Phoenix: International Multidisciplinary Research Journal
Vol 3, No. 2, April-June, 2025
ISSN: 2583-6897

SPATIOTEMPORAL DYNAMICS AND FUTURE PROJECTION OF LAND USE AND LAND COVER IN THE GHOD RIVER BASIN (2001–2040)

Mr. Kailas D. Sabale
Research Student, Department of Geography, University of Mumbai
Email: ksabale96@gmail.com

ABSTRACT

Understanding landscape dynamics and human consequences requires accurate evaluation of Land Use and Land Cover (LULC) change. This study uses Landsat 7 ETM+ and Landsat 8 OLI imagery to examine LULC patterns in the Ghod River Basin for the years 2001, 2014, and 2024. Confusion matrices and Kappa statistics were used to validate the classification performance of Supervised Maximum Likelihood Classification (MLC). The 2040 LULC scenario was predicted using a Cellular Automata–Markov model based on transition probabilities from multi-temporal data.

The results show important differences between land-cover classifications. Built-up areas are expected to reach 473.15 km² by 2040, having increased from 293.99 km² in 2001 to 422.62 km² in 2024. Increased anthropogenic stress and decreased ecological stability are reflected in the ongoing decline of dense forests, vegetation, and water bodies. The 2040 landscape simulation highlights additional natural cover fragmentation and is consistent with present development trends. Overall, the work shows how well spatial modeling and remote sensing can be used to assess landscape change and promote well-informed planning for land use.

KEYWORDS

The Ghod River Basin; Urbanization; Landsat; Accuracy Assessment; Land Use and Land Cover (LULC); Remote Sensing; GIS; CA-Markov Model; Maximum Likelihood Classification.

1. INTRODUCTION

Land use/land cover (LULC) is supposed to be an integral component of the terrestrial environmental system. LULC information plays animportant role in investigating various environmental transform processes and climate change on local and global scales (ZEPPEL, 2011). Land Use and Land Cover (LULC) studies are important for understanding how landscapes evolve under the combined influence of natural processes and human activities. As environmental pressures and socio-economic growth intensify, monitoring these changes has become increasingly important. Satellite-based Remote Sensing, by virtue of its ability to provide synoptic information of land use and land cover at a particular time and location, has revolutionized the study of land use and land cover change (Attri et al., 2015).Such assessments help identify the major drivers of change, urban expansion, agricultural growth, deforestation, and shifts in ecological or hydrological systems, especially in semi-arid and rapidly developing regions where land resources face continuous stress.

Changes in LULC modify the biogeochemical and earth's energy balance cycles, leading to changing climate, ecosystem services, and land surface properties. Around the world, 62% of land areas have undergone significant shifts in land use, transitioning from naturally vegetated areas to agricultural land and urbanized, built-up areas.(Afuye et al., 2024). There has been a growing trend in the development of methods for determining change using data from satellite images to assess the land use land cover changes (Mondal et al., 2015). Today, only a very few models of land-use change can generatelong-term, realistic projections of future land-use/cover changes at regionalto global scales (Lambin, 2001).To monitor the changes, advanced techniques in remote sensing and GIS, such as Cellular Automata (CA)-Markov Chain Model (CAMCM), were used to identify the spatial and temporal changes that have occurred in LULC in this area (Singh et al., 2015). Cellular automata are dynamic models that are discrete in time, space, and state (Probeck et al., 2016).

In this regard, the current work looks atthe Ghod River Basin in western Maharashtra,a region facing increasing land-use pressures from expanding settlements, agricultural conversion, shrinking water bodies, and rangeland degradation. The LULC datasets for 2001, 2014, and 2024, along with their accuracy assessments and computational outputs, provide the foundation for evaluating past changes and projecting future landscape trajectories.

1.2 Research Problem

Growing urbanization and agricultural growth are driving fast socioeconomic change in the Ghod River Basin. These changes have resulted in decreased vegetation, reduced surface water resources, and more forest area fragmentation. Although there are a number of LULC studies that use satellite images, their scope and methodology vary greatly, and few offer a consistent, long-term overview of the basin's changing landscape. As a result, current research has not fully examined the wider ramifications of these changes, including their significance for future land management, environmental planning, and resource sustainability.

1.3 Objectives of the Study

This research aims to:

1. To classify and map LULC using Landsat imagery for the years 2001, 2014, and 2024.
2. To use the CA-Markov model to predict the 2040 LULC scenario and to quantify significant LULC changes from 2001 to 2024.
3. To analyze how present and future LULC changes would affect the ecosystem and hydrology in order to inform sustainable land-use planning in the Ghod River Basin.

1.4 Significance of the Study

This study is important because it measures LULC changes over almost thirty years using a standardized multi-temporal classification framework, allowing reliable evaluation of landscape transformation. It provides an overview of how ongoing trends may reshape the basin using CA-

Markov modeling, which not only captures past and present conditions but also forecasts future patterns up to 2040. Through thorough accuracy evaluations using confusion matrices and Kappa coefficients from the thesis dataset, the work promotes a high level of scientific accuracy.

The study relates LULC change to more general environmental issues, such as decreasing water bodies, decreased vegetation, and growing urban areas, in addition to the scientific outcomes. These observations draw attention to the increasing ecological stress and provide useful, policy-focused suggestions for sustainable land management. The observed patterns also represent larger trends in peri-urban and semi-arid areas of India as well as comparable environments around the world.

2. Study Area

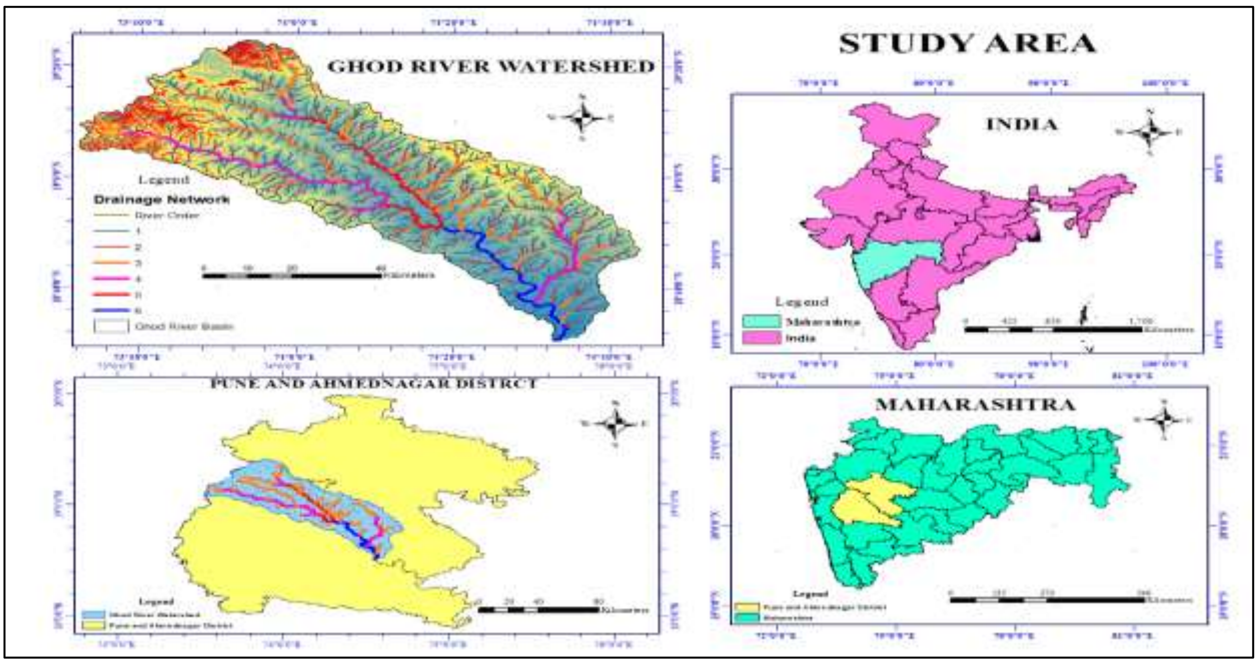

Figure 1. Study Area

The Ghod River Basin, a significant sub-basin of the Bhima River in western Maharashtra, extends approximately 4,594 km² on the Deccan Plateau in the districts of Pune and Ahilyanagar. At an elevation of approximately 1,090 meters, the river originates in the Sahyadri ranges near Ambegaon, Junnar, and flows eastward through various physiographic zones before joining the Bhima River, located closest to Kashti. The Deccan Traps' basaltic formations, which produce unique landforms like stepped terraces, flat-topped mesas, and sharply carved valleys, are largely responsible for the basin's shape.

The region's climate ranges from semi-arid to sub-humid, with hot summers, monsoon-dependent rainfall, and generally mild winters. The hydrology, vegetation patterns, and farming methods of the basin are all significantly impacted by these climatic characteristics. Because of the uniform basaltic geology, the drainage system is primarily dendritic, with significant tributaries like the Meena, Kukadi, and Pushpavati rivers developing fluvial connectivity. The soils, which support widespread cultivation of crops like sugarcane, wheat, and millet, range in color from deep black cotton soils to medium black and lighter clayey types.

The land-use pattern is dominated by agriculture, with rapidly growing built-up areas, scrublands, rangelands, and dry deciduous forests scattered throughout. Due to urbanization, deforestation, irrigation development, and climate unpredictability, the basin's land cover has changed significantly in recent decades. The region's water management system depends heavily on major reservoirs, such as Ghod, Manikdoh, Pimpalgaon Joge, Yedgaon, and Wadaj, for irrigation, water storage, and groundwater recharge.

In general, the Ghod River Basin is a landscape that is both socioeconomically and ecologically significant. Therefore, it is crucial to regularly evaluate its land use and land cover dynamics to promote long-term environmental stewardship, informed planning, and sustainable watershed management.

Data Sources and Methodology

This study mapped LULC changes in the Ghod River Basin using multi-temporal Landsat 7 ETM+ (2001) and Landsat 8 OLI/TIRS (2014, 2024) data, each at a resolution of 30 m. The 2040 LULC map was created at the same spatial scale by projecting future land-use patterns using the CA–Markov model.

Every dataset was subjected to normal preprocessing, which included layer building to create multi-band composites, radiometric calibration to translate DN values into reflectance, atmospheric correction done with the DOS method, and clipping to the basin boundary to preserve spatial uniformity. Water bodies, dense forest, vegetation, agricultural, built-up regions, rangeland, and barren land are the seven LULC types that were mapped.Whereas, supervised classification used when few numbers of classes are required for analysis. Some prior knowledge of pixels is also required that represent classes which you want to extract from the image after that analyst creates an appropriate signature form image for classification (Singh Sisodia & Tiwari, n.d.).Google Earth photos, reference datasets, and field observations were used to create training samples.

Confusion matrices, which provided Overall Accuracy and Kappa coefficients, were used to assess classification accuracy. While the 2024 classification obtained 91.5% accuracy and a Kappa of 0.89, suggesting greater class separability, the 2001 and 2014 maps achieved 86% accuracy with Kappa values of 0.80 and 0.82.

Post-classification comparison and cross-tabulation were used to evaluate LULC changes, identifying significant gains, losses, and category shifts. The CA-Markov prediction was based on these transition matrices. The model produced the 2040 LULC scenario, which included continuing trends in urban growth, agricultural expansion, and ecological decline, by combining transition probabilities from the 2001–2014 and 2014–2024 eras with Cellular Automata neighborhood rules.

Landsat dataset capture, preprocessing, supervised MLC classification, accuracy evaluation, post-classification change detection, and future prediction using the CA–Markov model comprised the process.

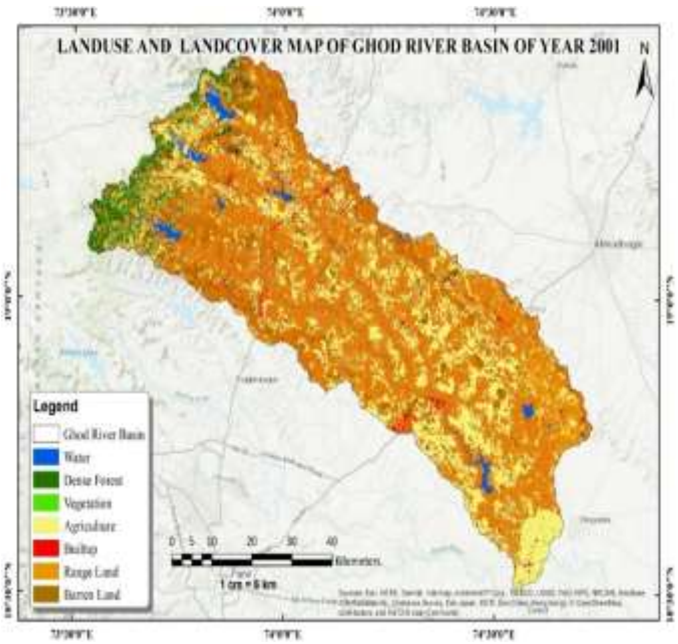

Figure 2. LULC map for the year 2001

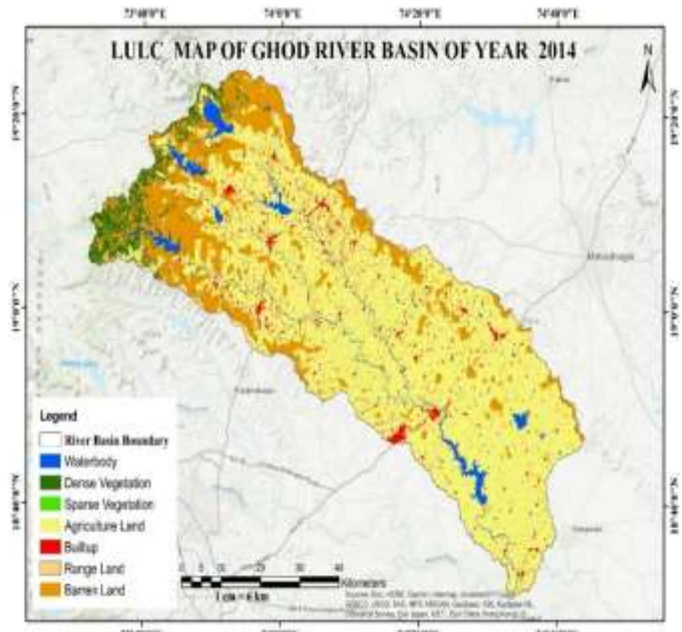

Figure 3. LULC map for the year 2014

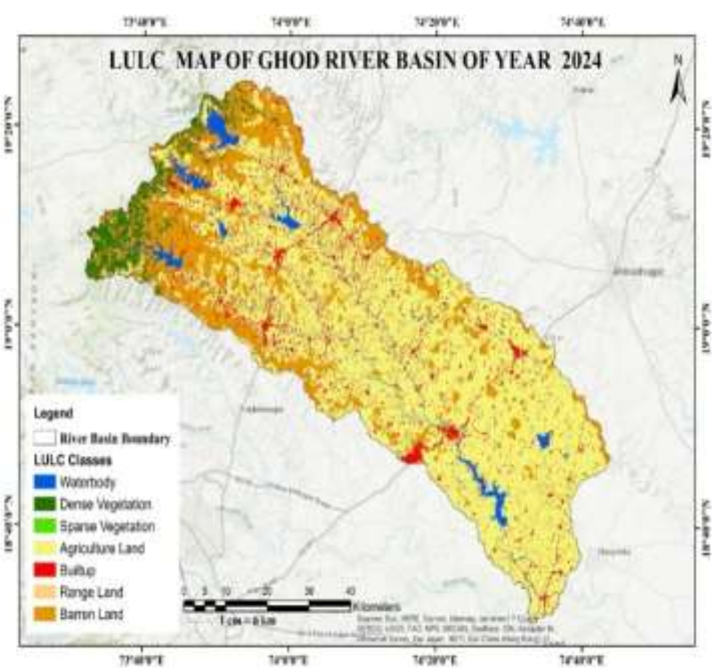

Figure 4. LULC map for the year 2024

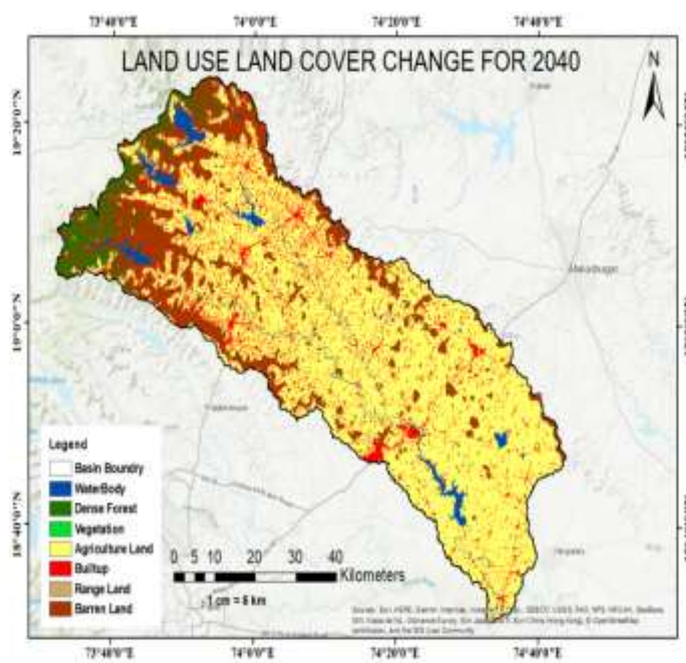

Figure 5. Predicted LULC map for 2040

4. Results

The categorized Land Use and Land Cover (LULC) outputs for 2001, 2014, and 2024 are shown in this section, followed by the CA–Markov modeling-based projected scenario for 2040. Area statistics, figure descriptions, assessments of categorization accuracy, and an analysis of landscape changes throughout the Ghod River Basin are among the findings.

4.1 Overview of Classified LULC Maps

Over the course of the study, the classed maps show notable changes in the main LULC categories. The topography of the basin is still dominated by agricultural land, although water bodies have drastically decreased, built-up areas have steadily increased, and dense woodland and flora have gradually decreased.

The following descriptions correspond to the visual maps.

Figure 2. LULC Map 2001

Figure 2 illustrates the 2001 LULC pattern with vast rangelands, somewhat dense forest cover in the upper catchments, and major agricultural areas dominating the basin. Water bodies are mostly related with reservoir locations and appear as tiny, dispersed patches.

Figure 3. LULC Map 2014

In Figure 3, the 2014 LULC distribution is shown, with a discernible increase in rangeland extent, a minor decline in thick forest cover, and a considerable expansion of built-up areas. The amount of agricultural land has slightly decreased since 2001.

Figure 4. LULC Map 2024

In Figure 4, the 2024 LULC circumstances, which are marked by increased agricultural activity and ongoing built-up land expansion, are depicted.Across the basin, vegetation appears scattered, thick forest areas decrease, and water bodies continue to decline.

Figure 5. Predicted LULC Map 2040

The prediction of LULC plays a crucial role increating plans for balancing conservation, competingusers, and developmental pressures(Kamaraj & Rangarajan, 2022).The expected LULC scenario for 2040 is depicted in Figure 5, which shows significant built-up growth around key towns and transportation links. Rangeland areas decrease somewhat as agricultural and urban uses increase, but water bodies and dense woods continue to decline.

4.2 LULC Area Statistics (2001, 2014, 2024, 2040)

Table 1. LULC Area Statistics for the Ghod River Basin (2001–2040)

All values in km²

LULC Class	2001	2014	2024	2040 (Predicted)
Water Bodies	192.93	146.99	142.40	137.81
Dense Forest	284.81	192.93	174.56	165.37
Vegetation	192.94	174.56	137.81	119.44
Agricultural Land	2737.83	2498.96	2682.71	2825.11
Built-up Areas	293.99	385.87	422.62	473.15
Barren Land	137.81	137.81	91.87	45.94
Rangeland	753.36	1056.55	941.70	826.86

Source: Classified outputs and projection results

4.3 Interpretation of LULC Trends

The analysis indicates that cultivable land will change the most, and will transform toprimarily three classes: waste land, agriculture, and built up(Singh et al., 2015). The combined effects of resource pressure, urbanization, agriculture, and ecological change throughout the Ghod River Basin are reflected in the long-term LULC patterns.

4.3.1 Water Bodies

Water bodies steadily decline from 192.93 km² (2001) to a projected 137.81 km² (2040). Rising irrigation demand, reservoir sedimentation, and decreased monsoonal recharge brought on by climatic fluctuations and changed land surfaces are probably the causes of this decline.

4.3.2 Dense Forest and Vegetation

Dense forest cover fell from 284.81 km² in 2001 to 165.37 km² by 2040, while vegetation decreased from 192.94 km² to 119.44 km². This loss appears to be mostly caused by agricultural growth, grazing pressure, and land conversion for settlements.

4.3.3 Agricultural Land

Although it changes, agriculture remains the main industry. It declines between 2001 and 2014, then rapidly recovers by 2024. By 2040, it is expected to reach 2825.11 km². This recovery is a result of increased irrigation, intensification, and the return of marginal lands to farming.

4.3.4 Built-up Area

From 293.99 km² (2001) to 473.15 km² (2040), built-up land has grown continuously and strongly, demonstrating ongoing urbanization along important transportation and development areas.

4.3.5 Barren Land and Rangeland

A significant decrease in barren land shows significant redevelopment and conversion. Due to land degradation or fallowing, rangeland first increases between 2001 and 2014 before decreasing by 2040 as settlements and agriculture grow.

4.4 Change Detection Results

4.4.1 Changes (2001–2014)

While built-up land increases by around 92 km², water bodies and dense forests significantly decrease. When huge areas of land convert into rangeland, agriculture declines, a sign of brief desertion or degradation.

4.4.2 Changes (2014–2024)

The quantity of forest and vegetation cover continues to decline, built-up areas continue to grow, and agriculture develops rapidly. The amount of barren ground has greatly decreased, indicating ongoing land reclamation.

4.4.3 Predicted Changes (2024–2040)

It is expected that water and forest cover will continue to decrease while built-up land will increase to 473.15 km². Degraded rangelands are projected to be restored by agriculture, and conversion will result in the extinction of almost all barren areas.

4.5 Spatial Pattern Interpretation

Towns, main thoroughfares, and industrial areas are where urban expansion is focused. Through restoration and increased cultivation, agricultural land is expected to spread into former rangelands. A need for combined land-water management is shown by declining forest and water resources, which cause issues with groundwater recharge, soil erosion, and habitat destruction.

4.6 Classification Accuracy Summary

Table 2. Overall Accuracy and Interpretation

Year	Overall Accuracy	Kappa	Interpretation
2001	86%	0.80	Good reliability
2014	86%	0.82	Strong agreement
2024	91.5%	0.89	Very strong agreement

Better spectral reparability and enhanced classification performance in recent years are indicated by the Kappa coefficient's steady growth.

5.Discussion

The Ghod River Basin is rapidly changing due to human activity, as indicated by the LULC patterns from 2001 to 2024 and predicted modification for 2040. Forests, water resources, agriculture, and communities have all changed, reflecting larger environmental and socioeconomic challenges typical of semi-arid developing countries.

5.1 Drivers of LULC Change

5.1.1 Urbanization and Built-up Growth

Due to population expansion, rising infrastructure, and industrial development along the Pune, Ahilyanagar corridor, built-up land has steadily increased from 293.99 km² (2001) to a projected 473.15 km² (2040). These patterns are similar to global urbanization processes, where corridor-based expansion is supported by economic growth and connectivity.

5.1.2 Agricultural Intensification

Although short-term changes, agricultural land is projected to increase through time and reach 2825.11 km² by 2040. Agricultural intensification is a set of patterns of land-use change with the common feature of increaseduse of the same resources for agriculturalproduction, usually as a result of a switch fromintennittent to continuous cultivation of the samearea of land. Associated trends are specialization incrop or livestock species utilized, increased managementintervention, and greater reliance on markets (Giller et al., 1997).

5.1.3 Loss of Forests and Vegetation

As agriculture, grazing, and growing settlements encroach on natural regions, dense forests and vegetation gradually decrease. This result is consistent with more detailed studies showing that peri-urban pressures and land conversion are the main causes of forest degradation in developing regions. The natural land cover would likely deteriorate due to the existing tendency of changing LULC due to build up area. Therefore, the pressure placed on these places will continue to increase, and it is anticipated that areas such as rangelands, salt marshes, nearhighways and human settlements will become prime candidates for transformation (Asif et al., 2023).

5.1.4 Reduction in Water Bodies

Due to sedimentation, decreased monsoon recharge, and increasing water withdrawals, water bodies are still getting smaller. Similar losses take place in semi-arid basins around the world, where human activity and climatic instability exacerbate water stress.

5.2 Hydrological and Environmental Implications

5.2.1 Surface Runoff and Flooding

Decreasing vegetation raises the risk of sedimentation and floods by increasing surface runoff and decreasing infiltration. These outcomes are compatible with a worldwide study that connects changed hydrology to land degradation.The consequences of land degradation are far-reaching.It has the potential to cause biodiversity loss, decreased agricultural output, and heightened susceptibility tonatural disasters like droughts and floods (Tahir et al., 2025).

5.2.2 Groundwater Stress

Groundwater recharge is weakened by the growth of impermeable built-up regions and decreasing water bodies, indicating increased stress by 2040 until recharge strategies are enhanced.The landusechange, variability in land use by humans and the resultingalterations in surface features were primary, but poorlyrecognized drivers of long-term global climate patterns.Additionally, the study LULC change effect on groundwater table(Gyamfi et al., 2016; Pielke, 2005; Salman et al., 2018)

5.2.3 Soil Erosion and Degradation

Changes in barren land and rangeland are indicative of cycles of restoration and decline. The long-term reliability of recovered soils is still an issue, even if it is expected that barren land will decrease by 2040.

5.3 Urban Sprawl Dynamics

The Ghod River Basin's urban growth follows a linear, corridor-based layout that spreads along significant highways and town centers. Similar structures have been noted in quickly developing parts of Brazil, China, and Kenya, as well in India along the Bengaluru–Mysuru expressway, the Delhi–Gurugram corridor, and the Pune–Mumbai Expressway. Concerns regarding constraints on mobility, growing carbon dioxide emissions, and disruption to ecosystem links within the basin are raised by the mapped LULC patterns (Figures 3–6), which show increasing fragmentation near transportation corridors.Urban expansion is a dynamicprocess resulted from rapid population growth, socio-economic developmentand policies taken by administrators, whereas urban sprawls are resulted fromthe loss of productive agricultural land, open green spaces, surface water bodies, and depletion of groundwater(Dutta et al., 2020)

5.4 Environmental Sustainability Concerns

5.4.1 Biodiversity Loss

The fragmentation of habitat is evident in the continual decline of dense forests and vegetation. Regional biodiversity is at risk as continuous biological corridors are split into isolated areas, species accessibility decreases, and ecosystem functioning deteriorates.

5.4.2 Climate Resilience

The local climate is impacted by LULC changes. Growing populated regions increase land surface temperatures, decrease evapotranspiration, and exacerbate the effect of heat islands. Regional climate shift may become possible due to further built-up expansion predicted for 2040; this is similar to habits observed in rapidly urbanizing South Asian countries.LULC changes are further exacerbated by the effects of climate change, which drive shifts in precipitation patterns and rising air temperatures. These factors directly influence the hydrological cycle, increasing the volume, variability, and intensity of rainfall. Such changes can intensify erosion processes and sediment transport, amplifying their environmental impact (Admas et al., 2024).

5.5 Implications for Planning and Policy

It is important to preserve the remaining forests through increased afforestation and expansion control is highlighted by the observed LULC patterns. Desiltation, tank rehabilitation, and groundwater recharge techniques can all enhance water resources. Transit-oriented development and corridor zoning will be necessary to control urban sprawl. Drought-resistant crop adoption, watershed management, and soil conservation are all essential to preserving the environment and output from agriculture.

6. Conclusion

The present study used multi-temporal Landsat data, MLC classification, accuracy evaluation, and CA-Markov modeling to analyze LULC trends in the Ghod River Basin from 2001 to 2024 and estimate patterns for 2040. The results completely indicate that urbanization, intensified agriculture, and ecological pressure are driving the basin's fast and ongoing land change.

From 293.99 km² in 2001 to 422.62 km² in 2024, built-up land grew steadily, and by 2040, it is predicted to reach 473.15 km². Following an initial downturn, agriculture recovered strongly by 2024 and is expected to develop even more, showing increased cultivation and the rehabilitation of degraded land. Dense forest, vegetation, and water bodies, on the other hand, are still decreasing, indicating increasing ecological stress, decreased hydrological stability, and deteriorating climatic resistance.

Overall Accuracy rose from 86% to 91.5% and Kappa values increasing from 0.79 to 0.89, the classification findings show good reliability. In a complex, semi-arid watershed, the CA–Markov model also shows accuracy in projecting future LULC shifts.

The study's overall findings emphasize the necessity of integrated watershed management, improved urban expansion control, and more robust forest, vegetation, and water resource conservation. In the Ghod River Basin, these steps are pivotal for striking a balance between ecological sustainability and development. In order to improve prediction accuracy and capture finer-scale landscape dynamics, subsequent research can benefit from higher-resolution imagery, socioeconomic data, climate projections, and advanced machine learning classifiers like random forests and SVM.

7. References

1. Admas, M., Melesse, A. M., & Tegegne, G. (2024). Prevendoosimpactos do uso/cobertura da terra e mudançasclimáticasnosfluxos de água e sedimentosnabaciahidrográfica de Megech, Bacia do Alto Nilo Azul. *Remote Sensing*, *16*(13), 2385. https://doi.org/10.3390/rs16132385
2. Afuye, G. A., Ndku, L., Kalumba, A. M., Santos, C. A. G., Orimoloye, I. R., Ojeh, V. N., Thamaga, K. H., & Sibandze, P. (2024). Global trend assessment of land use and land cover changes: A systematic approach to future research development and planning. In *Journal of King Saud University - Science* (Vol. 36, Issue 7). Elsevier B.V. https://doi.org/10.1016/j.jksus.2024.103262
3. Asif, M., Kazmi, J. H., Tariq, A., Zhao, N., Guluzade, R., Soufan, W., Almutairi, K. F., Sabagh, A. El, & Aslam, M. (2023). Modelling of land use and land cover changes and prediction using CA-Markov and Random Forest. *Geocarto International*, *38*(1). https://doi.org/10.1080/10106049.2023.2210532
4. Attri, P., Chaudhry, S., & Sharma, S. (2015). International Journal of Current Engineering and Technology Remote Sensing & GIS based Approaches for LULC Change Detection-A Review. In *3126| International Journal of Current Engineering and Technology* (Vol. 5, Issue 5). http://inpressco.com/category/ijcet
5. Dutta, D., Rahman, A., Paul, S. K., & Kundu, A. (2020). Estimating urban growth in peri-urban areas and its interrelationships with built-up density using earth observation datasets. *Annals of Regional Science*, *65*(1), 67–82. https://doi.org/10.1007/s00168-020-00974-8
6. Giller, K. E., Beare, M. H., Lavelle ’, P., Izac, A.-M. N., & Swift, M. J. (1997). Applied Soil Ecology Agricultural intensification, soil biodiversity and agroecosystem function. In *Applied Soil Ecology* (Vol. 6).
7. Gyamfi, C., Ndambuki, J. M., & Salim, R. W. (2016). Hydrological responses to land use/cover changes in the Olifants Basin, South Africa. *Water (Switzerland)*, *8*(12). https://doi.org/10.3390/w8120588
8. Kamaraj, M., & Rangarajan, S. (2022). Predicting the future land use and land cover changes for Bhavani basin, Tamil Nadu, India, using QGIS MOLUSCE plugin. *Environmental Science and Pollution Research*, *29*(57), 86337–86348. https://doi.org/10.1007/s11356-021-17904-6
9. Lambin, E. F. , G. H. J. ,& L. E. (2001). Dynamics of land-use and land-cover change in tropical regions. *Annual Review of Environment and Resources*, *28(1), 205–241*.
10. Mondal, M. S., Sharma, N., Kappas, M., & Garg, P. K. (2015). Critical assessment of land use land cover dynamics using multi-temporal satellite images. *Environments - MDPI*, *2*(1), 61–90. https://doi.org/10.3390/environments2010061
11. Pielke, R. A. (2005). Land use and climate change. *Science*, *310*(5754), 1625–1626. https://doi.org/10.1126/science.1120529

12. Probeck, M., Colgan, A., Krimly, T., Zárate, M., & Schneider, K. (2016). Land Use and land cover. *Regional Assessment of Global Change Impacts: The Project GLOWA-Danube*, *22*(2), 83–89. https://doi.org/10.1007/978-3-319-16751-0_9
13. Salman, S. A., Shahid, S., Mohsenipour, M., & Asgari, H. (2018). Impact of landuse on groundwater quality of Bangladesh. *Sustainable Water Resources Management*, *4*(4), 1031–1036. https://doi.org/10.1007/s40899-018-0230-z
14. Singh, S. K., Mustak, S., Srivastava, P. K., Szabó, S., & Islam, T. (2015). Predicting Spatial and Decadal LULC Changes Through Cellular Automata Markov Chain Models Using Earth Observation Datasets and Geo-information. *Environmental Processes*, *2*(1), 61–78. https://doi.org/10.1007/s40710-015-0062-x
15. Singh Sisodia, P., & Tiwari, V. (n.d.). *Analysis of Supervised Maximum Lil<elihood Classification for Remote Sensing Image*.
16. Tahir, Z., Haseeb, M., Mahmood, S. A., Batool, S., Abdullah-Al-Wadud, M., Ullah, S., & Tariq, A. (2025). Predicting land use and land cover changes for sustainable land management using CA-Markov modelling and GIS techniques. *Scientific Reports*, *15*(1), 1–23. https://doi.org/10.1038/s41598-025-87796-w
17. ZEPPEL, M. (2011). Ecological Climatology: Concepts and Applications, Second Edition. *Austral Ecology*, *36*(5), e20–e21. https://doi.org/10.1111/j.1442-9993.2010.02195.x