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WILDLIFE MANAGEMENT SCIENCES

GEOINFORMATICS PROGRAM

THESIS OF (PHD) DISSERTATION

**SPATIAL STATISTICS ANALYSES AND MODELING OF  
LAND COVER AND LAND USE CHANGE IN PRISHTINA  
REGION**

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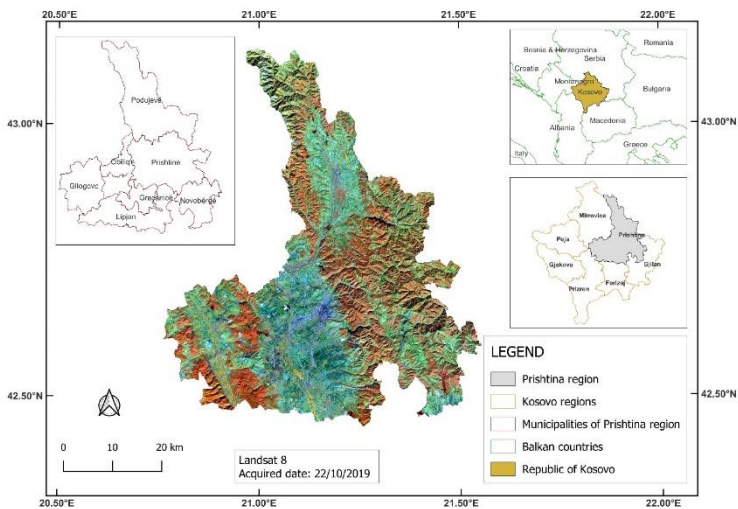
## **1. Introduction**

Land cover and land use (LCLU) change is one of the most critical processes shaping the environment today. It reflects both natural dynamics and human activities and has direct consequences for biodiversity, water resources, agricultural production, and urban development. In recent decades, the Prishtina region (Republic of Kosovo) has experienced rapid demographic and socio-economic transformations that have strongly influenced land use patterns.

Urbanization and rapid development of infrastructure and industry have led to significant changes in the balance between built-up areas, agricultural fields, forests and transitional lands. These dynamics require systematic monitoring, as unmanaged land conversion can contribute to landscape degradation, ecosystem fragmentation and unsustainable use of natural resources.

Modern geospatial technologies, particularly satellite-based remote sensing and Geographic Information Systems (GIS), provide an efficient means to document and analyze these changes. Remote sensing enables the repeated observation of the Earth's surface at multiple time steps, offering consistent, large-scale coverage that complements field-based surveys. The Landsat program, operating continuously since 1972, is especially valuable because of its long historical archive and free accessibility, making it a cornerstone for long-term LCLU monitoring worldwide.

Despite these opportunities, many regions, including Prishtina region (Figure 1.) still lack comprehensive, quantitative, and predictive studies of LCLU dynamics. Previous research has often focused on localized case studies, while systematic analyses that integrate machine learning and predictive modeling approaches remain limited.



*Figure 1. Geographical position of the Prishtina region in Kosovo*

By combining remote sensing, spatial statistics, and machine learning-deep learning, this study contributes to both scientific understanding and practical decision-making. Its results provide a foundation for sustainable spatial planning, improved land management, and policy development in one of Kosovo's most dynamic and rapidly changing regions.

## **2. Research questions and objectives**

In my Ph.D. thesis I stated five main objectives:

1. To provide LCLU maps for the designated research area at defined time intervals (2001, 2009, and 2019).
2. To use supervised image classification methods using different algorithms: Maximum Likelihood and Minimum Distance algorithms, Support Vector Machine and Neural Network.
3. To evaluate the precision of the categorization outcomes and methodologies used in this investigation.
4. To examine the patterns and dynamics of changes in LCLU use throughout certain time periods.
5. To assess the benefits and drawbacks of various LCLU categories, analyse the changes in land cover and land use throughout time.

## **3. Research objectives**

1. Did the LCLU undergo substantial changes within the chosen study periods?
2. What was the spatial distribution of LCLU use growth observed throughout the study periods?
3. What was the influence of various land cover categories on the growth of a certain land cover or land use type in the designated research region?
4. What is the level of reliability of Landsat satellite imagery for monitoring changes in LCLU in the specified region?

5. What type of classification method is the best to estimate LULC?
6. Was the categorization and change detection approach sufficient for the purpose of mapping and identifying changes?

#### **4. Methods**

The study was based primarily on multi-temporal Landsat imagery (Landsat-5 TM, Landsat-7 ETM+, and Landsat-8 OLI/TIRS) covering the years 2001, 2009, and 2019. Ancillary data included high-resolution orthophotos from the Kosovo Cadastral Agency, CORINE Land Cover (CLC) datasets (2006, 2012, and 2018), Google Earth Pro imagery, and spatial variables such as DEM, slope, hydrology, and transportation networks.

All images were processed as Level-2 surface reflectance products from the USGS Landsat Collection 2 archive. The spectral bands (Blue, Green, Red, NIR, SWIR1, and SWIR2) were clipped, stacked to the study area extent, and projected in WGS84/UTM Zone 34N.

Eight LCLU classes were defined based on the CLC classification system: agriculture, bare surfaces, forest, grassland, industrial, transitional land, urban, and water bodies. A total of 1,969 samples, supported by high-resolution imagery, were collected. Stratified random sampling was then used to split them into training (80%) and validation (20%) sets. Quantitative evaluation using spectral reflectance distribution and Jeffries-Matusita distance was conducted for the three sequential years.

Four supervised classification algorithms (Figure 2.) were tested in this study, namely Maximum Likelihood (ML), Minimum Distance (MD), Support Vector Machine with Radial Basis Function (SVM-RBF), and ANN-MLP (Artificial Neural Networks-Multi-Layer Perceptron). Based on their performance, the best classifier for each reference year was selected for subsequent change detection analysis.

Classification outputs were validated using confusion matrices and standard accuracy metrics: Overall Accuracy (OA), User's Accuracy (UA), Producer's Accuracy (PA), and Kappa Coefficient (KC).

Post-classification comparison was applied between the three time steps (2001–2009, 2009–2019, 2001–2019). Transition probability matrices were generated to quantify conversions among classes, and annual change rates were calculated.

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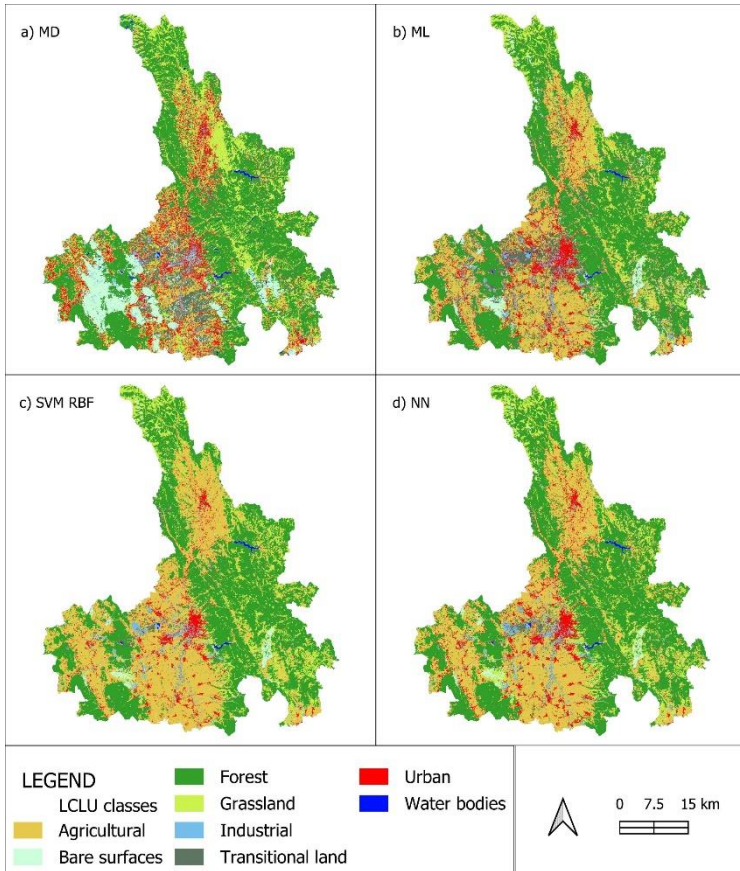


Figure 2. LCLU classification for the year 2019: a) Minimum Distance, b) Maximum Likelihood, c) Support Vector Machine—Radial Basis Function, and d) Neural Net.

To forecast future LCLU dynamics, a Cellular Automata – Artificial Neural Network (CA-ANN) model was applied using the MOLUSCE plugin in QGIS.

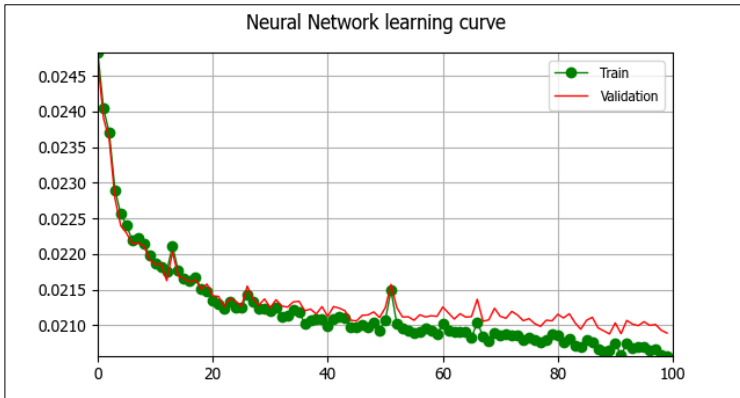


Figure 3. Figure 4. MLP-ANN learning curve.

Driving variables included DEM, slope, and distance to settlements, roads, rivers, and lakes. Model performance was validated using Kappa statistics and multi-resolution budget metrics. Future LCLU maps were simulated for 2029 and 2039.

## 5. Results and conclusions

The integration of multi-temporal Landsat data with supervised classification algorithms proved to be highly effective for mapping LCLU in the Prishtina region. The results demonstrate both the reliability of machine learning methods and the rapid pace of land transformation in the study area.

### Image Classifications

In terms of classification performance, the SVM-RBF classifier achieved the best accuracy in 2001, with an Overall Accuracy (OA) of 84.0% and a Kappa coefficient

(KC) of 0.79. In 2009, the Neural Network classifier performed best, reaching an OA of 87.2% and a KC of 0.83, while in 2019 the Neural Network again proved the most reliable, with an OA of 81.9% and a KC of 0.77. In contrast, the traditional classifiers (MD and ML) shown in Figure 5, consistently underperformed compared to the machine learning approaches, particularly in handling heterogeneous land cover classes.

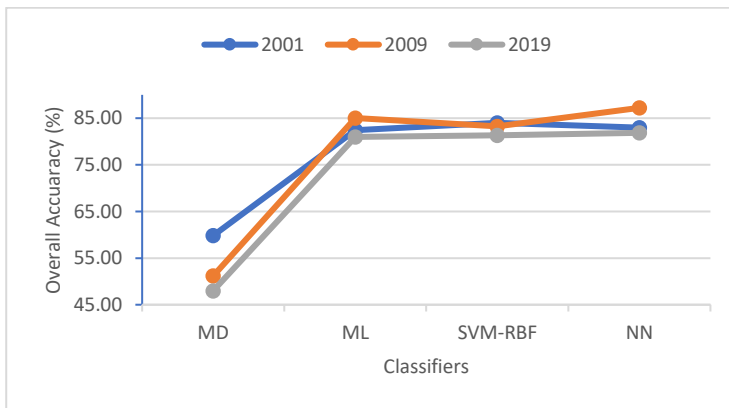


Figure 5. Overall Accuracy (OA)

### LCLU Change Dynamics (2001–2019)

Between 2001 and 2019, the Prishtina region underwent substantial land cover and land use transformations. Agricultural land decreased by 111 km<sup>2</sup>, mainly converted into urban, industrial, and transitional land. Urban areas expanded by 47.7 km<sup>2</sup>, with the fastest growth occurring between 2009 and 2019, while industrial land increased by 24.2 km<sup>2</sup>, closely linked to economic development and infrastructure expansion.

Forest cover declined by 135 km<sup>2</sup> during 2001–2009 but later recovered by 154 km<sup>2</sup> between 2009 and 2019, resulting in a slight net gain of 19 km<sup>2</sup> over the entire period. In contrast, grassland contracted by 10 km<sup>2</sup>, and water bodies decreased by 1.65 km<sup>2</sup>, indicating additional environmental pressures.

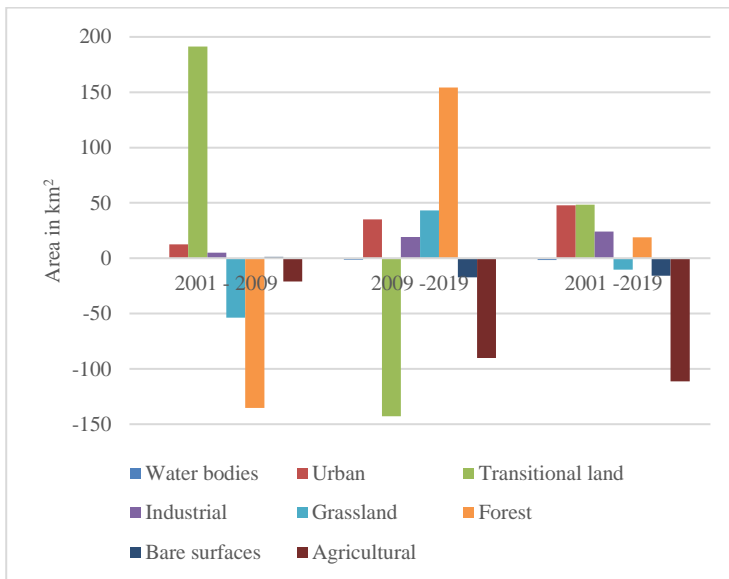
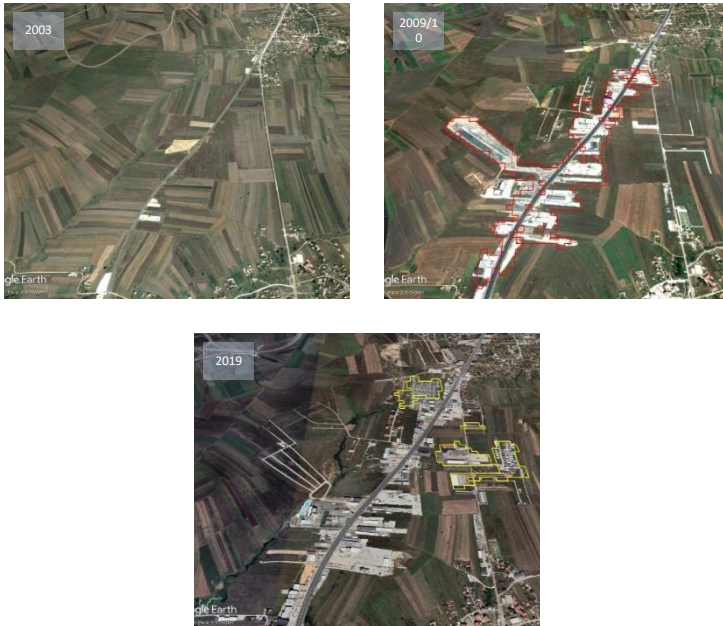


Figure 6. LCLU gains and losses in hectares for the three time periods: 2001-2009, 2009-2019, and 2001-2019.

The most dynamic transformations and hotspots as seen in Figure 7, occurred around Prishtina city, Fushe Kosova, and along transport corridors, where urban sprawl and industrial expansion were concentrated.



*Figure 7. Agricultural land shrinkage due to industrial and urban expansion: 2001 -2019*

### **LCU Change Modeling (2019–2039)**

The CA-ANN simulations forecast significant land cover and land use changes in the Prishtina region over the next two decades. Urban areas are expected to expand by 20.6 km<sup>2</sup>, while forest cover is projected to increase by 65.5 km<sup>2</sup>, reflecting natural regeneration and reforestation trends. Agricultural land is predicted to show slight net gains of 16.3 km<sup>2</sup>, although this growth is modest compared to other classes. In contrast, grasslands are projected to decline by 62.8 km<sup>2</sup>, and

water bodies are expected to decrease further by 1.4 km<sup>2</sup>, highlighting continued environmental pressures. The reliability of these projections was confirmed through validation with Kappa statistics, which yielded an overall value of approximately 0.59, indicating a moderate but acceptable level of agreement.

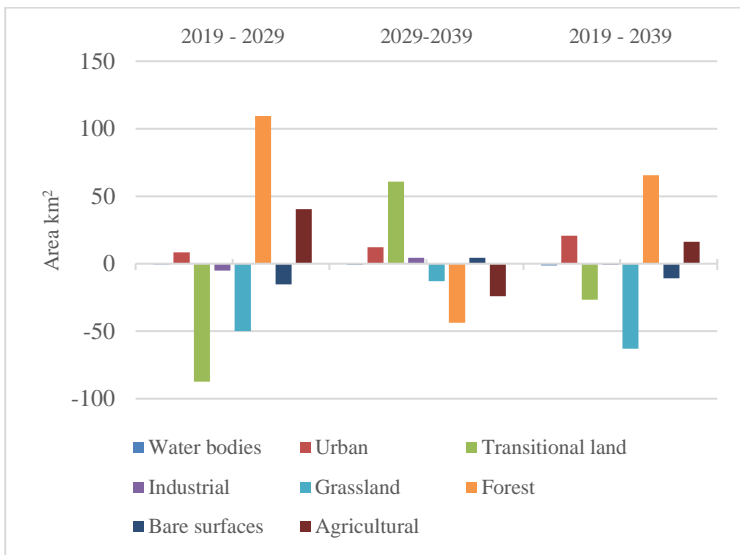


Figure 8. LCLU prediction gain and losses from 2019 - 2039

The study confirms that supervised classification of Landsat imagery, combined with spatial statistics and predictive modeling, provides an accurate and cost-effective framework for monitoring and forecasting land cover/use dynamics.

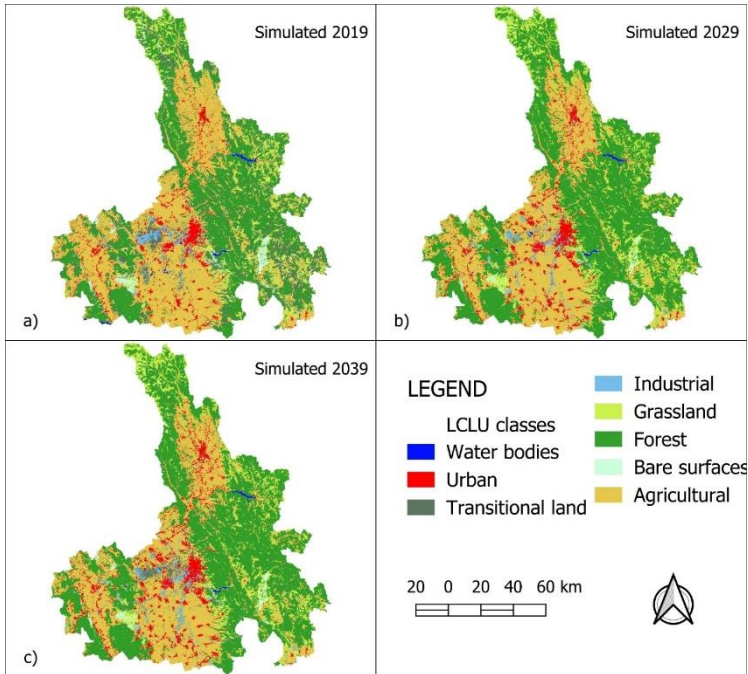


Figure 9. Simulated LCLU maps for 2019, 2029, and 2039.

## 6. Conclusions and suggestions

The study confirmed that the Prishtina region has undergone rapid land cover and land use changes since 2001. Urban areas expanded mainly at the expense of agriculture, while industrial zones grew along transport corridors. Forest cover showed strong resilience, with initial decline followed by recovery. Machine learning methods, particularly SVM-RBF and Neural Networks, provided the most reliable classifications, while CA-ANN

modeling successfully simulated future scenarios, projecting continued urban growth and forest regeneration by 2039.

The thesis recommends integrating remote sensing into planning, protecting farmland, supporting forest regeneration, safeguarding water resources, and applying higher-resolution data with advanced methods in future research.

## **7. Research thesis**

The dissertation advances knowledge on land cover and land use (LCLU) dynamics in Kosovo through the following main statements:

1. Spatio-temporal LCLU changes (2001–2019) in the Prishtina region can be accurately documented using multi-temporal Landsat imagery combined with supervised machine learning classifiers.
2. Optimizing training samples and classifier parameters significantly improves classification reliability, while class similarity (e.g., grassland vs. transitional land) remains a key challenge for accuracy.
3. Machine learning methods (SVM-RBF and Neural Networks) outperform traditional classifiers (MD, ML) in mapping heterogeneous urban–rural landscapes, achieving overall accuracies above 80% and Kappa values up to 0.83.

4. Post-classification comparison and transition probability matrices provide valuable insights into LCLU trajectories, demonstrating agricultural decline, urban-industrial growth, and forest regeneration patterns.
5. Future LCLU changes can be effectively predicted with Cellular Automata–Artificial Neural Networks (CA-ANN), which integrate spatial drivers (topography, accessibility, settlements) to simulate realistic development pathways up to 2039.

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