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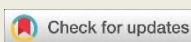
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SPATIO-TEMPORAL ANALYSIS OF LAND USE/LAND COVER CHANGES IN THE JIZZAKH REGION USING RANDOM FOREST ALGORITHM AND REMOTE SENSING DATA

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Key words: land use and land cover (LULC), spatio-temporal analysis, Sentinel-2 imagery, Random Forest algorithm, remote sensing, Machine Learning, Jizzakh region.

ABSTRACT

This study aims to analyze spatio-temporal changes in land use and land cover (LULC) in the Jizzakh region of Uzbekistan between 2016 and 2022. The research is based on multi-temporal Sentinel-2 multispectral satellite imagery and applies the Random Forest machine learning algorithm for supervised classification. Cloud-free images acquired during the vegetation growing season were processed using QGIS with the Semi-Automatic Classification Plugin. The results indicate that bare land dominates the study area, covering 79.79% of the total area, while vegetation accounts for 17.45%, water bodies 2.72%, and urban areas 0.04%. Comparative analysis reveals an expansion of built-up areas and fluctuations in vegetation cover, reflecting the influence of anthropogenic activities and climatic conditions in a semi-arid environment. The study confirms the effectiveness of integrating remote sensing data with machine learning techniques for accurate LULC mapping and provides a reliable basis for environmental monitoring and sustainable land management.

JIZZAX VILOYATIDA YER FOYDALANISHI VA YER QOPLAMI O'ZGARISHLARINI MASOFAVIY ZONDLASH MA'LUMOTLARI VA RANDOM FOREST ALGORITMI YORDAMIDA MAKON-VAQT TAHLILI

Kalit so'zlar: yer foydalanishi va yer qoplami (LULC), makon-vaqt tahlili, Sentinel-2 tasvirlari, Random Forest algoritmi, masofaviy zondlash, mashinaviy o'rganish, Jizzax viloyati.

ANNOTATSIYA

Ushbu tadqiqot 2016–2022 yillar oralig'ida O'zbekistonning Jizzax viloyatida yer foydalanishi va yer qoplami (LULC) o'zgarishlarini makon-vaqt jihatdan tahlil qilishga qaratilgan. Tadqiqot Sentinel-2 multispektral sun'iy yo'ldosh tasvirlari asosida olib borilib, nazoratli tasniflash uchun Random Forest algoritmi qo'llanildi. O'simliklar vegetatsiya davrida olingan bulutsiz tasvirlar QGIS dasturi hamda Semi-Automatic Classification Plugin yordamida qayta ishlangan. Natijalar shuni ko'rsatdiki, hududning 79,79% qismini yalang'och yerlar egallaydi, o'simlik qoplami 17,45%, suv obyektlari 2,72%, shahar hududlari esa 0,04% ni tashkil etadi. Taqqoslash natijalari qurilgan hududlar kengaygani va o'simlik qoplami o'zgaruvchanligini ko'rsatdi. Tadqiqot masofaviy zondlash va mashinaviy o'rganish integratsiyasi LULC xaritalashda yuqori samaradorlikka ega ekanini tasdiqlaydi.

Land use and land cover (LULC) change analysis plays a pivotal role in understanding environmental dynamics, ecosystem processes, and sustainable land management. Rapid urbanization, population growth, and increasing anthropogenic activities have significantly altered global land cover patterns, leading to critical challenges such as land degradation, biodiversity loss, and climate change [1, P.1; 2, P.1]. Therefore, accurate monitoring of LULC changes is essential for effective environmental assessment and informed decision-making. Remote sensing technologies have become indispensable tools for LULC mapping due to their capability to provide continuous, large-scale, and multi-temporal observations of the Earth's surface. Satellite data, particularly from Sentinel-2 missions, are widely used for detecting spatial and temporal variations in land cover owing to their high spatial and temporal resolution [3, p.10; 4, P.1].

Furthermore, the integration of remote sensing with geographic information systems (GIS) has significantly enhanced the capacity to analyze land use dynamics at regional scales [5, P.24].

In recent years, machine learning (ML) algorithms have been extensively applied in LULC classification, demonstrating improved performance compared to conventional methods. Algorithms such as Random Forest (RF), Support Vector Machine (SVM), and Classification and Regression Trees (CART) have proven highly effective in processing complex remote sensing datasets [6, P.5; 7, P.25]. Among these, the Random Forest algorithm is particularly distinguished by its robustness, resistance to overfitting, and high classification accuracy across diverse environmental conditions [8, P.2785; 9, P.294]. Numerous studies have successfully applied Sentinel-2 imagery and machine learning techniques to analyze LULC changes in various regions. These approaches have demonstrated strong capability in identifying spatial patterns and temporal variations in land cover [10, P.8; 11, P.170]. Moreover, machine learning-based approaches have been shown to outperform traditional classification techniques in terms of reliability and efficiency [12, P.90; 13, P.1].

Despite these advancements, research focusing on LULC dynamics in Central Asia remains limited, particularly in the Jizzakh region of Uzbekistan. This region is characterized by heterogeneous landscapes, including agricultural lands, semi-arid environments, and expanding urban areas, making it a significant case study for LULC analysis. Therefore, this study aims to analyze spatio-temporal changes in land use and land cover in the Jizzakh region between 2016 and 2022 using Sentinel-2 satellite imagery and the Random Forest algorithm. The specific objectives are to: (i) generate LULC maps for both years; (ii) analyze changes in land cover distribution; and (iii) compare class proportions to identify temporal trends.

DATA AND METHODOLOGY

The study was conducted in the Jizzakh region, located in the central part of Uzbekistan, Central Asia. The region lies approximately between latitudes $39^{\circ}30'$ – $41^{\circ}00'$ N and longitudes $66^{\circ}30'$ – $69^{\circ}00'$ E, covering an area of about 21,200 km². The Jizzakh region is characterized by diverse natural landscapes, including mountainous, semi-arid, and desert environments.

The northern and western parts are dominated by desert and semi-desert areas influenced by the Kyzylkum Desert, while the southern and eastern parts consist of foothills and mountainous terrains of the Turkestan mountain range. This geographical diversity makes the region particularly suitable for comprehensive LULC analysis. The climate of the study area is continental, with hot summers and cold winters. The average annual precipitation ranges from 200 to 400 mm, with most precipitation occurring during the spring and winter seasons. Due to low precipitation and high evaporation rates, vegetation cover is unevenly distributed across the region. Agriculture constitutes a key component of the regional economy, particularly in irrigated areas where crops such as wheat, cotton, and vegetables are cultivated. In addition, ongoing urban expansion and land use changes are observed around major settlements. These factors contribute to dynamic land cover transformations, making the Jizzakh region an important case study for spatio-temporal LULC analysis. The location of the study area is presented in Figure 1.



Figure 1. Geographic location of the study area in Jizzakh region, Uzbekistan

This study employs multi-temporal satellite imagery acquired from the Sentinel-2 mission, which provides high-resolution multispectral data suitable for land use and land cover (LULC) analysis. Sentinel-2 imagery was selected due to its high spatial resolution (10 m) and frequent revisit cycle, enabling effective monitoring of land surface dynamics.

Cloud-free images corresponding to the years 2016 and 2022 were selected to ensure temporal consistency in the analysis. The imagery was acquired during the vegetation growing season (April–October) in order to capture representative land cover conditions. The Sentinel-2 dataset comprises multiple spectral bands. In this study, all relevant bands—including visible, near-infrared (NIR), and shortwave infrared (SWIR) bands—were utilized to enhance classification accuracy and to capture detailed land cover characteristics. These spectral bands are widely applied for distinguishing among major land cover types such as vegetation, water bodies, and built-up areas. All data preprocessing and analysis were conducted using QGIS software, incorporating the Semi-Automatic Classification Plugin (SCP). This platform provides comprehensive tools for satellite image preprocessing, band combination, and supervised classification. A summary of the datasets and spectral bands utilized in this study is presented in Table 1.

Table 1

Description of datasets used in this study

DATA TYPE	SOURCE	SENSOR	BANDS	RESOLUTION	YEAR	DESCRIPTION
Satellite Imagery	ESA Copernicus	Sentinel-2	B2–B12	10–20 m	2016	Multispectral bands used for LULC classification
Satellite Imagery	ESA Copernicus	Sentinel-2	B2–B12	10–20 m	2022	Multispectral bands used for LULC classification
Boundary Data	GADM	–	–	–	–	Administrative boundary of Jizzakh region

Preprocessing

Preprocessing of satellite imagery is an essential step to ensure data consistency and suitability for land use and land cover (LULC) classification. In this study, Sentinel-2 Level-1C images were processed using QGIS software with the Semi-Automatic Classification Plugin (SCP).

Initially, suitable satellite images with minimal cloud coverage were selected for the years 2016 and 2022. The selection of cloud-free scenes ensured better visual interpretation and reliable classification results. The selected images were clipped to the study area boundary (Jizzakh region) to limit the analysis to the area of interest. All available spectral bands were extracted and organized into a band set using the SCP plugin for further analysis.

In addition, True Color Images (TCI) were generated using RGB band combinations (B4, B3, B2) to support visual interpretation and training sample collection.

These preprocessing steps ensured the preparation of consistent and high-quality datasets suitable for supervised classification.

The True Color Images (TCI) are presented in Figure 2.



Figure 2. True Color Images (TCI) of the study area for 2016(a) and 2022(b)

METHODOLOGY

In this study, land use and land cover (LULC) classification was performed using the Random Forest (RF) algorithm, a supervised machine learning method known for its high accuracy and robustness in handling complex datasets. RF is an ensemble learning technique that constructs multiple decision trees during training and determines the final class based on majority voting.

The classification process was conducted using QGIS software with the Semi-Automatic Classification Plugin (SCP). Training samples were manually collected based on visual interpretation of satellite imagery and True Color Images (TCI). All available spectral bands of Sentinel-2 were used as input features to improve classification performance and capture detailed land surface characteristics. The study area was classified into four major LULC classes: vegetation, water bodies, bare land, and built-up areas.

The trained Random Forest model was applied separately to the datasets of 2016 and 2022 to generate LULC maps for each year. The use of a consistent classification approach for both years ensured reliable comparison of land cover changes. The input features used for classification included all relevant spectral bands from the Sentinel-2 dataset (B2–B12), which provide comprehensive spectral information for distinguishing different land cover types.

The Random Forest classifier was trained using a set of labeled training samples, and the model parameters were adjusted to improve classification performance. The algorithm constructs multiple decision trees and reduces overfitting by aggregating their results, thereby enhancing generalization capability. The flowchart of the algorithm is shown in Figure 3.

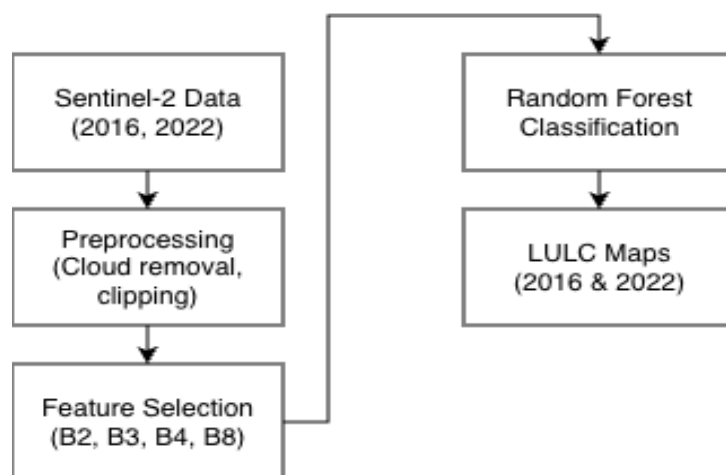


Figure 3. Workflow of LULC classification and change detection process

The trained model was applied separately to the 2016 and 2022 datasets to generate LULC maps for each year. The use of a consistent classification approach for both datasets ensures comparability of land cover patterns over time. The LULC maps are shown in Figure 4.

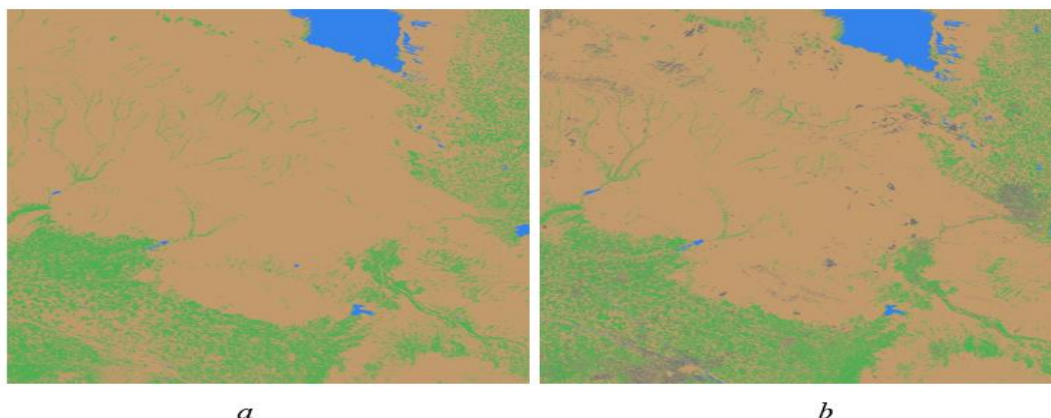


Figure 4. Land Use and Land Cover (LULC) maps for 2016 (a) and 2022 (b)

RESULTS

The land use and land cover (LULC) classification results for the years 2016 and 2022 are presented in Figures 2 and 3, respectively. The study area was classified into four major classes: vegetation, water bodies, bare land, and built-up areas. The spatial distribution of LULC classes shows noticeable variation between the two study years. In 2016, the region was predominantly characterized by bare land, while vegetation and built-up areas occupied relatively smaller proportions. In 2022, changes in land cover distribution are observed, particularly in the expansion of built-up areas and variations in vegetation cover. The True Color Images (TCI) support the interpretation of land surface conditions and confirm visible differences in land cover patterns between the two years. The comparative analysis of class proportions is illustrated in Figure 5. The results indicate an increase in built-up areas, while vegetation shows slight fluctuations. Bare land remains the dominant class in the region, reflecting the semi-arid environmental conditions of the study area. Overall, the results demonstrate dynamic changes in land use patterns in the Jizzakh region between 2016 and 2022.

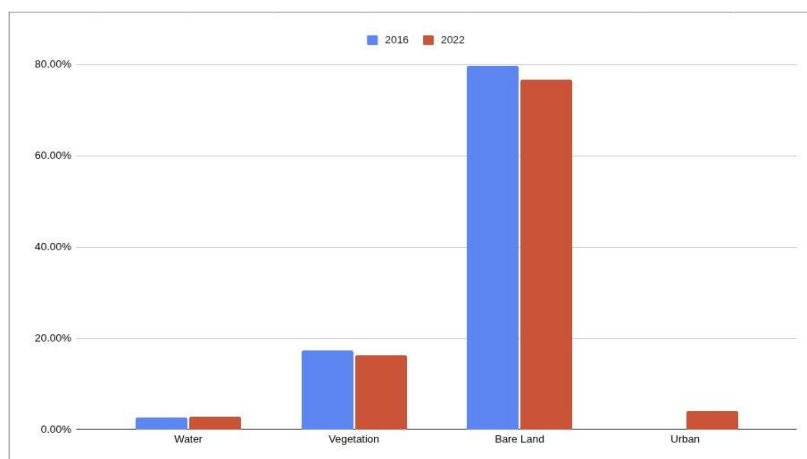


Figure 5. Comparison of LULC class proportions between 2016 and 2022

DISCUSSION

The findings of this study reveal significant changes in land use and land cover (LULC) patterns in the Jizzakh Region between 2016 and 2022. The observed expansion of built-up areas reflects the increasing influence of urbanization and infrastructure development. Comparable trends have been documented in other semi-arid regions, where land transformation is predominantly driven by socio-economic dynamics and regional development processes [12, P.90; 13, P.1].

Variations in vegetation cover identified in this study can be attributed to both natural and anthropogenic factors. Climatic conditions—particularly low precipitation and high evapotranspiration rates—combined with land use practices, play a decisive role in shaping vegetation dynamics. These results are consistent with previous research emphasizing the sensitivity of vegetation in dryland ecosystems [2, P.5]. Bare land remains the dominant land cover class within the study area, reflecting its semi-arid environmental characteristics. However, observed shifts in its spatial distribution indicate ongoing land transformation processes and evolving land use patterns.

The application of Sentinel-2 imagery in conjunction with the Random Forest algorithm proved highly effective for LULC mapping. The use of multi-spectral data enhanced class separability and improved overall classification accuracy. Overall, the results underscore the dynamic nature of land use changes in the Jizzakh region and highlight the importance of continuous monitoring through integrated remote sensing and Machine Learning approaches. These findings provide a valuable basis for regional planning and sustainable land management strategies. This study presents a comprehensive spatio-temporal analysis of land use and land cover (LULC) changes in the Jizzakh Region using Sentinel-2 multispectral imagery and the Random Forest machine learning algorithm. The classification results indicate that bare land constitutes the dominant land cover type, accounting for 79.79% of the total area, which reflects the semi-arid and desert characteristics of the region.

Vegetation covers 17.45% of the area, indicating the presence of irrigated agricultural lands and natural vegetation zones. Water bodies account for 2.72%, while urban areas represent only 0.04%, highlighting the relatively low level of urbanization within the study area. Comparative analysis between 2016 and 2022 reveals notable changes in land cover distribution, particularly the expansion of built-up areas and fluctuations in vegetation cover. These changes are associated with anthropogenic pressures, land management practices, and environmental conditions typical of semi-arid regions. The application of the Random Forest algorithm demonstrates high effectiveness for LULC classification, providing reliable results when applied to multispectral Sentinel-2 data.

The integration of remote sensing data with machine learning techniques enabled accurate detection of spatial patterns and temporal dynamics in land cover. The primary scientific contribution of this study lies in the development of an integrated methodological framework for analyzing land cover changes using multi-temporal satellite imagery and machine learning techniques, particularly in data-scarce environments. The proposed approach ensures methodological reproducibility and can be readily applied to other regions with similar climatic and geographical conditions. From a practical standpoint, the results support environmental monitoring, land resource management, and regional planning. The generated LULC maps and statistical analyses provide a robust foundation for informed decision-making and the development of sustainable land use strategies. Future research should incorporate additional data sources, including vegetation indices such as Normalized Difference Vegetation Index (NDVI), climate variables, and advanced deep learning models such as U-Net and Convolutional Neural Network (CNN), to enhance classification accuracy and improve the understanding of land cover dynamics over time.

CONCLUSION

This study provided a comprehensive spatio-temporal assessment of land use and land cover (LULC) dynamics in the Jizzakh region of Uzbekistan over the period 2016–2022, employing multi-temporal Sentinel-2 satellite imagery and the Random Forest classification algorithm. The results confirm that the study area is predominantly characterized by bare land, which reflects its semi-arid and desert environmental conditions, while vegetation and water bodies occupy comparatively smaller proportions. At the same time, the analysis revealed measurable transformations in land cover structure, particularly the gradual expansion of built-up areas and fluctuations in vegetation cover.

The detected increase in urbanized land indicates the growing influence of anthropogenic activities, including infrastructure development and population-driven land use change. Variations in vegetation distribution were found to be associated with both climatic constraints—such as limited precipitation and high evaporation rates—and human land management practices, especially in irrigated agricultural zones. These findings highlight the sensitivity of land cover systems in semi-arid environments, where even moderate external pressures can lead to noticeable spatial and temporal changes. Methodologically, the integration of multi-spectral satellite data with machine learning techniques proved to be highly effective for LULC classification. The use of Sentinel-2 imagery enabled the identification of fine-scale spatial patterns, while the Random Forest algorithm ensured high classification accuracy and robustness against overfitting. The applied approach demonstrated strong reliability and reproducibility, making it suitable for similar analyses in regions with limited ground-based data availability. Overall, the study confirms that land use processes in the Jizzakh region are dynamic and influenced by a combination of environmental and socio-economic factors. In particular, the integration of multi-temporal satellite data should be further utilized to ensure consistent long-term observation of land cover changes, especially in semi-arid regions where environmental conditions are highly variable. The study also indicates the importance of incorporating additional analytical variables, such as vegetation indices and climatic parameters, to improve classification accuracy and better capture ecological dynamics. Furthermore, the use of advanced machine learning and deep learning models may enhance the precision of land cover classification and provide deeper insights into spatial patterns. These directions are consistent with the methodological framework and findings presented in this research and represent a logical extension of the applied approach for improving future LULC analyses.

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EDITORIAL REVIEW

The submitted article addresses the spatio-temporal analysis of land use and land cover (LULC) changes in the Jizzakh region of Uzbekistan using Sentinel-2 satellite imagery and the Random Forest algorithm. The topic is highly relevant within the contemporary framework of environmental monitoring, particularly in semi-arid regions where land degradation, climate variability, and anthropogenic pressures significantly influence landscape dynamics. From the perspective of scientific novelty, the study contributes to the relatively limited body of research focused on Central Asia, and more specifically the Jizzakh region. While the methodological framework—based on remote sensing and machine learning—is not novel in a global context, its application to a data-scarce and geographically diverse region enhances its academic value. The integration of multi-temporal satellite data with supervised classification techniques provides a structured approach to identifying land cover transformations, which can serve as a baseline for further regional studies.

The relevance of the research is well justified. Monitoring LULC dynamics is essential for understanding environmental processes and supporting sustainable land management. The study effectively demonstrates how technological tools, such as high-resolution satellite imagery and machine learning algorithms, can be applied to address regional environmental challenges. In terms of practical significance, the results offer valuable insights for regional planning, resource management, and environmental monitoring, particularly in areas experiencing gradual urban expansion and ecological sensitivity. Methodologically, the research is sound and follows established scientific practices. The use of Sentinel-2 imagery ensures high spatial and temporal resolution, while the application of the Random Forest algorithm is appropriate given its robustness and classification accuracy. The selection of cloud-free images and the focus on the vegetation growing season further strengthen the reliability of the dataset.

However, the study would benefit from a more detailed discussion of classification accuracy assessment, including quantitative validation metrics such as confusion matrices or overall accuracy, which are essential for evaluating the reliability of the results. Among the strengths of the article are its clear structure, consistent methodology, and well-defined objectives. The integration of multi-spectral data enhances classification performance, and the results are presented in a logically coherent manner. Additionally, the study addresses a geographically underrepresented region, which increases its contribution to the field. Nevertheless, certain limitations should be noted. The absence of detailed accuracy assessment reduces the methodological transparency of the study. Furthermore, the discussion section could be expanded to provide deeper analytical interpretation of the observed changes, particularly in relation to socio-economic drivers. The incorporation of additional variables, such as vegetation indices or climatic data, could also strengthen the analytical depth.

In conclusion, the article represents a solid and relevant contribution to the field of remote sensing and land cover analysis. Despite minor methodological limitations, the study demonstrates sufficient scientific rigor, practical relevance, and regional importance. Therefore, it is recommended for publication in a scientific journal, subject to minor revisions addressing the noted issues, particularly the inclusion of accuracy assessment metrics and further elaboration in the discussion section.

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