Simulation of Land Use and Land Cover Using the MOLUSCE Plugin Integrated with QGIS for the Western Himalayan Region of India

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Abstract

The Western Himalayan biogeographic zone of India is characterized by highly fragile ecosystem, where land use and land cover (LULC) changes have impacted the environment as well as local biodiversity. This necessitates prediction of LULC changes to support sustainable land management practices. This study aims to address this need by projecting LULC and evaluating the changes anticipated for the year 2055, utilizing the MOLUSCE (Modules for Land Use Change Evaluation) plugin integrated into freely available QGIS software. MOLUSCE tool is used to simulate LULC change by incorporating predictive algorithms such as Artificial Neural Networks (ANN) and Weights of Evidence (WoE). In this study, decadal LULC data from 1975, 1985, 1995, 2005, and 2015 was extracted from reliable existing literature, including a recent study by (Rathore et al., 2022). The research is divided into two main stages: model calibration and model validation. For validation, LULC data from 1995 and 2005 were used to predict the LULC of 2015, and the model's output was then validated against the actual 2015 LULC data obtained from existing sources. The ANN-based approach showed an overall accuracy of 82% in this study, underscoring the model's effectiveness. The model was calibrated using LULC data from 1975 and 2015 to project the LULC scenario for the year 2055. This calibration accounts for historical trends and transitions, thereby improving the model's predictive accuracy for future scenarios. The study highlights the significance of using advanced geospatial tools like MOLUSCE in QGIS for LULC change modelling, especially in ecologically sensitive regions like the Western Himalayas. This study provides insights into potential future changes and contributes to ongoing efforts to preserve the ecological integrity of the Western Himalayan region.

INTRODUCTION

The Western Himalaya, a region defined by its rugged terrain, diverse wildlife, and varying weather, is now undergoing a significant transformation in land (Brown et al., 2022; Garg et al., 2019; Shahabuddin et al., 2021; Wiwoho et al., 2024). Traditional livelihoods, such as farming, forestry, and herding, are gradually being replaced by the rapid growth of urban (Deb et al., 2018), industries and tourism. This shift, however, is not without its environmental consequences. Deforestation and infrastructure development are causing ecological problems, contributing to the broader issue of (Baig et al., 2022) land use and land cover changes (LULCC) that are affecting our planet on a global scale (Ahmad et al., 2023). To better understand these complex changes and predict future trends, land change models, particularly when integrated with advanced techniques like Artificial Neural Networks (ANN) and Weights of Evidence (WoE), provides valuable insights (Mandal et al., 2023; Masruroh et al., 2024; Rahman et al., 2017; Shabani et al., 2022).

So, to gain insight how land use is going to modify in future, this work is an attempt to predict LULCC of Western Himalayan region of India. The objective of this work is “Projection of future Land Use Land Cover (LULC) for the Western Himalayas, India, for the year 2055, utilizing the MOLUSCE (Modules for Land Use Change Evaluation) plugin integrated into QGIS software”. The method adopted provides an insight for a comprehensive analysis of current trends as well as future land use patterns.

STUDY AREA

This study is carried out for the Western Himalaya region (1A, 1B, 2B and 2B) of India. This covers maximum part of Himalaya with respect to biogeographic zone wise classification (Kumar et al., 2022). This is comprising of four biogeographic

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provinces which are listed in Table (1). Each zone has a unique ecological aspect and biogeographic characters (Panda, 2022). The climatic condition of Jammu & Kashmir (comprising 1A, 1B and major parts of 2A) ranges from tropical in lower altitude to temperate in higher altitude, receives an annual average rainfall of about 600 mm to 800 mm with annual temperature varies between sub-zero to 40° C (Das & Meher, 2019). In Himachal Pradesh (comprising east part of 2A and west part of 2B) average annual rainfall is 1800 mm and temperature varies from sub-zero to 35° C. In Uttarakhand (comprising major parts of 2B), the eastern sides experience heavy rainfall while western part receives relatively less rainfall and dry in condition with average annual rainfall of 1,550 mm. The dominant vegetation type is tropical deciduous forest at lower elevations up to 1500 m, while above this elevation, the study area is dominated by evergreen forests, such as coniferous tree species. Rise of the population can be observed over the study area (Long, 2004; Singh & Kumar, 2014).

Table 1: Biogeographic zones distribution of study area

Class	Himalayan section	State covered
1A	Trans -Himalaya	Ladakh Mountain
1B	Trans -Himalaya	Tibetan Plateau
1C	Cold arid region of Eastern HP &UK	
2A	West Himalaya	Uttarakhand
2B	West Himalaya	Uttarakhand

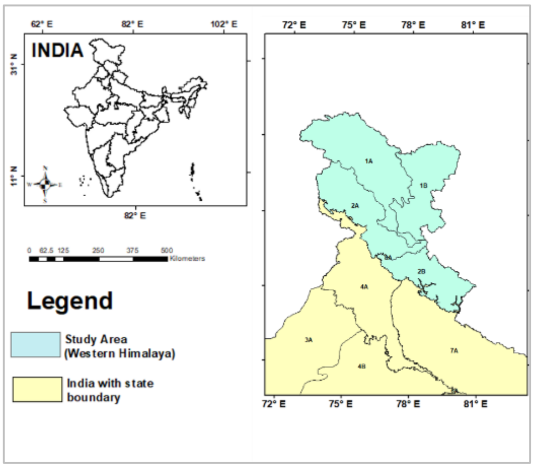

Figure 1: Illustration of study area

METHODS

To predict how land use will change in the future, used a software called MOLUSCE with QGIS. Further, gathered historical land use data from satellite images and other sources, covering time periods like 1975, 1985, 1995, 2005, and 2015. Then selected a predictive algorithm, Artificial Neural Networks (ANN) and Weights of Evidence (WoE), and trained it using this historical data. After testing the model to ensure its accuracy, we used it to predict land use for the year 2055. Finally, the results was analyzed to understand potential changes in land use patterns and their implications for environmental management and policy development.

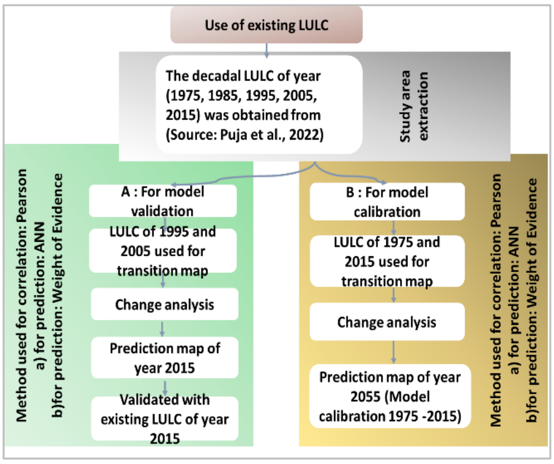

Figure 2: Workflow adopted to accomplish the objectives

RESULTS

From 1995 to 2005, as shown in Figure (3), Evergreen Forests and Waterbodies experienced slight growth, increasing by 1.14% and 0.40% respectively. In contrast, Scrubland and Deciduous Forests saw declines of 1.23% and 0.79%. Cropland and Grassland showed minor increases, while Built-up and Plantation areas experienced small decreases. Snow/Ice areas notably increased by 0.63%.

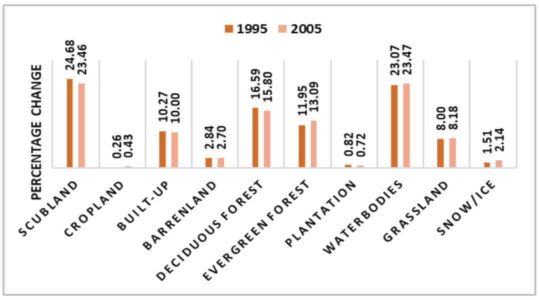

Figure 3: Illustration of Percentage of Land Cover Change from year 1995 to year 2005

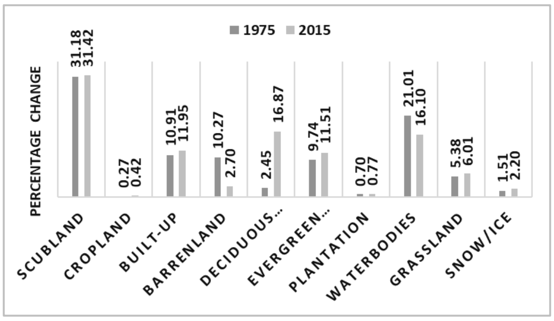

Figure 4:Illustration of Percentage of Land Cover Change from year 1975 to year 2015

Table 2: Transition matrix from year 1975 to 2015 (Barren land – BL; Built-up – BU; Cropland – CL; Deciduous forest – DF; Evergreen forest – EF; Grassland – GL; Plantation – PL; Snow/ice – SI; Scrubland – SL)

Class	SL	CL	BU	BL	DF	EF	PL	WB	GL	SI
SL	0.71	0	0	0	0	0.13	0	0.07	0.06	0.01
CL	0	0.69	0.25	0	0	0	0	0	0.01	0.01
BU	0	0.01	0.18	0.01	0.1	0.03	0	0	0.02	0.01
BL	0	0	0.03	0.88	0	0	0	0	0	0.02
DF	0.02	0	0.08	0.01	0.8	0.04	0	0	0.04	0
EF	0.19	0	0.05	0	0.1	0.46	0	0.08	0.06	0
PL	0	0.02	0.05	0.01	0	0	0.8	0	0.01	0
WB	0.28	0	0	0	0	0.05	0	0.6	0.02	0
GL	0.12	0	0.12	0.01	0.2	0.14	0	0.03	0.34	0.01
SI	0.08	0	0.05	0	0	0.02	0	0	0.01	0.79

Moving to the period from 1975 to 2015, depicted in Figure (4), we observe the probability of various land cover changes. Scrubland predominantly remained as scrubland, with a retention rate of 71%, although a portion transitioned to Evergreen Forest (13%) and Waterbodies (7%). Cropland had a high retention rate of 69%, but also transitioned significantly to Built-up areas, covering 25%. Barren land demonstrated the highest retention rate at 88%, while Evergreen Forest areas transitioned notably to Scrubland (19%) and Deciduous Forest (12%). Waterbodies retained 60% of their original area, with some portions transitioning to Scrubland (28%)

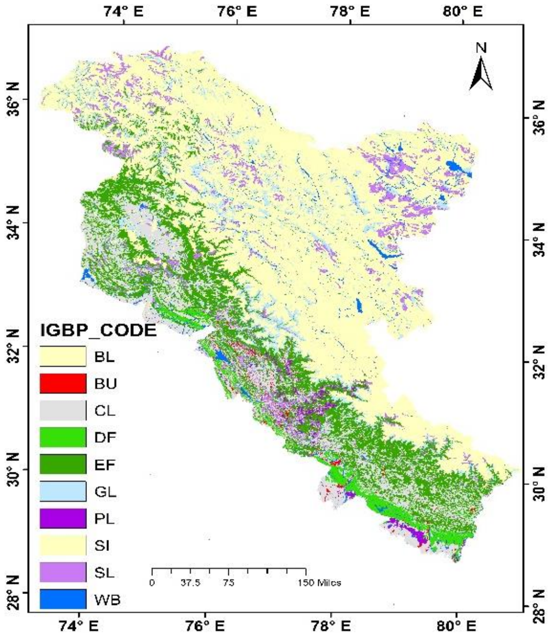

Figure 5: Illustration of Land Use Land Cover Change map of the projected year 2055

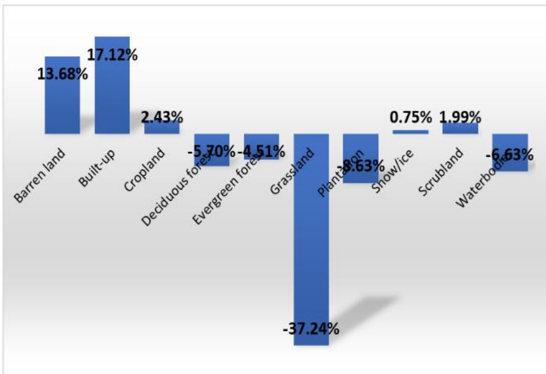

Figure 6: Projected percentage change of area of the year 2055 as compared to 2015 LULC

The projected Land Use and Land Cover Change (LULC) map for the year 2055, as illustrated in Figure 5, shows a distinct color-coded classification: built-up areas are marked in red, forest areas in green, water bodies in blue, barren land and snow-covered zones in yellowish tones, and agricultural land in grey. The projected percentage change in area for 2055, compared to 2015 LULC data, is shown in Figures 5 and 6. The projections reveal an increase in barren land by 13.68%, indicating a notable expansion. Built-up areas are projected to grow significantly by 17.12%, reflecting ongoing urban expansion and progress. Cropland is projected to see a modest increase of 2.43%, suggesting slight agricultural expansion. The area of shrub land is expected to grow slightly by 0.75%, while savanna regions are projected to increase by 1.99%.

Conversely, deciduous forests are projected to decline by 5.70%, signaling a reduction in these forest areas. Evergreen forests are expected to show a slight decrease of 4.51%, indicating a minor reduction in their coverage. Grasslands are projected to decrease substantially by 37.24%, marking a significant reduction. Permanent wetlands are expected to shrink by 8.63%, reflecting a loss in wetland areas, while water bodies are projected to decline by 6.63%, suggesting a reduction in their extent.

CONCLUSION

This research work shows significant environmental changes and emphasizes the importance of effective land management. Using the MOLUSCE plugin tool that is free and available as open source in QGIS, along with Artificial Neural Networks (ANN) and Weights of Evidence (WoE), the model showed an accuracy of 82% in predicting land use changes, allowing reliable projections. By 2055, broadleaf forests and built-up areas are expected to expand, suggesting both forest growth and rising urbanization. However, evergreen forests, grasslands, and water bodies are projected to shrink, potentially impacting biodiversity and regional stability. A notable reduction in barren land from 1975 to 2015 reflects improved land management. The study underscores LULC models as important tools for guiding sustainable decisions to protect the Western Himalayas' ecosystems.

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