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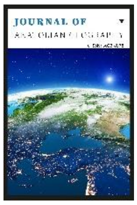

Makine öğrenimi ve uzaktan algılama verilerini kullanarak Orta Apeninler'deki biyolojik çeşitlilik değişiminin tahmin edicilerini toplamak ve manzara geçmişini yeniden oluşturmak

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Anahtar Kelimeler
Yapay Sinir Ağı
Karar Ağacı
Coğrafi Veri
Ekoloji
Rastgele Orman
CBS
İtalya

Araştırma Makalesi
Geliş:25.04.2025
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Yayınlanma:29.06.2025

Özet

Görüntü işleme ve yazılım işlevselliği için yöntemlerin seçimi, Dünya manzaralarını izlemek için çok önemlidir. Bu çalışma, uzaktan algılama (UA) veri işleme için Makine Öğrenmesi (MÖ) yöntemlerinin kullanımını sunmaktadır. Amaç, İtalya'nın merkezi Apeninler örneği ile arazi örtüsü değişikliklerinin kartografik analizini gerçekleştirmektir. Teknik olarak, Python kütüphanesi Scikit-Learn ile entegre GRASS CBS yazılımını kullanan bir MÖ tabanlı sınıflandırma yöntemi sunuyoruz. MÖ yöntemlerini kullanarak görüntü işleme, GRASS CBS algoritmaları işletim araştırılmıştır. Veriler Amerika Birleşik Devletleri Jeolojik Araştırması (ABDJA)'den elde edilmiştir ve Landsat 8-9 OLI/TIRS uydu görüntülerinin bir zaman serisini içerir. Görüntü işlemenin operasyonel iş akışı, UA veri işlemeyi içerir. Görüntüler, otomatik olarak algılanan arazi örtüsü türü kategorileriyle raster haritalara sınıflandırılmıştır. Yaklaşım, rastgele piksel tohumlarının eğitim veri kümesi olarak kullanılan gözetimsiz sınıflandırma dahil olmak üzere GRASS CBS'in betik dilinde bir dizi modül kullanılarak uygulanmıştır. MÖ sınıflandırıcıları, görüntülerden türetilen arazi örtüsü türlerindeki değişiklikleri tespit etmek için kullanılmıştır. Sonuçlar, ilkbahar ve sonbahar dönemlerinde farklı bitki örtüsü koşullarını göstermektedir. Mevcut görüntü sınıflandırma yöntemlerinden farklı olarak, MÖ, yamaların topolojisini modellerken piksellerin spektral yansıması arasındaki farkları dikkate alır. Diğer avantajlar, ML'nin rastgele karar ağaçları oluşturma süreci sırasında komşu manzara yamalarının benzerliğini ölçmek için doku ve spektral özelliklerle ilgili verileri kullanmasıdır. Bu çalışma, MÖ'nin kartografi, UA veri işleme ve jeoenformatik için faydalarını göstermiştir.

Gathering predictors of biodiversity change and reconstructing land cover history in Central Apennines using machine learning and remote sensing data

Keywords
Artificial Neural Network
Decision Tree
Geospatial Data
Ecology
Random Forest
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Abstract

The selection of methods for image processing and software functionality is crucial for monitoring Earth's landscapes. This work presents the use of Machine Learning (ML) methods for remote sensing (RS) data processing. The aim is to perform cartographic analysis of land cover changes with a case of central Apennines, Italy. Technically, we present a ML-based classification method using GRASS GIS software integrated with Python library Scikit-Learn. Image processing using ML methods was investigated by employing the algorithms of GRASS GIS. The data are obtained from the United States Geological Survey (USGS) and include a time series of Landsat 8-9 OLI/TIRS satellite images. The operational workflow of image processing includes RS data processing. The images were classified into raster maps with automatically detected categories of land cover types. The approach was implemented by using a set of modules in scripting language of GRASS GIS, including for non-supervised classification used as training dataset of random pixel seeds. The ML classifiers were used to detect changes in land cover types derived from images. The results show different vegetation conditions in spring and autumn periods. Unlike the existing methods of image classification, ML considers the differences among the spectral reflectance of pixels when modelling topology of patches. Other advantages are that ML uses data on texture and spectral features to measure the similarity of neighbouring landscape patches during the process of generating random decision trees. This study demonstrated the benefits of ML for cartography, RS data processing and geoinformatics.

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1. Introduction

1.1. Background

The increasing volume of Earth observation (EO) data and speed of satellite imagery acquisition driven by the development in Remote Sensing (RS) technologies make it possible to monitor Earth's surface with unprecedented detail and frequency. Current methods of RS data processing in Geographic Information System (GIS) struggle to detect and quantify spatial processes and derive information visible from space. Monitoring of many natural phenomena (land cover changes, earthquakes, tsunami, floods, landslides) and social activities (smart agriculture, effective land planning, decisions on urbanization) are linked to optimized map making using RS data. In this process, using RS data affects the functionality and informativeness of maps and provides geospatial information to support decision making. Therefore, there is a need for automated methods that can process RS data to effectively derive and visualize information.

The machine learning (ML) and deep learning (DL) technologies and growth of automation algorithms have greatly widened the possibilities of generating maps based on RS data. The integration of ML in RS data processing significantly improves the quality of RS-based maps through improved precision and accuracy of cartographic workflow and possibility to operate with large volumes of spaceborne data in real-time regime. ML applications and algorithms of programming languages have shown potential in handling geospatial data. These techniques can process data with robustness and high speed (generating a series of maps in a few seconds) while distinguishing shapes of objects or seasonal changes in land cover properties using analysis of time series. Its proven sensitivity makes ML promising for RS data.

This paper presents the use of the ML for EO-based cartographic approach in the case study of Italy. Here we demonstrate the best state-of-the-art practices and applications of the AI tools in RS and cartography. Using the foundations of ML methods of RS data processing, the DL approaches were applied to image processing to overcome the challenges in EO-driven cartography and explore the applications of using AI/ML in RS data analysis in central Italy. We focus on the capability of ML/DL methods for detecting changes in Earth's landscapes, quantifying environmental dynamics and processes related to climate change and discuss these technologies as a solution to future RS challenges.

1.2. Study area

1.2.1. General ecological characteristics of the region

The study area is located in central Italy, (Figure 1). Landscapes of central Italy include a unique mosaic of land cover types. To mention a few most important ones, these encompass broadleaved forests, coniferous forests, arable lands (olive plantations, vineyards, fruit trees and berry plantations) (Baldini, 2003; De Luca et al., 2024), pastures, terraced mountainous landscapes (Tecilla & Cosner, 2024; Lemenkova, 2020; Cavalli et al., 2013), wetlands and contrasting coastal marine environments along the Adriatic (Mačić, 2014), Tyrrhenian (Renda & Gıacobbe, 2021) and Ligurian Seas.

1.2.2. Water balance and the impacts of climate change

Droughts caused by climate change and exacerbated by the ongoing anthropogenic processes of land use in rural Italy affect fragile ecosystems in the central Apennines. These ecosystems have high importance for human water resources at the European Union (EU) regional level and the local and mesoscale climate (Antrop, 2005).

Figure 1. Landsat -8 OLI-TIRS satellite image with depicted geographical features: Lake Trasimeno, Lake of Bolsena and Central Apennines. (Source: USGS. Image modification: Author).

Besides, grasslands and forests in mountainous areas of Apennines are ecologically significant for Italy, due to their primary role in maintaining balance of unique biodiversity and resilience of vulnerability to climate change (Vessella, 2024; Agnoletti et al., 2019).

1.2.3. Measurement techniques and methodological approaches

In ecohydrology, changes in land cover types reflect water balance that is available for vegetation. Measuring these parameters can be resolved by separating evapotranspiration into evaporation from surfaces inside the forest canopies or forest landscapes and transpiration by the vegetation (Maselli et al., 2004).

In humid subtropical climate that is typical for central Italy, high and constant fluctuation in humidity is known. This includes variations in droughts to wet periods with diverse frequency and lead to land degradation (Agnoletti, 2007). Such a specific climate setting affects the sustainability of ecosystems which heavily rely on groundwater as a primary water source (Salvati & Colantoni, 2013). The surrounding mountainous landscapes are strongly affected by regional climate settings. Dry periods are characterized by low precipitation and high temperatures, while wet periods are notable for occasional floods, landslides in mountainous regions and high variations in temperature.

Climate extremities in central Italy are reflected in all components of ecosystems of Apennines: soil, vegetation coverage and land cover types (Calfapietra et al., 2015; Barbati et al., 2012) Nevertheless, the relevance of seasonality of water balance and fluctuations of land cover and vegetation coverage in lakes of Parco Nationale del Lago Trasimeno and Lago di Bolsena is still largely unknown. For the landscapes of Mediterranean climate and coniferous forests of Central Apennines, water balance is influenced by climate and geological properties (mineral content of soil) that enables water infiltration to supply groundwater horizon. At the same time, soil properties directly affect the capacity of groundwater table to accumulate in reservoirs for maintaining water balance, which is crucial for dry periods with occasional droughts to support vegetation and root system (Ball & Douglas, 2003).

This study aims to evaluate changes in land cover types in selected region of Central Italy using satellite images. The objective of this paper is to apply ML methods for cartographic analysis and mapping. The research question of the present study is following:

According to the literature review and analysis of the state-of-the-art research on Italy there are following identified knowledge gaps: the presented two lakes are not evaluated using ML learnign methods and RS data. In view of the missing research on this specific area, the objective of the study is to evaluate the environmetnal dynamics in the Central Alps using RS data.

1.3. Objectives and goals

1.3.1. The objective of the study and the identified gap in the literature

The aim of this study was to estimate, for the first time, the effects of seasonal meteorological variations on land cover types around the lakes of Lago Trasimeno and Lago di Bolsena and Central Apennines. While previous studies have measured different components of the water balance, little is known about the frequency and influence of seasonal effects of droughts on landscapes and land cover types in Central Apennines.

This study aims to answer the following question:

How do seasonal climatic fluctuations affect land cover types around Central Italian lakes and mountainous areas?

To answer primary question, we detail the following auxiliary questions:

(a) What is the direct contribution of climate to land cover change?

(b) What do the drivers of biodiversity change and landscape dynamics in Central Italy?

(c) What are the most dominating vegetation types controlled by the distribution of soil?

(d) What is the role of ML in the automated identification of patterns on the satellite images?

(e) Are there any regional differences between vegetation types around the two lakes?

(f) What is the role of the RS data as sorce of information for cartographic modelling?

To answer these questions, we complemented a highly automated cartographic workflow for RS-based monitoring of the study area around the two lakes. The methodology is based on the Machine Learning (ML) approach in geoinformatics. Variations in the biodiversity and land cover types on the several satellite images captured in different seasons are routinely performed using GRASS GIS using scripts implemented by modules of this software.

1.3.2. Description of the study areas and rationale for their selection

In this study, we compared land cover changes in three contrasting areas of Central Italy, (Figure 1):

1. National Park – Lago Trasimeno (Umbria region)
2. National Park – Lago di Bolsena (Lazio region)
3. Central Apennines and coasts of the Adriatic Sea (Marche region and Acona district)

High importance of these fragile ecosystems for global sustainability consists in balancing water resources on Apennine Peninsula and the local and mesoscale climate (Salvati et al., 2016). A special role is played by the two lakes located in centre of the country near the western border – Lago Trasimeno and Lago di Bolsena. While previous studies have measured different components of the water balance in Italy (Corbari & Mancini, 2014; Onofri et al., 2011; Caparrini et al., 2004), little is known about the frequency and influence of seasonal climate fluctuations in the land cover types and water balance around these lakes.

1.3.3. Methodological approach: The use of Machine Learning and GRASS GIS

This study employs a Machine Learning (ML) approach to satellite image analysis in Central Italy. This approach was selected to define changes in land cover types that reflect variations in water balance during seasonal period of 5 years. To assess the role of the climatic variations on vegetation coverage in lacustrine and mountainous ecosystems, we conducted a comprehensive study of a satellite image analysis using a machine learning (ML) approach implemented in GRASS GIS.

1.3.4. Water balance and soil-related factors during dry and wet periods

During dry periods with extreme heat and no rainfall, ground water remains the only available water resource for vegetation. This affects lacustrine and mountainous ecosystems of Central Italy. Groundwater in soil supports the functionality of the surrounding ecosystems. In turn, diverse types of soil moisture influence the saturated zone where pores and rock fractures are filled with water and form water table.

During wet periods and rainfalls, the variability of soil water content is increased by drainage, because coarser texture of soil drains faster than finer-textured parts (Lindh & Lemenkova, 2022, Lindh & Lemenkova, 2023; Batey, 2009). Besides, complex, diversified and ragged geomorphology of central Italy and Apennine Mountains also plays important role in accumulation of water which affects vegetation (Tarolli & Straffelini, 2020). Besides rock content, smooth topography, micro-relief and groundwater table position are key factors affecting water flow paths and root system characteristics.

1.3.5. Water flow pathways and evapotranspiration in ecosystems of Italy

In hydrological approaches with a focus on contrasting ecosystems in lacustrine and mountainous environments, water balance and land cover type modelling are widely based on simplifications and model generalizations. Existing experimental studies evaluate different components of water cycle in rivers and lakes using direct measurements. Scarce existing studies evaluate land cover types during periods of short flash floods in mountains and their seasonal fluctuations. A modeling technique is often used to evaluate one or more of the balance's components indirectly (Isaia et al., 2014).

Major atmospheric boundary fluxes such as evapotranspiration (evaporation and transpiration) and irrigation and the lower boundary fluxes above the mountainous lakes such as soil percolation are essential elements of water balance and environmental sustainability of mountainous forests of Central Italy. This requires studying the mechanisms of their functions within water cycle. In this regard, remote sensing data present valuable source of information supporting research on areas affected by natural hazards: droughts and floods during dry and wet periods, respectively.

Changes in landscapes reflect variations in annual water balance and all its components of lacustrine environments and mountainous landscapes of Central Apennines based on data measured in 2018-2023. To estimate the land cover, change reflecting water balance in Central Italy, we measured the relative contribution of the pixels corresponding to land cover types and ecosystem components in the water balance at the catchment level. It is like other Mediterranean ecosystems (e.g., Greece, Spain, Türkiye, Croatia, France), climate change has a key influence on the annual and seasonal land cover changes and water budget. Likewise, lacustrine environment and mountainous ecosystems are affected by climate variations. Moreover, climate has noticeable impact under certain meteorological conditions of Central Italy, as demonstrated on time series of the processed satellite images.

2. Study area

The topography of the Central Apennines is characterized by diversity of accumulated and depleted landforms that resulted from the millennial history of geologic formations of Apennines, (Figure 2). The area of central Apennines is notable for high forest cover and high biodiversity according to the soil types. The dominating vegetation species include Silver fir, Norway spruce, Beech, Black pine, Birch). Groundwater represents an essential source of water availability in Central Apennines. Nevertheless, effects of the water balance components on land cover types in context of droughts and climate change are surrounded by considerable uncertainties.

Meanwhile, numerical assessment of water balance components using satellite images and ML methods is crucial for sustainable management of water basin and analysis of water cycle and land cover changes in Central Italy – a country with contrasting climate and occasional climate hazards (droughts, avalanches, landslides and floods). Unpredictable and variable rainfall patterns over Italian Peninsula, high temperature variability, and scarcity of water, typical central regions, are affected by climate change in environmental processes. Land cover changes in Central Italy reflect availability of water in mountainous regions. Such environmental processes are expected to become even more crucial under climate change conditions. Vegetation interacts profoundly with the water cycle captured from ground water. This influences both water availability for human needs and the distribution between sensible heat and latent heat. Climate-environmental interactions over Italy present complex mechanism of ecosystems sustainability. For instance, in mountainous regions of central Apennines, the primary cause of land desertification and land cover change is degradation of vegetation. In turn, one of the main causes of vegetation deterioration is water stress.

The water cycle mechanisms are inextricably linked to the water required in soil for vegetation development (Brady & Weil, 1999). In turn, they are influenced by climate change, seasonal variations and effects of anthropogenic activities in central Italy. Mountain regions of Apennines and lakes – Lago Trasimeno and Lago di Bolsena – are essential sources of water in the surrounding ecosystems. As a result, changes in land cover types influenced by water availability have an impact extending far wider than their actual range. However, they are also strongly affected by climate change with past and projected warming exceeding the global average (Boisvenue & Running, 2006). The variety of landforms and topographic structure created conditions for diverse soil types, (Figure 3).

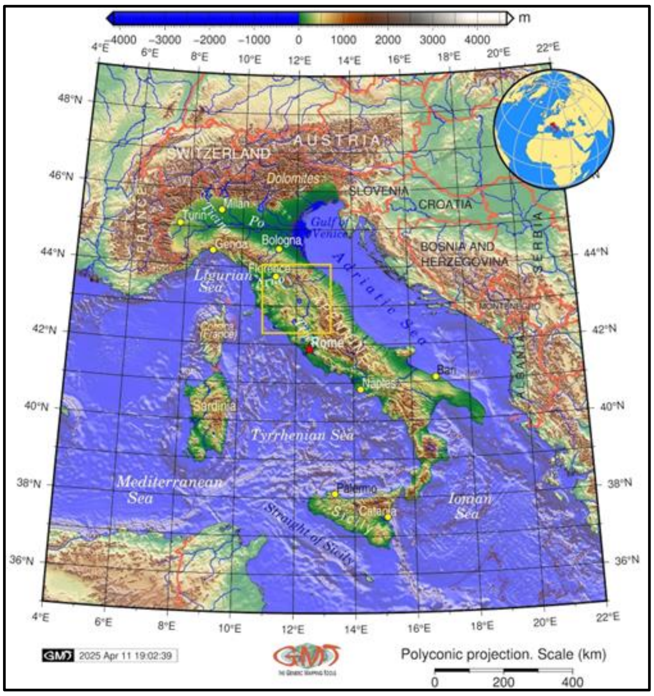

Figure 2. Study area and location of the satellite images. (Source: Author. Software: Generic Mapping Tools (GMT)).

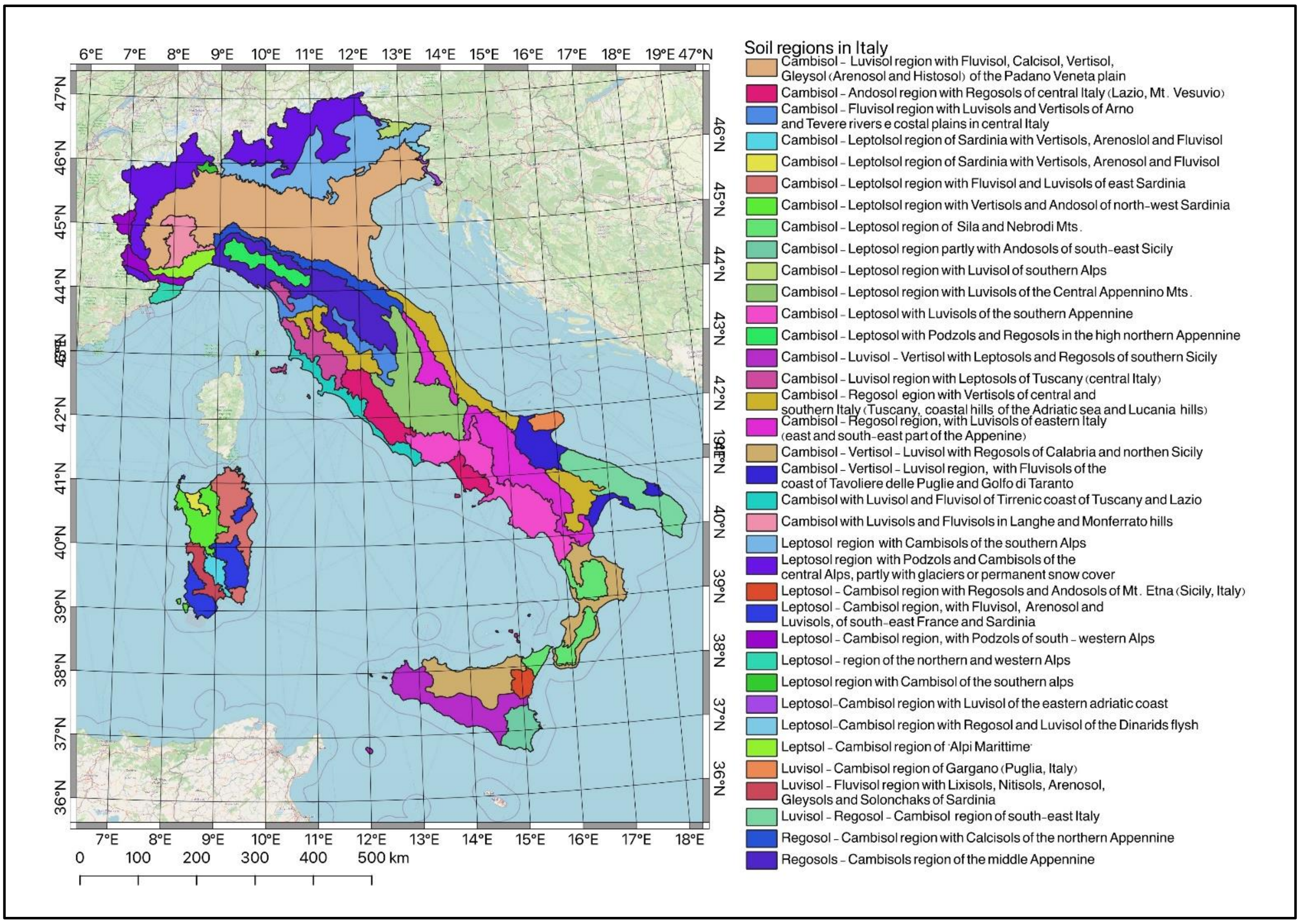

Figure 3. Soil types in Italy: 10 major categories generalised from the database with thematic maps showing soil regions of Italy, scaled 1:5,000,000. (Map source: Author. Software: QGIS).

Lacustrine regions are of essential importance for water provision in water-scarce mountainous regions of Italy with an impact extending far wider than their actual range. Besides, they are strongly affected by climate change with past and projected warming exceeding the global average. The distribution vegetation of lacustrine and coastal regions around the Adriatic Sea is driven by the change of climatic and soil conditions along elevation gradients and influenced complex micro-topography and geochemistry.

However, the important link between climate change and vegetation response often remains neglected in studies on Central Italy. Specifically, there are no studies investigating land cover change and water balance in the environments of Lago Trasimeno and Lago di Bolsena. In landscapes of southern Italy (e.g., Basilicata, Calabria, Puglia), seasonal climate fluctuations are mostly dependent on meteorological conditions and effects of droughts (Peres et al., 2023). However, central regions are insufficiently studied. In this regard, this work presents the contribution to the missing research on variations in central Italian landscapes. The goals of this research are aligned to reinforce the environmental objectives of nature protection in European Union (EU), namely:

1. Adaptation to climate change in Central Apennines region of Italy in a spatial-explicit manner using computational remote sensing techniques.
2. Time series analysis to evaluate risks associated to climate change around two lakes – Lago Trasimeno (Umbria) and Lago di Bolsena (Lazio).
3. The protection and restoration of biodiversity and ecosystems of saline lake as unique landscape of mountainous regions (Central Apennines).

3. Materials and Methods

3.1. Conceptual approach

In this study, ensemble learning was implemented using the Random Forest classifier in GRASS GIS to classify Landsat-8 OLI-TIRS imagery from 2018–2023, based on selected spectral bands and specific preprocessing procedures. With existing applications in the environmental and Earth science sector, many studies are currently investigating the applicability of programming algorithms in processing Remote Sensing (RS) data (Lemenkova, 2019; Lemenkova, 2025c). On the one hand, the availability of the RS data supported by the increasingly rising pool of Earth observation sensors and products of satellite missions, both commercial and open, brings new opportunities to the thematic mapping or terrain-based modelling. On the other hand, such challenges require the development of the advanced methods for processing these datasets, as discussed earlier (Lemenkova & Debeir, 2023; Khan et al., 2021; Lemenkova, 2023). In this regard, advanced methods present significant benefits since ML helps avoid subjectivity compared to the traditional cartographic methods using Geographic Information Systems (GIS) (Klaučo et al., 2013; Klaučo et al., 2017; Lemenkova, 2021). For instance, due to the introduced training and randomness in raster data processing ensured by computer-vision algorithms of automated image analysis, ML enables to avoid subjectivity in image classification (Lemenkova, 2024a; Lemenkova, 2024b).

The specific application of the Machine Learning (ML) methods within the cartographic approach consists in the following foundation. The techniques of Random Forest (RF), and ensemble learning enable pattern recognition in the satellite image processing using automated algorithms of the computer vision. This enables to technically minimize the possible errors and misclassification in the pixels assigned to various target classes. As a result, classified imagery are accurately and precisely deciphered and designated classes are recognised using ML techniques. Adopted from the programming and general computer vision domains, the ML well serves the needs of RS data processing and cartography, as demonstrated below.

Environmental techniques of land cover monitoring are largely based on the field observation and in-situ fieldwork. For instance, while transpiration and soil evaporation can be measured directly through sap flow sensors, using canopy chambers, evaporation from lakes and rivers, and coastal wetlands can only be estimated indirectly or through modelling and simulation techniques. Another important parameter is water infiltration in soil, which indicates the flow of water into the ground soil level, followed further as percolation. These parameters still represent major uncertainties to be resolved in the issue of ecohydrology and environmental monitoring.

The rate of wet canopy evaporation in mountain forests can be estimated from eddy covariance measurements or as the differences between precipitation, throughfall and stemflow in arid lands, or those using the conventional Penman-Monteith-equation. Nevertheless, RS data present robust technique and precise source of information for modelling land cover types in response to water fluctuations at precipitation level.

Ensemble learning approach of image processing is the method of image processing that applies several learning paradigms to achieve high-performance satellite image processing. The effects of the ensemble learning resulting in the improved cartographic outputs approach are explained by the integrated power of different tools which bring their benefits to the workflow compared to these algorithms when used alone. In ML-based satellite image analysis, the ensemble learning includes a series of alternative models, such as Random Forest (RF) or decision trees, ensuring a more adjusted workflow. In computer vision, ensemble learning methods of ML are an essential part of automated image analysis and mapping based on these images. Such benefits of ML for cartographic workflow have been reported in some publications in recent decades (Elshewy et al., 2024; Lemenkova, 2025a; Lemenkova, 2025b).

As one of robust ML methods, random forest can be used in diverse environmental applications, including landslide susceptibility assessment (Manzo et al, 2012), forest mapping, lithology analysis, disaster monitoring (Diehr et al., 2025), to mention a few. Moreover, selected works also introduce a modelling method for assessing soil salinity based on remote sensing imagery for agricultural purposes. However, the suitability of specific software that includes these methods as embedded algorithms for image processing requires more attention. In remote sensing, two major methods have been discussed and compared recently: supervised and unsupervised image classification.

3.2. Data and Image Classification Procedure

This research aims to build a workflow for satellite image processing using ensemble learning techniques of Random Forest (RF) algorithm.

Data included eight multispectral satellite images from Landsat satellite mission. Specifically, the sensors used are Landsat 8-9 Operational Land Imager (OLI) and Thermal Infrared Sensor (TIRS images that are projected automatically in the Universal Transverse Mercator (UTM) Zone 33 for Italy in WGS84 Ellipsoid/Datum with the following coordinates, (Table 1).

Table 1. Coordinates of upper and lower left and right corners of the satellite images Landsat 8-9 OLI/TIRS.

Image characteristics	Coordinates
Corner upper left latitude	44.22284
Corner upper left longitude	11.08013
Corner upper right latitude	44.28620
Corner upper right longitude	14.04998
Corner lower left latitude	42.05848
Corner lower left longitude	11.21622
Corner lower right latitude	42.11724
Corner lower right longitude	14.08305

The essential characteristics and feature attributes of the images are summarised in the (Table 2).

Table 2. Metadata of the Landsat 8-9 OLI/TIRS satellite images: major technical characteristics of scenes with cloudiness.

Date	Satellite Scene ID	Cloud %
20/04/2018	LC81910302018110LGN00	0.55
27/09/2018	LC81910302018270LGN00	0.26
22/03/2019	LC81910302019081LGN00	0.67
14/09/2018	LC81910302019257LGN00	0.06
14/03/2022	LC81910302022073LGN00	7.41
06/09/2022	LC81910302022249LGN00	0.06
17/03/2023	LC81910302023076LGN00	2.52
03/09/2023	LC91910302023276LGN00	4.24

Each Landsat image comprising the dataset was processed, and the maps were visualised in 2018, 2019, 2022 and 2023 for spring and autumn periods. For import, the ‘r.import’ module was used, and then the multispectral bands were grouped together using command ‘i.group’. This enabled to integrate raster map layers in a collection of bands and assigned them to a cluster.

Based on integrating several ML approaches, it includes the decision trees algorithm with controlled variance that improves the accuracy of image partition. Technically, the research is performed using the ML-based modules of the Geographic Resources Analysis Support System (GRASS) GIS software. The aim of this study is to dissect the effects of seasonal land cover types of fluctuations in the central Italy on spatial heterogeneity and patterns of the land cover patches in the surrounding lacustrine and coastal landscapes of Central Italy, Apennines.

The practical goal of this study is to apply the scripting techniques of GRASS GIS with the objective to assess the novel method of ensemble learning with a case of RF algorithms applied to cartographic workflow adopted from previous studies (Lemenkova, 2024c). The RF approach was selected as a valuable method since it uses the computer vision approaches that have the anti-noise capacity which is useful for image processing used for mapping changes in the basin from evaporated to flooding period. Such benefits are useful when processing data with high spectral heterogeneity and landscape fragmentation as in Central Italy.

3.3. Applicability

In view of repetitive droughts in central regions of Italy, current research contributes to developing the regional adaptation strategies to climate change in Europe including the following categories:

- Technological level: monitoring land cover types for detecting drought-tolerant crops and adjusting irrigation types in central Italy:
- Agronomic level: crop diversification in Italy
- Institutional level: insurance schemes, policy reforms for climate change adaptation in EU.

Stakeholder involvement into climate change monitoring in Italy at practical level relies on quantitative analyses and mapping that match qualitative versions of possible climate scenarios in drought-prone regions in central Apennines.

3.4. Organization and structure

The paper is organized as follows. Chapter 2 explains the ensemble learning method with RF approach to RS data processing. The methodology is presented in snippets of GRASS GIS code. In the following section, the results of image classification are presented. Finally, the last section concludes the paper with the discussion regarding the landscapes and climate-related land cover changes in the Central Apennines. The ML methods of image processing were employed using different mathematical algorithms embedded in the GRASS GIS. These approaches were used for image classification to detect changes in land cover types over the study area in central Italy and map them during the 5-year period of 2018 to 2023.

3.5. Algorithms

Several ML algorithms embedded in the GRASS GIS have been used in this study to classify Landsat 8-9 OLI/TIRS multispectral satellite images based on certain feature combinations. Specifically, the tested classifiers included Random Forest (RF), Support Vector Machine (SVM), and Classification using clustering techniques (k-means). The area is covering the region of central Apennines in a regional scale. Diverse land cover types have distinct spectral reflectance that can be recognised using computer vision algorithms. This principal characteristic of the satellite images is used for image processing in GRASS GIS. Technically, the script with defined parameters of image classification was applied to each ML algorithm for satellite image processing. The classified areas detected on the satellite images were technically validated against CORINE land cover types using correlation error matrices and accuracy analysis. As previously described, classification was performed using RF, SVM, DT, and MLPC algorithms. Among them, the SVM method was reasoned as the most effective approach.

4. Results and Discussion

4.1. Classification Accuracy and Algorithm Performance

In the database, the categories included following classes: *'Non-irrigated arable land', 'Permanently irrigated land', 'Rice fields', 'Vineyards', 'Fruit trees and berry plantations', 'Olive groves', 'Pastures', 'Annual crops associated with permanent crops', 'Complex cultivation patterns', 'Land principally occupied by agriculture, with significant areas of natural vegetation', 'Agro-forestry areas'*, (Figure 4).

We tested the ML algorithms in order to compare them and define the appropriate classifier. The performance of each classifier was evaluated based on overall classification accuracy and Cohen's Kappa coefficient, using the Corine Land Cover (CLC) Land Use Land Cover (LULC) dataset as a reference. Defining optimal classification approach supports the accurate discernibility of the land cover features, and to map the variability of landscapes over time. The data were validated against the CORINE land use land cover (LULC) Copernicus database which was generalized for the study area. This was done using vector geometry tools in QGIS.

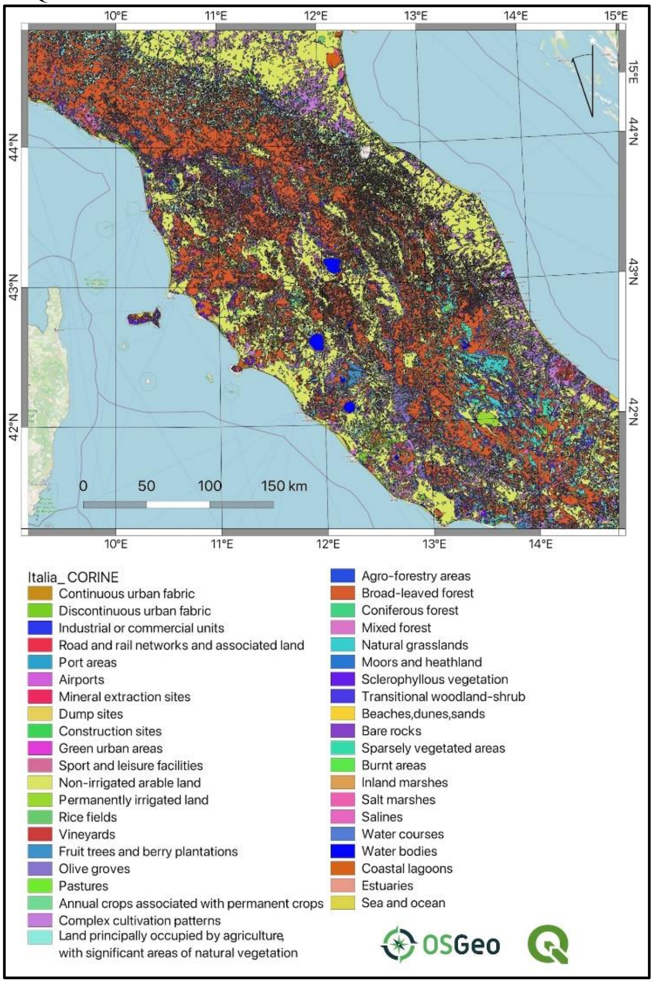

Figure 4. Validation of land cover types according to CORINE categories. (Mapping software: QGIS. Source: Author).

4.2. Spatiotemporal Changes in Land Cover

The paper compares land cover type variations in these three regions and evaluates the role of climate fluctuations in the water balance using satellite images Landsat. In this study, we performed a Machine Learning (ML) – based analysis of satellite imagery to visualise and evaluate fluctuations of the two lakes in central Italy and Apennine Mountains using seasonal series of satellite images.

The cartographic plotting of the images with ML methods is presented in (Figure 5) and (Figure 6). The land cover types in the northern Italy were identified as following 10 classes according to the existing adopted, modified and generalized classification schemes: 1) urban areas, 2) arable lands and agricultural fields, 3) water areas, 4) needle-leaved trees, 5) bare lands and soils, 6) pastures, 7) permanent herbaceous vegetation, 8) croplands, 9) broadleaved trees, 10) shrubland. Final mapping outcomes were carried out by the classification using the four algorithms (RF, SVM, DT and MLPC) from four satellite images allows the analysis of the interannual effects (2019, 2022 and 2023) on the types of land cover in Apennines.

4.3. Climatic and Hydrological Interpretations

Special focus is placed on the hydrological interpretation and environmental settings of the two lakes. The ground water horizons in both lakes – Lake Bolsena and Lake Trasimeno – represent an additional source of water in surrounding landscapes of central Italy, not quantified by the commonly used methods, to the overall water input. Lakes play an important role of a water condensate which is formed in larger quantities at higher temperatures.

4.3.1. Hydrological Role and Morphology of Lake Trasimeno

Lake Trasimeno belong to the tectonic types and alluvial origin. Located in the province of Perugia, in the Umbria region, it has a surface area of 128 km². Lake Trasimeno is the largest lake in central Italy and a transboundary area of laminar lake in shallow topographic depression. This lake has shallow depth (average 4.3 m, max – 6 m). Climate fluctuations play an important role in the land cover types and water balance of Central Apennines and related two lacustrine basins. This is especially notable for the periods based on the observation during numerous days with mixed precipitation (satellite images for spring), maintaining for several days a high relative humidity inside the lacustrine environment composing the landscape (during winter period). Moreover, lacustrine processes related to water collection is crucial for water supplies of two lakes – Lake Bolsena and Lake Trasimeno, maintaining surface water in the conditions of climate warming and groundwater that are critical for Mediterranean ecosystems of Italy.

4.3.2. Climatic Vulnerability and Geomorphology of the Lake Bolsena

The basin of Lake Bolsena developed from the lake in central Italy, located in upper Lazio, in the northern part of the province of Viterbo (Alta Tuscia). Formed over 300,000 years ago following the caldera collapse of some volcanoes of the Volsini mountains complex that accompanied the volcano-tectonic subsidence of the area, nowadays, it presents the depression that collects waters from three drainage systems off the highlands, and the surroundings river network system.

This lake is the largest lake of volcanic origin in Europe. The topography of the region is generally hilly which causes the diurnal oscillation of wind and variations in thermo-topographical gradients. Highly changing hydro-geomorphological setting of the deltaic drainage system of lake leads to the regular fluctuations of the local weather where temperature changes according to diurnal and seasonal cycles. The changes in land cover types reflected difference between water input in form of precipitation over the lake and surroundings and water output as evapotranspiration and water discharge, plus the variation in the soil water content, demonstrated variations in different months from March to August, within the uncertainty range of the measurements.

Image analysis demonstrated that 'pastures' and 'herbaceous vegetation' classes have the increase in coverage of occupied areas at 15% and 17%, respectively, while coniferous forests decreased by 5% (regional species: Silver fir, Norway spruce, Beech, Black pine, Birch).

Shrubland expanded to 29% indicating graduate replacement of other vegetation types. For broadleaved forests, the results show insignificant increase at 2%. Specifically, this can be explained by the high increase in herbaceous vegetation related to climate effects, as reported in spring periods between 2018 and 2023. The results of image processing using ML are presented in figures below. The results are illustrated on a series of maps showing the distribution of land cover types and how landscapes in Central Apennines change in a short-term 5-years period, (Figure 5) (for 2018) and (Figure 6) (for 2023).

For example, in periods of droughts and dry seasons (summer heat), ecosystems with high and constant frequency of droughts are supplied by groundwater that in turn is supported by lakes. Moreover, the occurrence of higher temperatures and raindrops creates favourable conditions for such processes and land cover fluctuations in the lacustrine environments. This can be illustrated by the lacustrine basins, where mixing of fresh and rainfall groundwater contributes to the hydrological and geochemical and multi-environmental water balance. In turn, water supply supports functionality of vegetation in the surroundings land cover types. However, the relevance of aquifers for the water balance of mountainous landscapes of Apennines is still largely unknown and changes in land cover types in these regions are more profound.

The amount of water intercepted by the lakes in diverse seasons varies with temperature, wind and duration of droughts. Depending on these characteristics, for instance, severe heat waves, changing weather patterns, is a major predictor of water interception rates. Nevertheless, important features are the occurrence of droughts and duration of the period without stable precipitation which may intercept high amounts of water going to groundwater. Thus, they store water inside the lake, sustain evapotranspiration in the surrounding vegetation, decrease the ratio of water, and increase the air humidity. Climate-related hazards such as frequent and severe droughts, unstable water inflow and extreme temperatures typical for arid and semi-arid climate of Central Apennines affect rare species that use lacustrine ecosystems as shelter habitats.

The influence of seasonal climate effects on the water balance in the landscapes surrounding two lakes – Lake

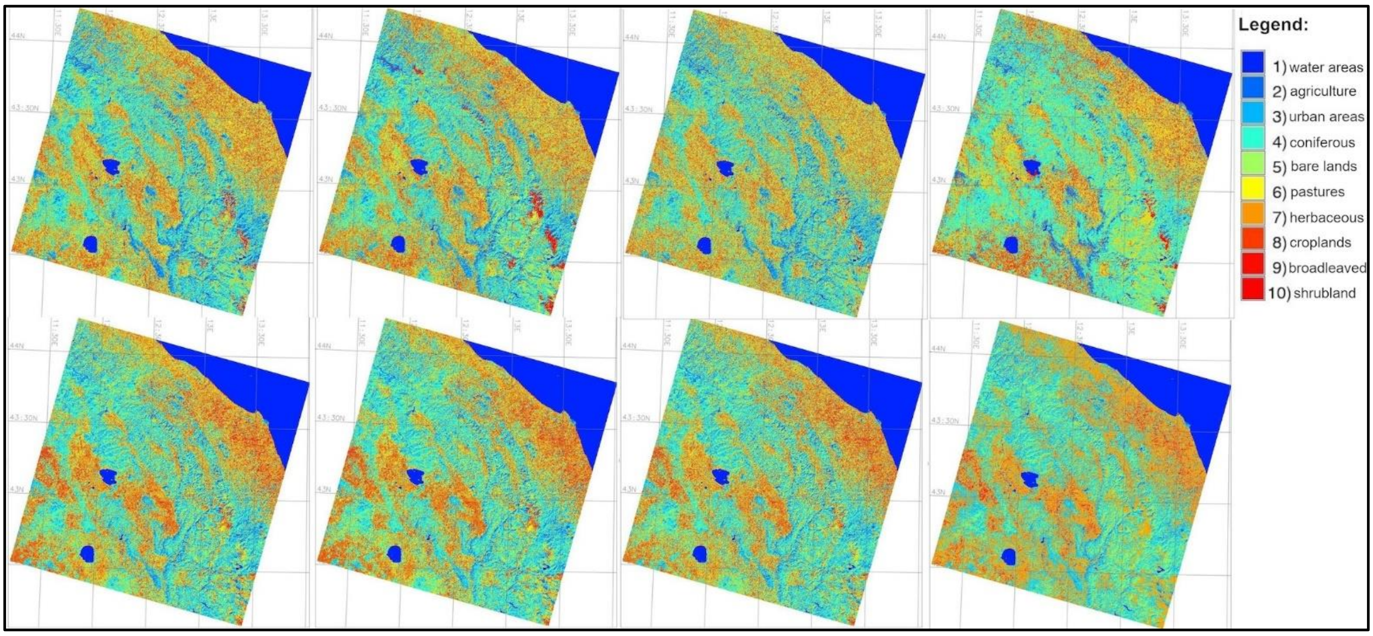

Figure 5. Time series analysis of satellite images on 2018: classified 10 key land cover types of Software: GRASS GIS. (Source: author).

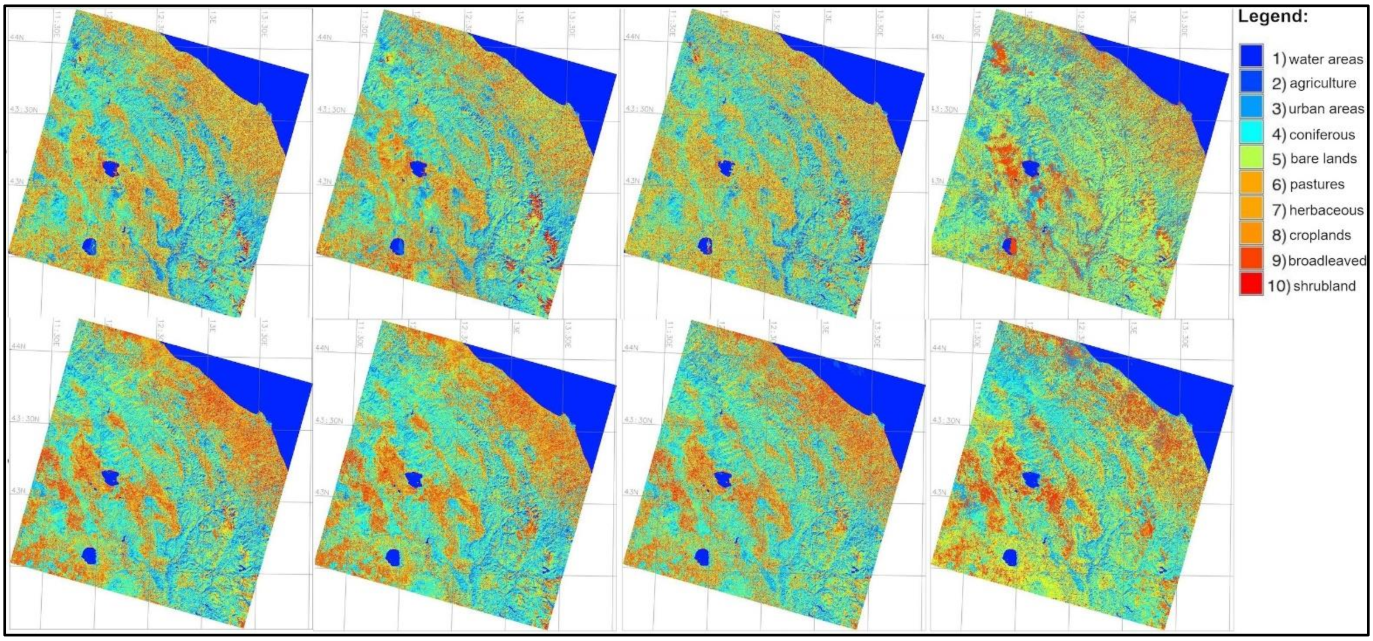

Figure 6. Time series analysis of satellite images on 2023: classified 10 key land cover types of Software: GRASS GIS. (Source: Author).

Bolsena and Lake Trasimeno – was studied by estimating and comparing land cover types by satellite image analysis. In this way, current study contributed to the environmental analysis, apart from existing studies that evaluated hydrological analysis of water interception and changes in shoreline detectable on the satellite images. In our study, we identified dynamics of land cover classes at different patterns of landscapes with an adjacent land cover type. To this end, the classified maps of 10 land cover types of composites were created using the available dataset, which are presented in (Figures 5) and Figures 6) from the Landsat bands. The raw dataset illustrates the environmental changes in Central Italy that fluctuates from the wet period to the dry period with general calendar gap of 5 years (2018-2023).

In mountains, oscillations in hydrological patterns from seasonal spring flooding (including related hazards such as avalanches and landslides) to desiccation during summer heat indicate the progressively increasing aridity and desertification of the Central Apennines and mountainous river network affected by regional droughts, impacts from the climate change and anthropogenic activities due to active crop cultivation (Ceotto, 1999). Two distinct seasons – dry from April to September and wet from October to March – distinctly divide the climate and environmental patterns, while the intra-seasonal water influx is unstable and depend on the mountainous streams forming occasional flash floods in Central Apennines. As for coastal regions along the coasts of the Adriatic Sea, unique landscapes create a habitat for ecosystems used by migrating birds and rare species as habitats. In these areas, the ability of wetland birds to predict rain fronts and showers using changes in pressure gradients enables them to rapidly find water available in reservoirs and coastal wetlands. This results in several migrating rare birds that use this region as a destination place during droughts in other regions of Italy.

Apart from the physiological aspect of water use by the plant, the capacity of vegetation around saline lake to act as a climate regulator is climatologically relevant at a local scale for Central Apennines and the regional scale compared to southern regions of Italy prone to droughts. Severe droughts in recent years lead to disasters with consequences both for social well-being (agrarian sector) and environmental sustainability. Moreover, the experience of mountainous regions demonstrated high susceptibility to drought, sensibility of heat, increased the temperature and decreased the availability of water vapour in the air. Necessarily, such climate processes created feedback in the water cycle, affected the presence of dense vegetation, and caused land degradation, and decreasing the availability of water vapour.

5. Conclusion

The central contribution of this study lies in the use of ML within GRASS GIS for monitoring land cover changes in drought-prone Mediterranean environments. As a central added value of this paper, we demonstrated that ML technique of GRASS GIS software is a robust tool for image analysis by applying the state-of-the-art Random Forest (RF) approach to a RS corpus of data. The aim of this research was to classify a time series of images covering ecosystems near two lakes – Lake Bolsena and Lake Trasimeno – in various periods of the year in order to detect landscape dynamics. Currently, the studies focusing on central Italy are missing ML components for environmental remote sensing. However, the data analysis based on Earth observations will be expanded and environmental information will be retrieved using ML methods. Here, we presented the workflow of image processing by GRASS GIS using RF approach and illustrated gradual landscape changes in the surroundings of the Central Apennines. General performance of GRASS GIS demonstrated reliable results in image processing.

This research complements, in a climate-hydrological perspective, recent evidence that indicates that climate fluctuations play a key role in dampening heat extremes. With a case study of Central Apennines, we studied the selected region of vegetated terrestrial ecosystems above two lakes – Lake Bolsena and Lake Trasimeno. It also attributes to seasonal variations in precipitation that contribute to lacustrine ecosystems and surrounding vegetation. Using satellite images as time series enabled to highlight the role of linkage in the positive feedback between the heat, dry, cool and humid meteorological conditions and their effects on natural vegetation and lacustrine environment in Central Italy.

The capacity of the ecosystems around two lakes was quantified to reflect the scarcity of water and intercept water in the vegetation canopy using RS dataset. The analysed time series provided an estimate of the changes in contrasting land cover types in the lakes and mountains of Central Italy, and capacity in the two different seasons, a dry period with drought (summer months) and a wet period (autumn). The higher water storage capacity of the autumn-winter period depended on the lower temperatures and increased precipitation level, which was comparable in the time series of the satellite images. Such climate fluctuations typically represented by response of vegetation were relevant for the water cycle in central Italy and had a water-holding capacity higher in autumn periods, as assessed on the Landsat images for each scene. The landscape patches are more diversified and fragmented with more details detected for smaller polygons both within and beyond the area of two lakes – Lake of Bolsena and Lake Trasimeno.

The frequency of land cover changes over central Italy was quantified and mapped in a drought-prone central region of the country and assessed the hydrological balance at basin of two lakes – Lake Bolsena and Lake Trasimeno – using satellite images in short-term perspective. As we are now facing a reduction of water vapour in the air due to the global climate change, this possibly causes future disruption of the positive feedback in the water cycle in terrestrial ecosystems. Hence, the presence of the vegetation in central regions of Italy represents a critical element for climate regulation. This evidence is in line with recent studies indicating the capacity of vegetation, even scarce patches, regulates extreme heat conditions in arid and Mediterranean environment of Italy.

Though ML has not been used widely in previous studies focused on central Italy so far, our study revealed that ML techniques combined with satellite images contributed to better understanding of the linkages between the environmental and climate processes. In this way, this study contributed to environmental monitoring of Central Apennines using Landsat-based spatial analysis. The comparison of the classified images enabled to analyse higher net precipitation (soil water recharge) during summer months due to the absence of runoff, and evaporative conditions inside the vegetation coverage.

Contribution of researchers

Polina Lemenkova: Editing, Analysis, Literature review, Modelling, Article writing.

Conflict Statement

The author declares no conflict of interests.

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