines the framework of LCC in Basilicata, investigating various aspects of land consumption, going into specific details of some sample areas.

In this work we tried to propose new approaches for data management and processing applicable to the entire regional territory, in order to better understand the LCC and all its facets and monitor its evolution over time. For this reason, the completion of the analysis of historical trends of the phenomena analyzed is essential.

The complexity, the relevance of the topics discussed with and the usefulness of the contents produced so far, underline the need for a continuation of this research.

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