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Investigating urban development using remote sensing and GIS techniques (A case study: Sheberghan city (2005-2024)

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Abstract

While global urban research heavily focuses on megacities, the rapid, unregulated horizontal expansion of low-population secondary cities remains critically understudied. To address this gap, this study investigates land-use changes in Sheberghan, Afghanistan, from 2005 to 2024, where continuous, irregular growth has caused severe socio-ecological degradation. Utilizing remote sensing and GIS, multi-temporal land cover transitions were analyzed. Landsat imagery from 2005, 2014, and 2024 were preprocessed and classified using the Random Forest machine learning algorithm within Google Earth Engine and ArcGIS, integrating NDBI and NDVI indices. Findings reveal a profound transformation in the city's spatial structure, characterized by massive built-up expansion and a severe depletion of agricultural fields, trees, and bare land. Quantitatively, road infrastructure underwent the most radical expansion, growing from 3.36 km² in 2005 to 9.91 km² in 2024. While this physical expansion signifies rapid development, it has induced negative socio-ecological consequences, including threats to local food security, degraded air quality, and soil erosion. Classification accuracy was higher for buildings and trees than for mixed terrains. Ultimately, these empirical results offer a precise change-detection matrix serving as an essential blueprint for municipal authorities to update policies and establish a structured sustainable urban master plan.

Keywords: Change Detection, Google Earth Engine, Land use changes, Random Forest, Urban Sprawl.

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1. Introduction

Monitoring land use changes is essential for understanding the natural state of land [1], as land use refers to the utilization of available natural resources according to human needs. This use may align with land capability and employ scientific methods, or follow traditional and potentially land-degrading approaches. It may simultaneously alter existing structures and processes in the environment [2]. Today, land use change as a global environmental change holds paramount importance and attracts attention from scientists and decision-makers [3]. Changes resulting from human activity transform natural growth areas into other uses, causing habitat loss, degradation, and fragmentation. The excessive growth and development of cities and their disproportionate density constitute environmental problems [4].

Urban physical development is a dynamic and continuous process through which the physical boundaries of a city and its spatial structures increase vertically and horizontally in both quantitative and qualitative terms [5]. Factors driving these cities' growth include social, economic, institutional, demographic, market, and technological factors, with principal findings showing that increased per capita gross domestic product has caused urban expansion [6]. More than 50 percent of the world's population lives in urban areas, and this figure is projected to reach 69.6 percent by 2050 [7]. Population concentration in major cities progresses to the point where it encompasses even 96 percent of the population in some countries. These large metropolises have caused social, economic, health, and other problems [8]. In recent years, with the rapid growth of large cities in developing countries and the emergence of issues related to housing unit shortages and high unemployment rates, some researchers have proposed that development planning be prepared based on emphasizing small city dynamics, since, due to employment opportunities, education, and other basic needs, large cities constitute the ultimate destination for most rural migrants and small city migrants [9].

Urban development was calculated through the conversion of undeveloped land to developed land, experiencing reduction in undeveloped land [10]. In many cities, urban sprawl may accompany increased wealth. Therefore, policies limiting urban area expansion may restrict economic growth, as housing prices in the LUZ area increase, developable land becomes scarce, and individuals and businesses decide to relocate to another city where space for new peripheral development still exists [11]. Forest areas and agricultural regions have primarily decreased, while built-up areas have increased dramatically [12], causing conversion of agricultural lands, pastures, and green spaces into building and infrastructure zones [13]. Understanding and analyzing these changes is critically important for sustainable natural resource management, urban planning, and environmental protection [14]. Studies have shown that social welfare, social inequality, and suppression of social interactions result from segregated land use, intensifying financial inequalities and long commutes stemming from urban sprawl.

These studies have also discovered evidence regarding economic consequences associated with urban expansion, including decreased economic density and productivity in central urban areas and social and economic weakening of impoverished populations [15]. In recent decades, cities have rapidly expanded and transformed into large cities.

This expansion is more severe in developing countries. Meanwhile, rapid global urbanization has not occurred uniformly across all cities but has primarily included large cities and capitals. Most developing countries are dissatisfied with the spatial development process of settlements and regional distribution of population and economic activities. Particularly, excessive concentration of economic, social, political activities and population in countries' largest cities has not only attracted major portions of developmental capabilities but has also confronted these cities with issues and problems [16]. Irregular expansion is recognized as an aesthetically unappealing and economically inefficient settlement form [17]. Therefore, for optimal urban area management, land use changes are considered. In this context, remote sensing technology and geographic information systems are recognized as the best tools for detecting and evaluating changes, serving as complementary instruments in descriptive analyses to play an efficient role in understanding, planning, and evaluating urban land use schemes [18].

While global urban research heavily focuses on primary capitals and megacities, the rapid, unregulated horizontal expansion of low-population secondary cities like Sheberghan remains critically understudied. Over the past two decades (2005–2024), Sheberghan has experienced continuous, irregular physical growth driven by localized demographic shifts and rural migration without structured master plans, leading to severe fragmentation and the conversion of vital agricultural lands into infrastructure. To address this gap, this study introduces a distinct contextual and methodological framework by shifting the analytical focus entirely toward small-scale urban dynamics, innovatively fusing high-efficiency cloud computing in Google Earth Engine (GEE) for multi-temporal satellite processing with advanced desktop spatial analysis in ArcGIS for localized error correction. By utilizing index-driven automated spectral classification over a rigorous 20-year timeline, this research moves beyond simple descriptive trends to deliver a highly precise, quantitative change-detection matrix that establishes an empirical blueprint for small-town sustainable planning.

The primary objective of this research is to identify and analyze spatial land use changes in Sheberghan city between 2000 and 2024. Over the past two decades, Sheberghan city, as one of northern Afghanistan's important cities, has witnessed rapid urban growth and expansion. This development has largely occurred irregularly and without precise planning, causing considerable changes in the city's spatial structure and land use. Remote sensing technology alongside geographic information systems has provided researchers and planners with novel and powerful tools for examining spatial changes. This technology, using multitemporal satellite imagery, enables precise monitoring of land use changes, urban development trends, environmental degradation, and spatial development assessment.

2. Materials and Methods

2.1. Study Area

Sheberghan is the capital of Jawzjan Province, located in northern Afghanistan on the southern bank of the Amu Darya River. The city is located at 36 degrees and 39 minutes north latitude and 65 degrees and 45 minutes east longitude in a relatively flat area, and

its average altitude is 380 meters above sea level. The climate of this region is semi-arid and is affected by significant seasonal changes, Figure 1.

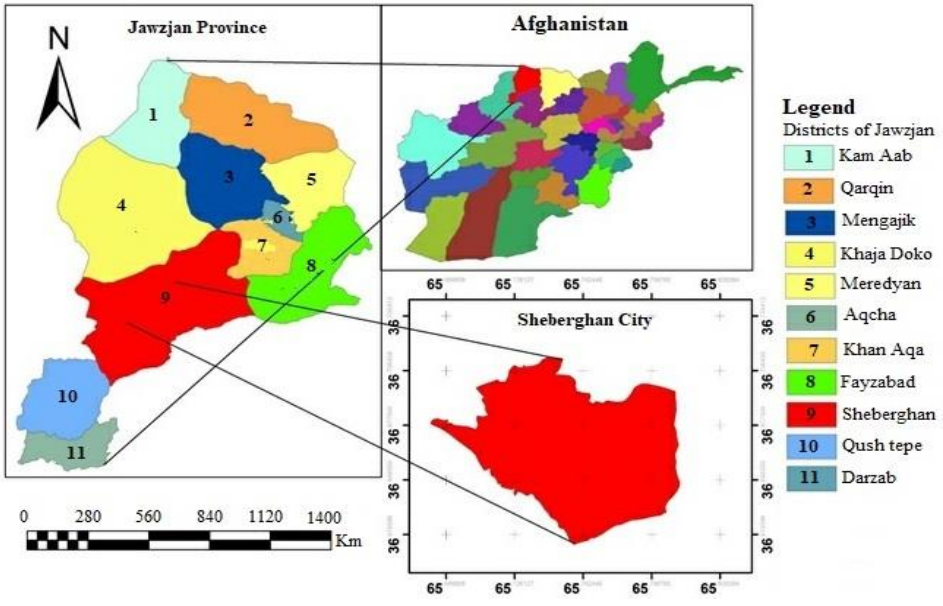


Fig. 1. Study Area.

Sheberghan is strategically located on the north-south and east-west trade routes of Afghanistan. Its proximity to important provinces such as Balkh, Sar-e-Pul, and Faryab, as well as its proximity to the Turkmenistan border, has given this city a special position in economic exchanges and regional communications. The approximate area of the city is estimated to be about 73 square kilometers, but in recent years, this amount has increased significantly due to population growth and the expansion of construction areas. The lands within the city limits include residential, agricultural, and dry lands, which have changed over time.

2.2. Datasets

In this study, Landsat_7 (ETM+) satellite images were used for 2005 and Landsat_8 (OLI/TIRS) for 2024. These images are very suitable for analyzing land use changes due to their good spatial resolution (30m) and long-term temporal coverage. To ensure the quality of the images, a cloud filter with a threshold of less than 10% (Cloud Cover < 10%) was applied. The Median Composite method was used to reduce noise and provide a representative image for each year.

Table 1. Description of the Data Set in the Study [16].

Band Name	Wavelength of Landsat-7	Wavelength of Landsat-8	Spatial resolution of Landsat-7	Spatial resolution of Landsat-8
B1	0.45 - 0.52 µm	0.435-0.451 µm	30m	30m
B2	0.52 - 0.60 µm	0.452-0.512 µm	30m	30m
B3	0.63 - 0.69 µm	0.533-0.590 µm	30m	30m

B4	0.77 - 0.90 µm	0.636-0.673 µm	30m	30m
B5	1.55 - 1.75 µm	0.851-0.879 µm	30m	30m
B6	10.40 - 12.50 µm	1.566-1.651 µm	60m	30m
B7	2.08 - 2.35 µm	2.107-2.294 µm	30m	30m
B8	0.52 – 0.90 µm	0.52 - 0.90 µm	15m	15m

2.3. Methodology

The figure below shows the research steps for the investigation and analysis of land use changes in Sheberghan city between 2005 and 2024, using satellite data and spatial analysis in Google Earth Engine (GEE) and ArcGIS. In the first stage, the dataset and its analysis software were introduced, utilizing multi-temporal satellite imagery directly available in GEE that was already atmospherically and radiometrically corrected. Then, the images were classified using automated spectral indices, where exactly 150 training samples were utilized for each land use and land cover (LULC) class to train the classifier. Afterward, the total area for each class was obtained, and localized error correction was performed. Finally, change detection was performed using the difference in classifications; maps of land use/urban cover changes in Sheberghan city were prepared, and the percentage of changes was calculated, Figure 2.

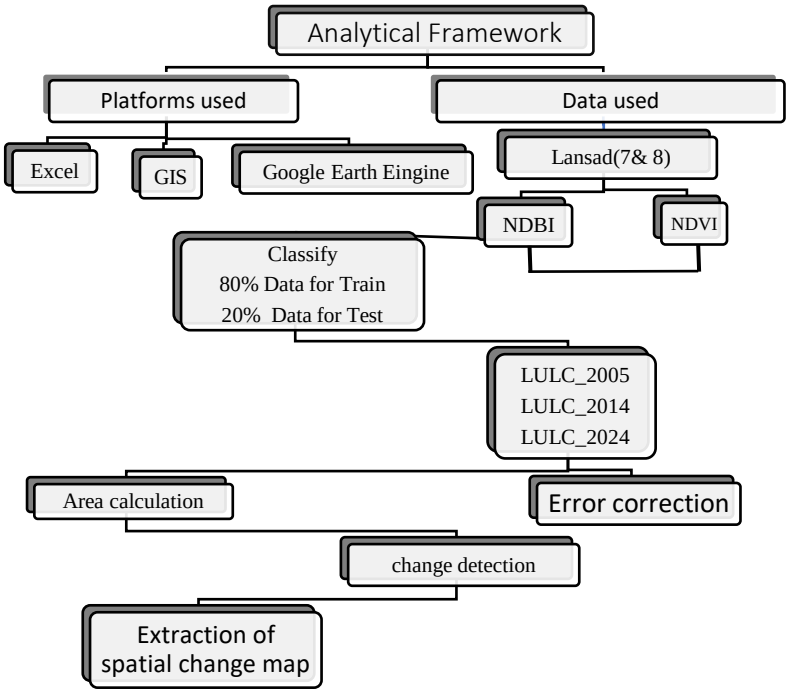


Fig. 2. Research Methods.

2.3.1. NDVI (Normalized Difference Vegetation Index):

This index represents the density and health of vegetation and is calculated using the red and near-infrared (NIR) bands. It is a very useful tool for determining the health of vegetation and its spatial distribution in the region, and its formula is as follows[3].

$$NDVI = \frac{(NIR - RED)}{(NIR + RED)} \dots\dots\dots\dots\dots\dots\dots\dots 1$$

In the above relationship, NIR is the near-red band, and RED is the Landsat red band.

2.3.2. NDBI (Normalized Difference Built-up Index)

This index is used to identify built-up areas and is calculated using SWIR and NIR bands. It clearly identifies the boundary between urban and non-urban areas, and its formula is as follows[3].

$$NDBI = \frac{(SWIR - NIR)}{(SWIR + NIR)} \dots\dots\dots\dots\dots\dots\dots 2$$

In the above relationship, SWIR is the short-wave infrared band, and NIR is the near-red band of Landsat.

2.3.3. Image classification

Training sample points for five main classes, including Building, Road, Tree, Bareland, and Farmlands, were prepared by drawing points at specific locations. These points were defined as a Feature Collection and used to train the classification algorithm. A satellite image was selected, training samples were combined, and the Random Forest classification algorithm was used to generate classification maps. To avoid data overload, the sample set was reduced using random Column functions. For model evaluation, the samples were divided into two training parts, where 80% of the data was used to train the model. This part helps the model to learn patterns and relationships between spectral bands and classes. And 20% of the data was used to evaluate accuracy. This data did not participate in training and is used to check the quality of the model's prediction. After performing the classification, the final image was displayed in color based on classes with a specific color palette in the GEE environment. Also, the Reduce Region function was used to extract the area of each class, and the results were exported to Google Drive in the form of a table in the CSV file format. Finally, the classified maps were exported as GeoTIFF and used for final analysis and preparation of output maps in ArcGIS software.

2.3.4. Calculation of land use changes

One of the key steps in studying the spatial changes of Sheberghan city during the years 2005 to 2024 is the accurate calculation of the area of land use changes in the GIS environment. In this research, ArcGIS analytical tools were used to calculate the area (Area Calculation) and examine the urban development trend. The steps of this process are as follows: First, the classified maps obtained from satellite images of the desired

years were entered into the ArcGIS software environment. If the data is in raster format, it is first converted to vector format (polygon) using the Raster to Polygon tool to enable accurate calculation of the area. Then, using the Extract by Mask tool, the urban area of Sheberghan was separated from the overall map to focus only on changes in the urban area. After that, to calculate the area of different land use classes, a new field with a name such as "Area_2005" or "Area_2024" was created in the descriptive information table (Attribute Table), and the area of each polygon in square meters or square kilometers was calculated using the Add Geometry Attributes or Field Calculator tool. To identify and calculate the amount of change between years, the Intersect or Union tool was used to combine layers related to different years. This operation allows the identification of places that have undergone a change in land use. In the final stage, by creating a new field called Change Area was created, and using a formula such as: {!Area_2024! -!Area_2005!}. In Field Calculator, the difference in area between two years was calculated and analyzed. The result of this process is the preparation of maps of land use changes and a statistical table of area changes of different urban classes during the period under study, which plays an effective role in analyzing city development patterns.

2.3.5. Preparing the final map in the ArcGIS environment

At the end of the data processing and spatial change analysis stages of Sheberghan city, the final maps were designed and exported using the ArcGIS software environment. This step includes setting up the graphic view of the map, inserting basic cartographic elements, and extracting the map as an image or PDF file. The steps were as follows: First, using the Insert Layout option, a standard size paper (A4 or A3) and appropriate orientation (horizontal or vertical) were selected. Then, using the Insert Map Frame tool, the processed map was transferred to the Layout space and its scale and position were adjusted. Next, the essential map elements, including the map guide (Legend), scale (Scale Bar), north direction (North Arrow), map title, coordinate system information, and descriptions of the data source, were inserted into the Layout. The arrangement of these elements was done carefully and in accordance with the principles of map design to maintain the clarity, readability, and visual appeal of the map. After the final review of all components, the final map was saved in JPEG or PDF format with the appropriate resolution (at least 300 dpi) using the Export Layout option. This stage is essential for preparing the final project output, including it in the scientific report, and presenting the research results, and plays an important role in documenting the findings.

3. Results

Spatial change analysis of Sheberghan city shows that the city has experienced significant land use changes between 2005 and 2024. In 2005, satellite images were classified using the Random Forest algorithm, and the results indicated the initial stages of urban

development. According to Figure 3, the main focus of construction has been in the city center, accompanied by limited expansion of the road network. Drylands occupied a significant portion of the city area and provided a high capacity for future development. Agricultural lands were mostly seen in the southern and eastern regions, and tree cover had a smaller portion and was mainly scattered in the northern and western regions.

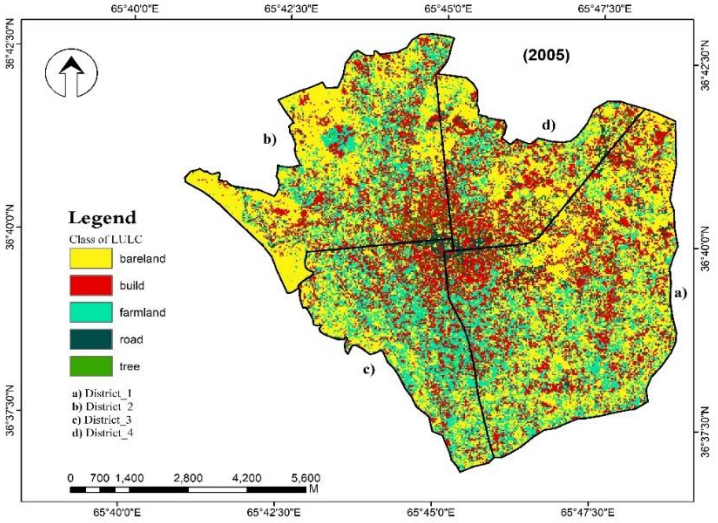


Fig.3. Land use of Sheberghan city in 2005.

In the analysis of the four urban districts, it was found that Districts 1 and 3 had the most changes. District 1 is located in the northwest, and District 3 is located in the central and southwestern parts of the city. These districts have experienced the most urban and infrastructural expansion. In contrast, Districts 2 and 4 have experienced fewer changes and have largely preserved their natural and agricultural characteristics. The area of dry land had the largest share this year, with 31.57 km^2, while agricultural land covered 18.2 km^2, and buildings covered 18.317 km^2. The road network was about 3.366 km^2, and tree cover had the smallest share with 1.843 km^2 Figure 4.

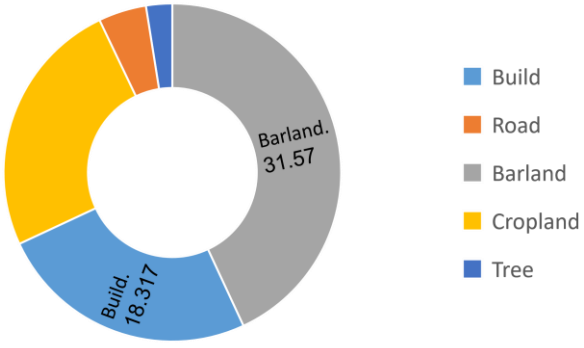


Fig. 4. Area of each class in km^2 per year (2005).

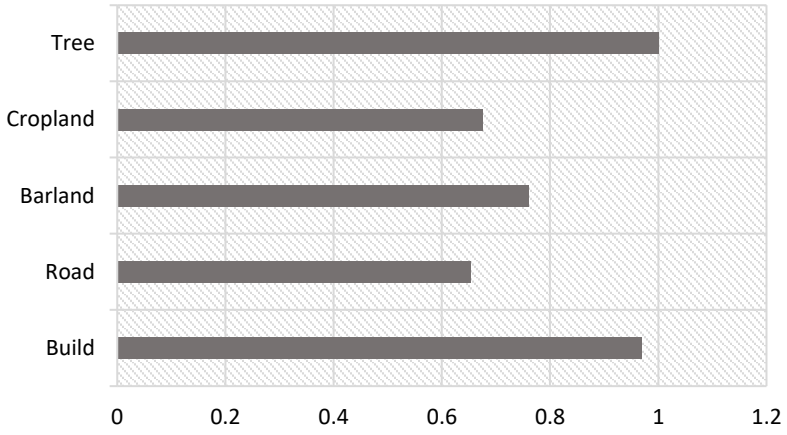


Fig. 5. Accuracy of the model in each class for examining spatial changes in 2005.

In 2014, there were noticeable changes in the land use structure of the city. Construction increased and spread to the northeast and southeast. The road network was also developed, and many dry lands were converted to residential and agricultural uses. Although tree cover did not change significantly, a slight increase was observed in some areas. Compared to 2005, the area of buildings increased by 2.16 km^2, while dry lands decreased by 3 km^2. Agricultural lands increased by 1.26 km^2, and tree cover grew by 1.68 km^2. These changes reflect attention to the development of green space and the utilization of unused lands, as seen in the map and chart of Figures 6 and 7.

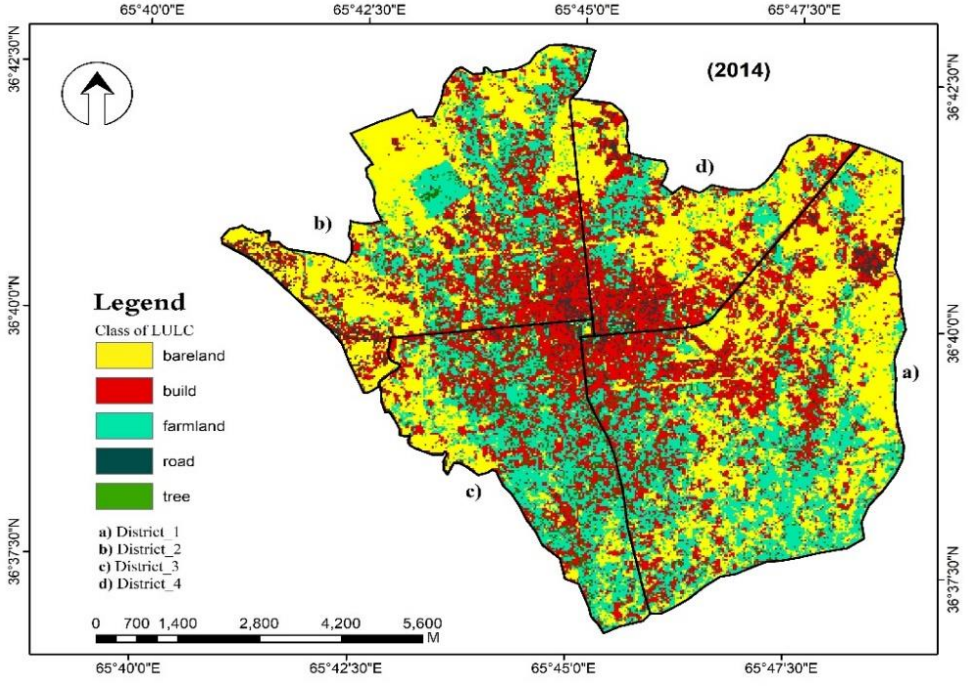


Fig. 6. Land use of Sheberghan city in 2014.

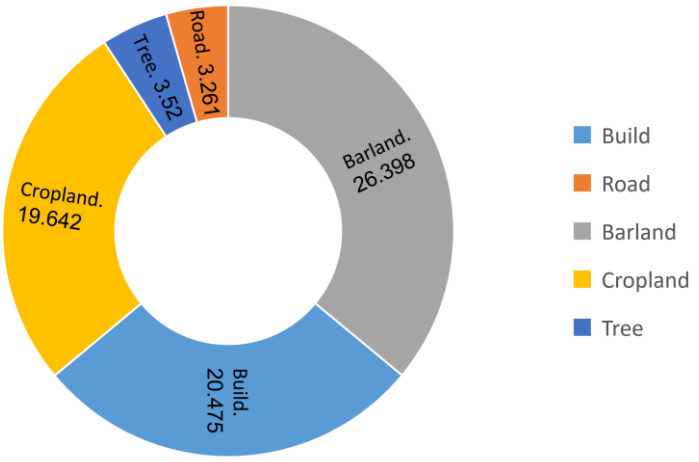


Fig. 7. Area of each class in km^2 per year (2014).

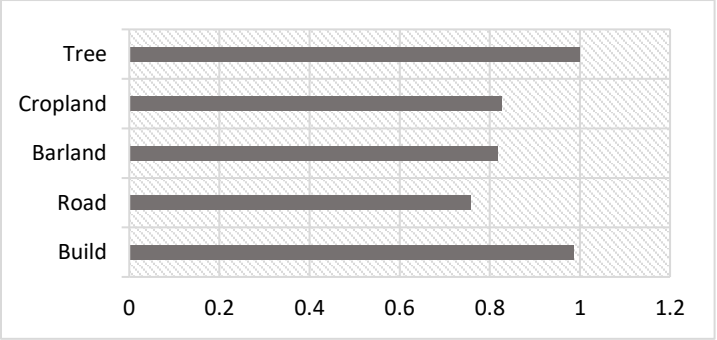


Fig. 8. Accuracy of the model to examine spatial changes in 2014.

According to Figures 9 and 10 in 2024, the urban development trend intensified. Construction has expanded significantly compared to previous periods. The focus of development is no longer limited to the city center, but the eastern, southern, northeastern, and even northwestern areas of the city have also witnessed urban growth. This expansion could be due to migration, population growth, and increased demand for urban services. The road network has expanded significantly compared to previous periods, and new routes have been extended to the outskirts of the city. Dry lands, which in previous years constituted a major part of the city's surface, have now been extensively converted to other uses. Agricultural land has decreased in some areas but still plays an effective role in the regional economy. Tree cover has remained relatively stable, with slight increases in some areas. The greatest changes in 2024 will also be seen in the first and third districts, where extensive construction has taken place and a large portion of agricultural and dry land has been converted into urban areas. The second zone has also undergone changes, while the fourth zone has remained largely natural. The area of buildings has increased by 2.79 km^2 compared to 2005, and the area of roads has grown significantly by 4.55 km^2.

Dry land has decreased significantly by 11.22 km^2. Agricultural land has also increased by 2.78 km^2. However, the decrease in tree cover is somewhat worrying and necessitates the need for planning to protect natural resources.

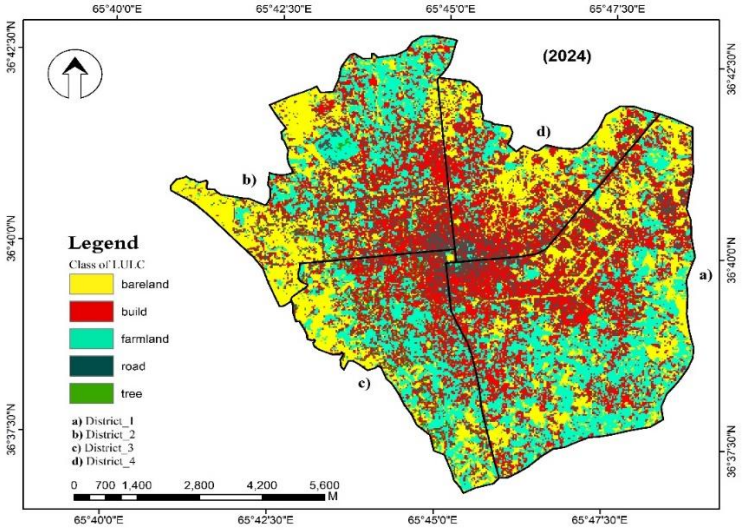


Fig. 9. Land use of Sheberghan city in 2024.

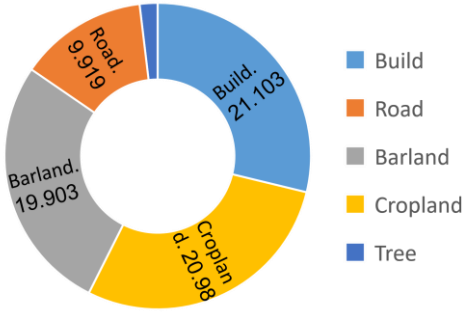


Fig. 10. Area of each class in km^2 per year (2024).

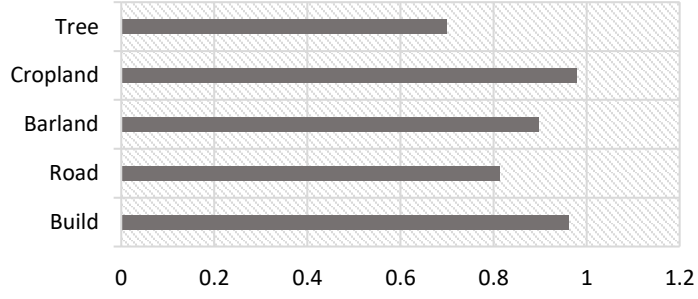
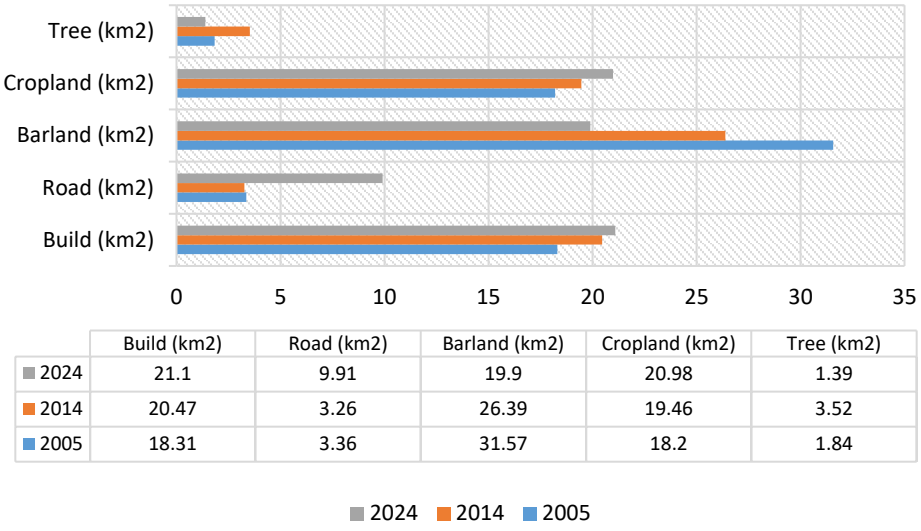


Fig. 11. Accuracy of the model to investigate spatial changes in 2024.



	Build (km2)	Road (km2)	Barland (km2)	Cropland (km2)	Tree (km2)
2024	21.1	9.91	19.9	20.98	1.39
2014	20.47	3.26	26.39	19.46	3.52
2005	18.31	3.36	31.57	18.2	1.84

Fig. 12. Area of land-use changes in (km^2) Sheberghan city.

Overall, land use changes in the three time periods studied show a trend of increasing urban development accompanied by a decrease in natural lands. Although dry lands initially constituted the largest portion, over time, they have been converted to construction and agricultural uses. The agricultural land portion has been largely preserved, and construction has been the main driver of change, especially in the east and south of the city. Tree cover, although fluctuating, has shown a slight decline, which could have long-term environmental consequences, as seen in Figures 12, 13, and 14.

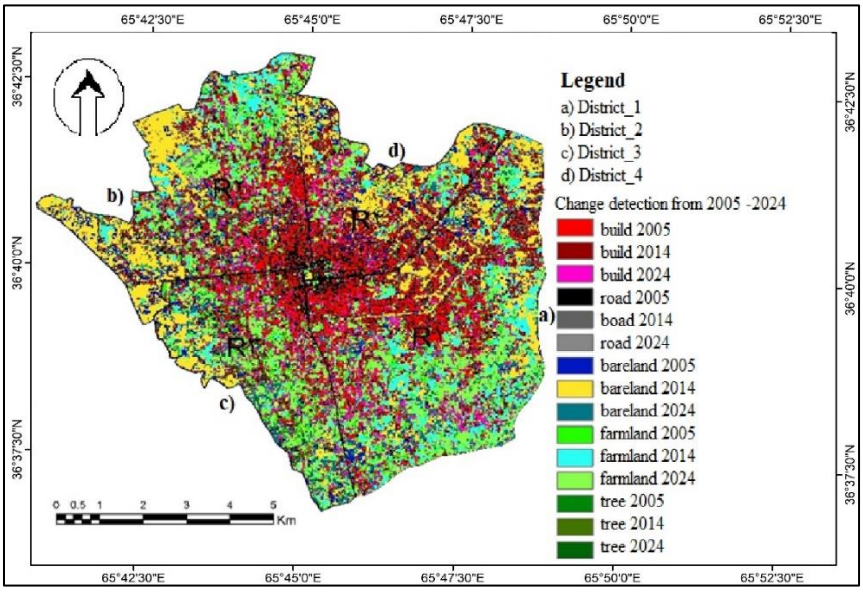


Fig. 13. Urban changes in Sheberghan city from 2005 to 2024.

This pattern of land transformation reflects broader urbanization pressures commonly observed in rapidly developing cities across Afghanistan and similar regions. The conversion of dry lands into built-up areas represents not only physical expansion but also fundamental shifts in the socio-economic fabric of the urban landscape. The concentration of construction activities in specific zones suggests uneven spatial development, likely driven by factors such as proximity to major transportation routes, availability of infrastructure, and land market dynamics. Furthermore, the gradual reduction in tree cover, even if modest, raises concerns about urban heat island effects, reduced biodiversity, and diminished ecosystem services that vegetation provides, including air quality improvement and stormwater management. These environmental degradation trends underscore the urgent need for integrated urban planning strategies that balance development demands with environmental sustainability, incorporate green infrastructure policies, and establish protective measures for remaining natural areas to ensure livable and resilient urban environments for future generations.

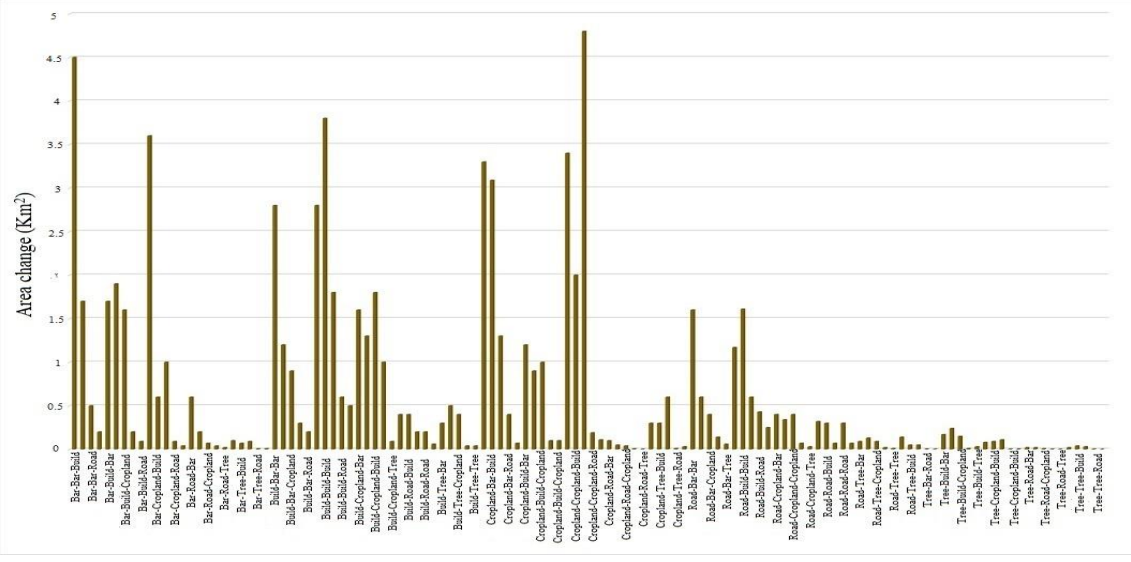


Fig. 14. Total area of land changes in Sheberghan city.

Technically, the Random Forest algorithm has shown good performance in classifying specific classes such as buildings and trees. These classes are easily distinguishable from other uses due to their distinct spectral characteristics. In contrast, the classification of classes such as roads and agricultural land has been associated with challenges that can arise from spectral similarities or a lack of suitable training data. To improve classification accuracy in the future, it is suggested to use data with higher spatial resolution, such as Sentinel-2 and radar (SAR) data. Also, the use of more advanced deep learning algorithms can increase the accuracy of the model.

Finally, the findings of this study show the high importance of the application of remote sensing and geographic information systems in understanding, managing, and planning urban development. Accurate spatial and temporal analyses can be effective tools for guiding sustainable development, conserving natural resources, and making informed decisions for the urban future.

4. Discussion

The final analysis of the land use change pattern in Sheberghan city shows that this city, like many developing cities, has faced a rapid, intensive, and sometimes uncontrolled process of urban development. The results of the classification of Landsat satellite images during the years 2005, 2014, and 2024 show a clear trend of increasing construction uses and decreasing natural and agricultural lands. These changes have not only transformed the physical structure of the city, but have also had profound effects on the environment, natural resources, and livelihoods of surrounding residents. The continuous increase in construction areas has often been at the expense of the loss of agricultural lands, vegetation, and dry lands. Urban development, which in many cases has been carried out without scientific planning and consideration of environmental capacities, is known as one of the main factors in the destruction of natural resources in urban areas. Pressures from population growth, internal migration, and the growing need for housing and infrastructure have led to the expansion of construction into agricultural lands and biological resources. This pattern is particularly evident in the first and third districts of the city, which have experienced the most changes. The second and fourth districts have largely retained their traditional and natural land uses. On the other hand, technical analysis of the accuracy of the classification model used in this study, the Random Forest machine learning algorithm, provides valuable information regarding the technical capabilities and limitations of the methods and data used. The model used was able to identify and separate classes such as buildings and trees with high accuracy.

This success is largely due to the distinct spectral characteristics of these two classes in satellite images. For example, dense vegetation has a distinct light reflectance in the near-infrared (NIR) and red bands, which allows it to be separated from other land uses. Building materials and hard surfaces also typically have a distinct spectral behavior that can be identified with high accuracy by machine learning algorithms, especially Random Forest. However, there have been challenges along the way. The model's performance in classifying classes such as agricultural land and roads has been much weaker. This problem can be caused by several factors. One of the main reasons is the spectral similarity between some sparse vegetation and road surfaces, which prevents the algorithm from making an accurate distinction. In addition, the spatial dispersion of these classes, the lack of sufficient spectral contrast between them, and the low quality of some images, especially during periods of cloud cover or heavy shadows, are also considered technical challenges. Also, the imbalance in the number of training samples between different classes, especially for small-area classes such as roads or vegetation, has reduced the overall accuracy of the model for these classes. To improve classification accuracy in the future, several solutions can be proposed. First, the use of satellite images with higher

spatial and temporal resolution, such as Sentinel-2, which has better resolution (10 to 20 meters) and more spectral bands, can help increase accuracy. Second, radar data such as Sentinel-1 or SAR data, due to their sensitivity to the physical structure of the Earth's surface and the ability to record information in cloudy and night conditions, are considered a suitable option for areas with high cloud cover. The use of combined optical and radar data, or so-called data fusion, is one of the new approaches to improve classification accuracy.

From an algorithmic perspective, the use of deep learning models such as convolutional neural networks (CNNs) can also provide higher efficiency in classifying complex urban landscapes. These models have a high ability to extract multidimensional spatial-spectral features and can better model nonlinear and complex relationships between data. However, these models require larger training data and more powerful processing resources. The findings of this study also once again emphasize the importance of using remote sensing tools and geographic information systems (GIS) in urban management. Spatio-temporal analyses based on satellite data allow for accurate monitoring of land use change trends, identification of sensitive areas, and guidance of urban policies. Especially in cities such as Sheberghan, which are in the transition phase from traditional to modern development, such tools can play a fundamental role in informed decision-making. From a sustainable development perspective, one of the important findings of this study is the gradual decline of natural resources, especially agricultural lands, which can have several negative consequences, including reduced food security, increased dependence on imports, and weakening of local ecosystems. Therefore, it is suggested that environmental considerations be included as an integral part of planning in the urban development process.

Also, the development of comprehensive urban plans that are periodically updated and adjusted based on spatial data and ground realities can prevent the continuation of the process of natural resource degradation. Finally, this study shows that although urban development is inevitable, in the absence of a scientific, data-driven, and participatory approach, it can be a serious threat to natural resources and the quality of life of citizens. Combining modern methods of spatial analysis with local policymaking, public education, and participatory management will be the key to achieving sustainable urban development.

5. Conclusion

The results of this study provide an accurate depiction of the trends in land use change in Sheberghan city over the past two decades, reflecting profound transformations in the city's spatial and ecological structure. The rapid increase in built-up areas alongside a significant reduction in agricultural lands, vegetation cover, and bare land reflects unplanned urban development, population growth, intra-regional migration, and socio-economic pressures. The most significant changes in land use are shown in 2024, where the areas of built-up land, roads, and agricultural fields have increased compared to previous years, while the areas of trees and wastelands have decreased. The land use that

has undergone the most significant changes over the two decades is roads, whose area has increased from 3.36 km^2 in 2005 to 9.91 km^2 in 2024.

The expansion of the city during the previous 20 years, although seen as a sign of development, has brought numerous negative environmental and social consequences. The reduction of agricultural land poses a threat to the region's food security and increases its dependence on external sources. Also, the reduction of vegetation cover and tree lands has led to poor air quality, habitat destruction, and a decline in ecosystem function. Drylands, which play an important role in ecological sustainability, have been converted to construction or agriculture without environmental considerations, which poses risks such as soil erosion and destruction of native habitats. The city of Sheberghan is currently facing challenges such as spatial disorder, depletion of natural resources, and lack of appropriate infrastructure. To address this situation, it is vital to review urban development policies, implement smart land use management, restore green spaces, and support the agricultural sector. The use of new technologies, environmental protection, and public participation can pave the way for balanced and sustainable development. Only by adopting a comprehensive and interdisciplinary approach can we prevent the spread of environmental and social crises in the future and build a livable and sustainable city for future generations.

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