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Impacts of Land-Use Change on Carbon Sequestration and Climate Mitigation Potential in Central Nepal

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Abstract

Ongoing land use and land cover (LULC) changes in Nepal's mid-hill districts have important implications for carbon sequestration and climate finance potential, as shifts among forest, agricultural, built-up, and other land-cover classes influence landscape-level carbon storage. This study presents an integrated geospatial and economic analysis of LULC dynamics and their impacts on carbon stocks in Kavrepalanchowk District, Bagmati Province. Using harmonized National Land Cover Monitoring System (NLCMS) maps for 2013 and 2022 as baseline data, historical LULC transitions were analyzed through remote sensing and Geographic Information Systems (GIS) techniques. TerrSet's Land Change Modeler (LCM), employing a Cellular Automata–Markov chain framework with drivers including elevation, slope, population density, proximity to roads and buildings, distance from rivers, and soil type, simulated a 2032 LULC scenario with 95.3% validation accuracy. Forest cover is projected to increase from 62.3% (2022) to 66.6% (2032), while cropland is projected to decline from 33.4% to 29.4%. The InVEST Carbon Storage and Sequestration model quantified baseline carbon stocks at 13.92 million Mg C (51.0 MtCO, e), projected to rise to 14.68 million Mg C by 2032. A net gain of 762,195 Mg C (2.79 MtCO, e) is projected. Economic valuation, aligned with Nepal's Emission Reductions Payment Agreement (ERPA) framework at USD 5 per tCO, e, estimates the standing stock notional value at USD 255 million. The realizable results-based payment potential for Kavrepalanchowk is estimated at USD 9.1–9.7 million, which could support climate change adaptation and mitigation in the Kavrepalanchowk District. These findings provide district-level evidence for Nepal's Measurement, Reporting, and Verification (MRV) system and underscore the need to extend carbon finance mechanisms beyond the Terai lowlands into Nepal's mid-hill districts.

Keywords: *Carbon stock, community forestry, land use change, REDD+, spatial modeling*

1. Introduction

Terrestrial carbon sequestration has emerged as a cornerstone of global climate mitigation, with land use and land cover (LULC) change recognized as a primary driver of carbon stock fluctuations (Selmy et al., 2023; Zafar et al., 2024). In Nepal, socioeconomic development is tightly coupled with natural resources, rapid urbanization and shifting agricultural practices have transformed mid-hill landscapes, creating a paradox in which national forest cover nominally increased to 43.38% by 2022 (FRTC, 2024) while localized degradation persists in districts experiencing infrastructure expansion.

Kavrepalanchowk (Kavre) District encompasses extensive community-managed forests that serve simultaneously as local livelihood assets and national carbon sinks. Despite this significance, district-level, spatially explicit assessments integrating predictive LULC modeling with carbon quantification and economic valuation remain largely unexplored. Most existing analyses operate at national scales or examine land use change and carbon stocks in isolation (Chaulagain et al., 2024). Nepal's enactment of the Carbon Trade Regulation 2025 (MoFE, 2025) and the 2021 Emission Reductions Payment Agreement (ERPA) with the World Bank's Forest Carbon Partnership Facility (FCPF), committing to reduce 9 MtCO, e for USD 45 million, have elevated the demand for thorough subnational carbon evidence (Nepal Economic Forum, 2023; World Bank, 2021). Results-based payment under REDD+ (Reducing Emissions from Deforestation and Forest Degradation) requires verified, incremental emission reductions relative to a forest reference level, making localized, MRV-compatible assessments a prerequisite for accessing climate finance (MoFE, 2023).

This study addresses these gaps by: (1) analyzing historical LULC transitions from 2013 to 2022 using remote sensing and GIS; (2) simulating 2032 LULC scenarios using a Cellular Automata–Markov (CA–Markov) framework in TerrSet's Land Change Modeler; (3) quantifying carbon storage and sequestration dynamics and their associated economic value under projected emission reduction scenarios using the InVEST Carbon module.

2. Materials and Methods

2.1 Study Area

Kavre District lies within Nepal's mid-hill physiographic region (Fig. 1), extending from lower river valleys to ridges approaching 3,000 m above sea level. The district covers 1,396 km² across 13 municipalities, characterized by a mosaic of community-managed forests, rain-fed agriculture, grasslands and rapidly expanding built-up areas. Community Forest User Groups (CFUGs) manage tens of thousands of hectares, providing timber, fuelwood, and fodder while functioning as significant carbon sinks central to Nepal's REDD+ commitments (Chaulagain et al., 2024; FRTC, 2022).

2.2 LULC Data and Classification

Annual land cover datasets for 2013 and 2022 were obtained from the National Land Cover Monitoring System (NLCMS) developed by the Forest Research and Training Centre (FRTC, 2024) in collaboration with ICIMOD. The NLCMS applies cloud-based machine learning classifiers to Landsat imagery within Google Earth Engine, producing harmonized, nationally consistent maps. Nine land cover classes

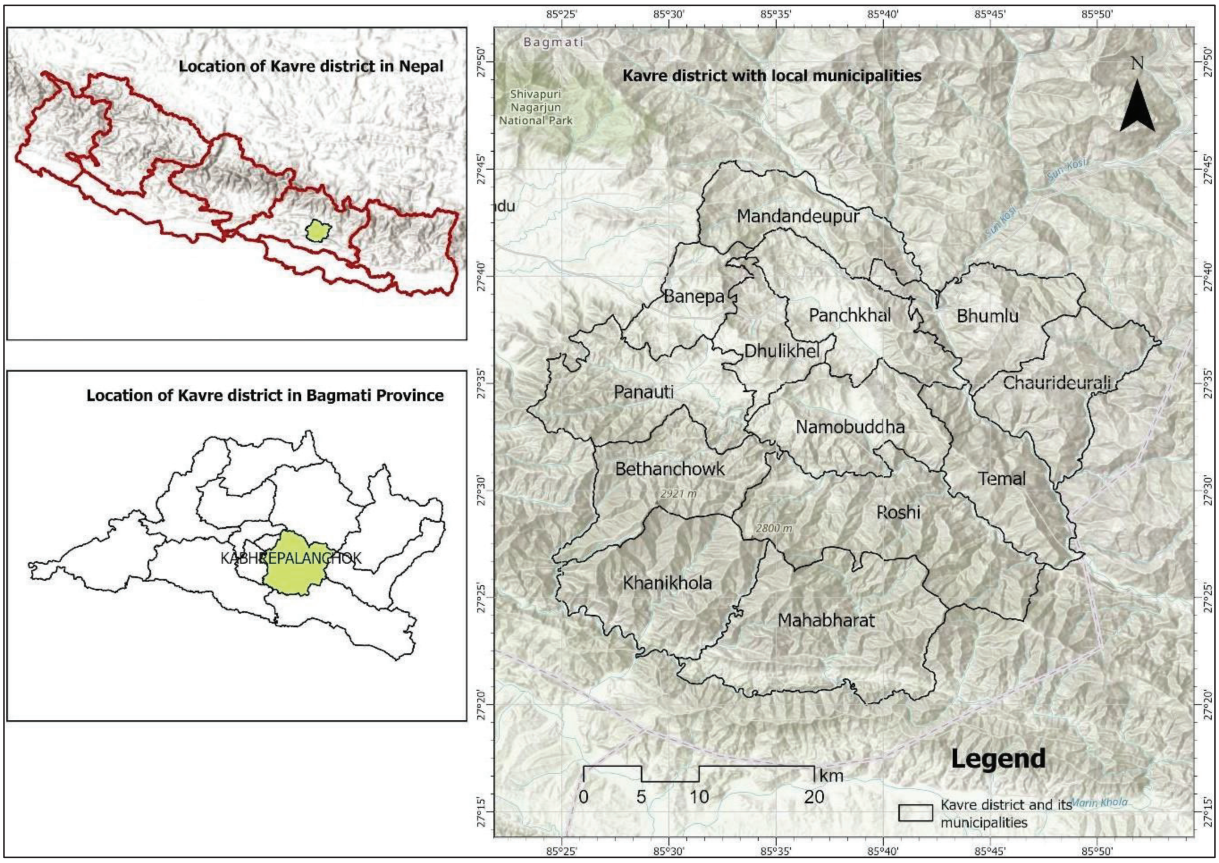

Figure 1: Location map of Kavre District.

Table 1: Land cover classes and definition.

Main land cover class	Description	IPCC land cover class
Forest	Land spanning more than 0.5 ha with trees higher than 5 m and a canopy cover of more than 10%, or trees able to reach these thresholds in situ. It does not include land that is predominantly under agricultural or urban land use.	Forest
Other wooded land (OWL)	Land not classified as forest spanning more than 0.5 ha, having at least 20 m width and a tree canopy cover of trees between 5% and 10%, or the canopy cover of trees less than 5% but the combined cover of shrubs, bushes and trees more than 10%; includes area of shrubs and bushes where no trees are present.	Forest
Grassland	Areas covered by herbaceous vegetation with cover ranging from Closed to Open (15–100%). This category includes rangeland and pasture that is not considered cropland.	Grassland
Cropland	This category includes arable and tillage land, and agroforestry systems where vegetation falls below the thresholds used for the forest land category, consistent with the selection of national definitions.	Cropland
Built-up area	Built-up areas refer to artificial structures such as towns, villages, industrial areas, airports, etc.	Settlements
Water body	Rivers are natural flowing water bodies and typically have elongated shapes. Lakes and ponds are perennial standing water bodies.	Water body
Riverbed	A tract of land without vegetation surrounded by the waters of an ocean, lake, or stream; it usually includes any accretion in a river course.	Water body
Bare soil	A soil surface devoid of any plant material.	Other
Bare rock	Non-vegetated areas with a rock surface.	Other

Note: Adapted from National Land Cover Monitoring System of Nepal, 2020–2022 (p.06), by Forest Research and Training Centre (FRTC), 2024, Ministry of Forests and Environment, Government of Nepal (ISBN: 978-9937-1-7322-3).

consistent with IPCC categories were used: Forest, Other Wooded Land (OWL), Grassland, Cropland, Built-up area, Water body, Riverbed, Bare soil, and Bare rock (FRTC, 2024).

2.3 LULC Prediction Modeling

Land change analysis was conducted using TerrSet Land Change Modeler (LCM, version 20.0.4; Clark University). Transitions were organized into 18 sub-models by applying a minimum area threshold of 47.5 ha to filter minor transitions and focus modeling on dominant spatial processes, following the methodological logic of Chaulagain et al. (2024). Seven explanatory driver variables were prepared: distance from buildings (derived from 2022 LULC), elevation and slope (from SRTM 1 arc-second DEM; USGS, 2019), Kernel density-smoothed population (WorldPop, 2018), soil type (ISRIC SOTER database; Dijkshoorn & Huting, 2009), and distance from roads (Department of Roads, 2024) and rivers. Variables with a Cramer's V coefficient below 0.3 in any sub-model were excluded to improve predictive reliability. This threshold was selected empirically through iterative model runs to enhance the performance of transition potential modeling. Transition potential maps were then generated using neural network analysis. Future LULC for 2032 was simulated using a Markov Chain framework based on change demand modeling. Model validation showed strong performance, with an overall accuracy of 95.3%, based on a comparison between the projected 2022 LULC map and the actual 2022 NLCMS map. The same variables mentioned above were used for validation as well.

2.4 Carbon Storage and Sequestration Quantification

The InVEST Carbon Storage and Sequestration model (Natural Capital Project, 2025) was applied

Table 2: Carbon pool used as input for InVEST software

LULC code	LULC name	C_above	C_below	C_soil	C_dead	C_total
1	Water	0	0	0	0.01	0.01
2	Forest	66.42	21.14	59.01	2.97	149.54
3	River Bed	0	0	0.08	0.08	0.16
4	Built-up	5	1	5	0	11
5	Cropland	3.95	2	6.6	1	13.55
6	Baresoil	3.6	4	10	0	17.6
7	Barerock	0	0	0	0.16	0.16
8	Grassland	0	0	84.9	0	84.9
9	OWL	13.3	5.15	27.24	2.54	48.23

to the 2022 baseline and projected 2032 LULC maps. The model aggregates four terrestrial carbon pools: aboveground biomass (C_above), belowground biomass (C_below), soil organic carbon (C_soil), and dead organic matter (C_dead) using class-specific carbon density values (Mg C ha{ ^{1}). Class-specific carbon density values (Mg C ha{ ^{1}) for each pool were sourced directly from Chaulagain et al. (2024). For unused land such as bare rock and sandy areas, dead organic matter is expected to be negligible compared to other categories, supporting the assignment of 0.08 Mg/ha to C_dead (Tang et al., 2018).

2.5 Economic Valuation

Carbon stocks and projected emission reductions were monetized using parameters aligned with Nepal's TAL ERPA and Benefit Sharing Plan (MoFE, 2023). A reference carbon price of USD 5 per tCO$_2$e was applied, and carbon values expressed in Mg C were converted to CO, equivalent using the IPCC stoichiometric conversion factor of 3.67 (IPCC, 2006). A 5% real social discount rate was adopted as the central estimate because it provides a balanced and context-appropriate valuation for Nepal. This rate is close to the World Bank's growth-based benchmark, where a 3% per capita growth rate implies approximately a 6% discount rate, while remaining within the broader 2–10% range suggested for varying growth assumptions. At the same time, it is lower than the 8–15% rates often used in developing-country project appraisal, thereby avoiding excessive discounting of long-term climate and environmental benefits while still reflecting Nepal's capital scarcity better than very low ethical discount rates such as 2% (World Bank, 2016; Zhuang et al., 2007). A 2.25% annual real carbon price escalation was also applied, consistent with the World Bank Shadow Price of Carbon trajectories (World Bank, 2024).

To address uncertainty in the valuation estimates, a sensitivity analysis was incorporated around the key parameters that influence the final economic value. These include the carbon price, discount rate, uncertainty and risk reversal buffer, and operational cost deductions. The central case applied a carbon price of USD 5 per tCO, e, a 5% discount rate, a 23% uncertainty and risk reversal buffer, and 10–15% operational cost deductions, consistent with the TAL Benefit Sharing Plan (MoFE, 2023). Conservative and optimistic scenarios were used to test the effect of lower and higher carbon prices, higher and lower discount rates, and variation in carbon stock estimates and buffer deductions. Therefore, the monetized carbon value has been interpreted as an indicative range rather than a fixed exact value. Realizable payment potential was estimated after applying the 23% uncertainty and risk reversal buffer and 10–15% operational cost deductions, as prescribed in the TAL Benefit Sharing Plan (MoFE, 2023).

3. Results and Discussion

3.1 LULC Dynamics: 2013–2022 and Projected 2032

LULC analysis reveals a clear pattern of forest recovery alongside cropland contraction across the study period (Table 2 and Fig. 2). Forest cover expanded from 56.8% (793 km²) in 2013 to 62.3% (870 km²) in 2022, and is projected to reach 66.6% (930 km²) by 2032, a cumulative gain of 9.8 percentage points over two decades. Simultaneously, cropland declined from 38.2% (533 km²) to 33.4% (466 km²) and is projected to fall further to 29.4% (411 km²) by 2032. Built-up land, while numerically small, more than tripled from 0.19% (2.7 km²) in 2013 to 0.67% (9.3 km²) in 2022 and is projected to reach 1.1% (15.4 km²) by 2032, reflecting persistent urban expansion along highway corridors.

The observed LULC dynamics indicate that Kavre District has experienced a typical mid-hill forest transition, where forest recovery has occurred alongside a gradual decline in agricultural land. The increase in forest cover from 56.8% in 2013 to 62.3% in 2022, and its projected rise to 66.6% by 2032, suggests that natural regeneration, community forest management, and reduced cultivation pressure

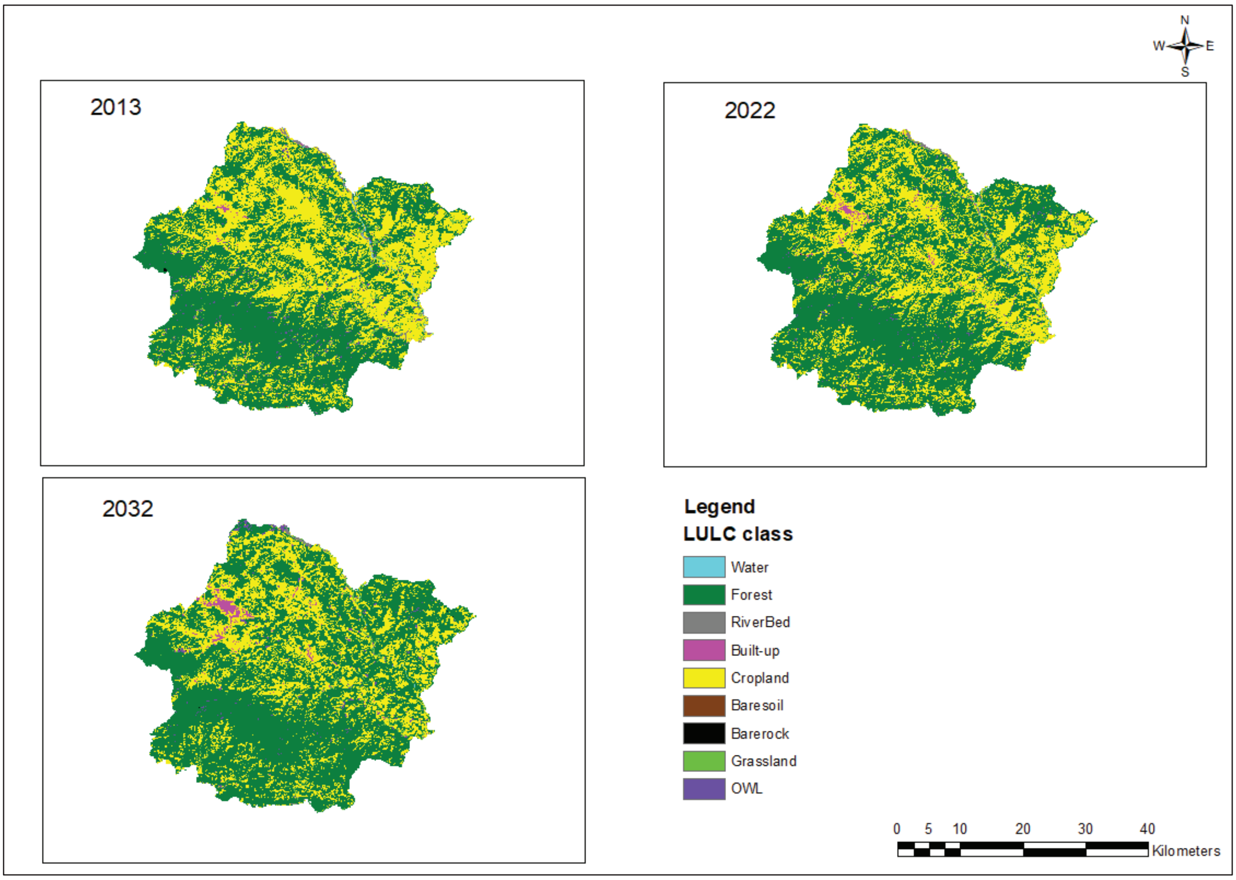

Figure 2: Historical and projected land use and land cover maps of the Kavre District

Table 3: Area and proportional extent of LULC classes in Kavre District for 2013, 2022, and projected 2032

LULC class	Area 2013 (km²)	% 2013	Area 2022 (km²)	% 2022	Area 2032 (km²)	% 2032
Water	2.93	0.21	1.38	0.10	0.60	0.04
Forest	793.02	56.81	870.10	62.33	929.70	66.60
River bed	6.23	0.45	4.11	0.29	2.64	0.19
Built-up	2.70	0.19	9.30	0.67	15.43	1.10
Cropland	533.12	38.19	466.30	33.40	410.87	29.43
Bare soil	0.24	0.02	0.05	0.004	0.05	0.004
Bare rock	0.24	0.02	0.11	0.008	0.11	0.008
Grassland	34.61	2.48	27.27	1.95	21.68	1.55
OWL	22.90	1.64	17.37	1.24	14.92	1.07

on marginal lands have contributed to landscape-level biomass recovery. This pattern is consistent with the broader forest recovery trend reported in Nepal's mid-hill regions, where community forestry, outmigration, and abandonment of less productive agricultural land have encouraged secondary forest growth. However, the reduction in cropland from 38.2% in 2013 to a projected 29.4% in 2032 also indicates a land-use trade-off. While cropland-to-forest transition increases carbon storage, it may also have implications for local agricultural livelihoods, food production, and future land-use planning.

These trends reflect the "forest transition" phenomenon documented in Nepal's mid-hills, where outmigration-driven agricultural abandonment and CFUG management have jointly increased forest biomass. The results are consistent with NLCMS national findings (FRTC, 2024) and align with observations from neighboring Kathmandu Valley, where unplanned land-use conversion eroded ecosystem service value by approximately 20.6% over three decades (Shrestha et al., 2022). The persistent built-up expansion in Kavre, driven by proximity to Kathmandu via the Araniko Highway underscores the ongoing risk that infrastructure development poses to forest margins and carbon sequestration capacity.

The projected expansion of built-up land, although small in total area, is important from a planning perspective. Built-up area increased from 2.7 km² in 2013 to 9.3 km² in 2022 and is projected to reach 15.4 km² by 2032. This indicates a rapid proportional increase in settlement and infrastructure development, particularly along accessible corridors such as the Araniko Highway and areas influenced by proximity to Kathmandu Valley. Although built-up land contributes only a minor share to total district carbon stock, its spatial location is important because future expansion may occur at the expense of cropland, open land, or regenerating forest patches. Therefore, land-use planning should prioritize compact settlement growth, protection of high-carbon forest patches, and control of scattered urban expansion in carbon-sensitive areas.

3.2 Carbon Storage and Sequestration

Total carbon storage in Kavre increased from 13.92 million Mg C (51.0 MtCO, e) in 2022 to a projected 14.68 million Mg C (53.8 MtCO, e) in 2032; a net gain of 762,195 Mg C (Table 3 and Fig. 3). Forests dominate the landscape's carbon budget, storing 12.96 million Mg C in 2022 and projected to reach 13.85 million Mg C by 2032 (+6.87%). Cropland and grassland collectively lose approximately 122,000 Mg C over the decade, partially offsetting forest gains. Built-up areas show a 65.9% increase in associated carbon stock; however, this reflects built-up area expansion and the low but non-zero carbon density assigned to mixed settlement pixels, not carbon sequestration by impervious surfaces.

The carbon storage results show that Kavre District is projected to remain a net carbon sink during 2022–2032. Total carbon stock increased from

Table 4: Net carbon stock change by LULC class in Kavre District, 2022 and 2032

LULC Class	Stock 2022 (Mg C)	Stock 2032 (Mg C)	Sequestration 2022–2032 (Mg C)	Annual Rate (Mg C yr^{-1})
Forest	12,961,336.33	13,851,151.03	+889,814.70	+88,981.47
Cropland	630,442.12	555,440.40	−75,001.72	−7,500.17
Grassland	230,659.13	183,248.97	−47,410.16	−4,741.02
OWL	83,446.16	71,495.62	−11,950.54	−1,195.05
Built-up	10,260.99	17,027.21	+6,766.22	+676.62
Riverbed	65.41	42.48	−22.93	−2.29
Water	1.40	0.59	-0.81	-0.08
Bare soil	77.19	77.19	0	0
Bare rock	1.72	1.72	0	0
Total	13,916,290.45	14,678,485.21	+762,194.76	+76,219

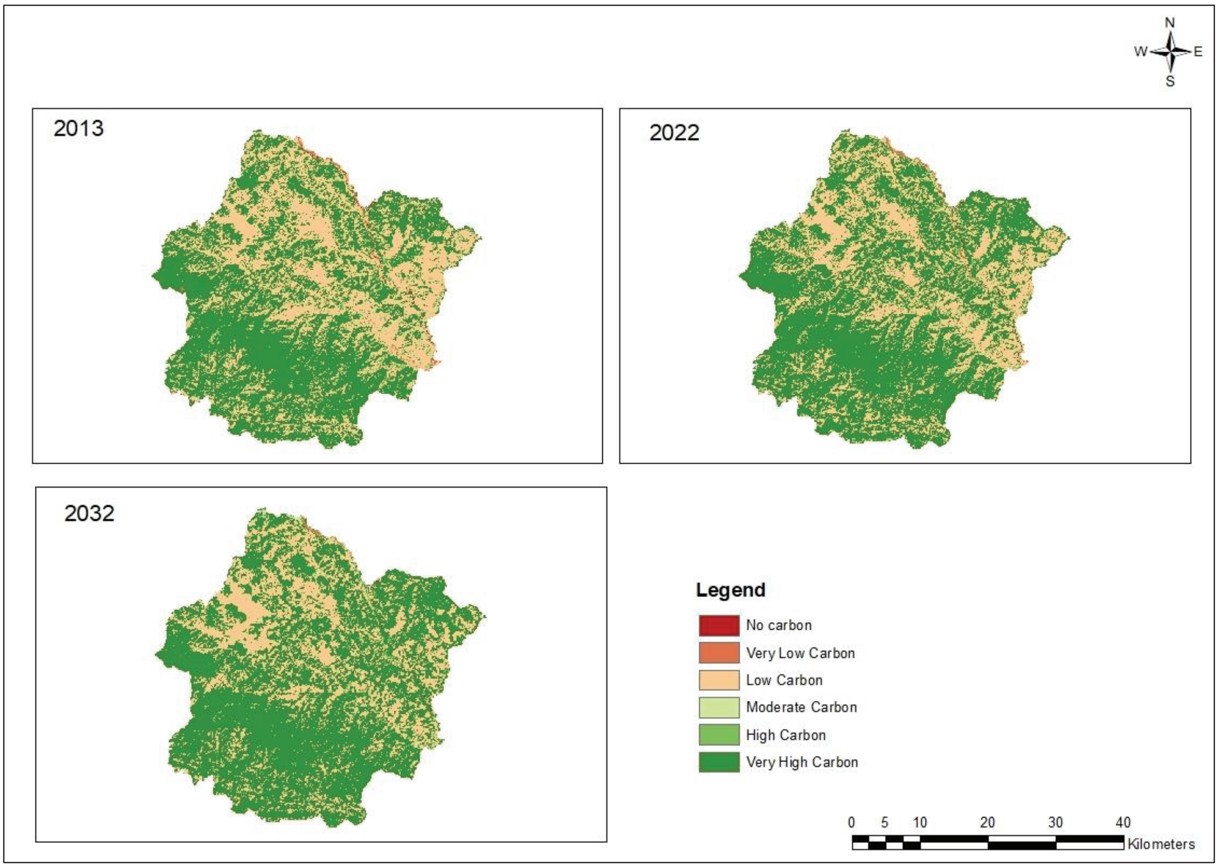

Figure 3: Spatial distribution of carbon density in Kavre District for 2013, 2022 and 2032

13.92 million Mg C in 2022 to a projected 14.68 million Mg C in 2032, resulting in a net gain of approximately 762,195 Mg C, equivalent to 2.79 MtCO, e. This gain is primarily driven by forest expansion, which contributes an additional 889,815 Mg C during the period. However, the overall district-level gain is partially offset by carbon losses from cropland, grassland, and other wooded land. Therefore, the increase in carbon stock should not be interpreted simply as a result of forest area expansion, but as the net outcome of multiple land-cover transitions. Forest recovery remains the dominant factor, while continued conversion of cropland and grassland modifies the overall carbon balance.

The projected net carbon gain demonstrates Kavre's continued role as a carbon sink, driven mainly by forest expansion into abandoned croplands. This forest transition dynamic is consistent with findings by Upadhyay et al. (2011), who reported that labor emigration and changing crop prices in Nepal's watersheds have contributed to land abandonment and natural forest regeneration. Since the InVEST model applies static carbon density values and accounts for land-cover transitions rather than dynamic vegetation growth, these estimates may be conservative. Actual sequestration could be higher if regenerating forests continue to accumulate biomass during the decade (Natural Capital Project, 2025).

The increase in carbon stock under the built-up class should be interpreted cautiously. The built-up class was assigned a low but non-zero carbon density of 11 Mg C ha{ ^{1} in the InVEST biophysical table, representing residual soil carbon and limited vegetation within mixed settlement pixels, such as gardens, roadside trees, open plots, and small vegetated patches. Therefore, the increase in built-up carbon stock from 10,260.99 Mg C in 2022 to 17,027.21 Mg C in 2032 mainly reflects built-up area expansion, not carbon sequestration by impervious surfaces. For this reason, the term "net carbon stock change" is more appropriate than "sequestration" when interpreting changes across all LULC classes.

Spatially, the net present value (NPV) map of carbon sequestration (Fig. 4) reveals distinct carbon hotspot zones in the northern ridges and eastern forest blocks where forest recovery and densification are occurring. In contrast, red and orange zones of negative NPV are concentrated along cropland-to-built-up transition corridors in valley bottoms adjacent to the Araniko Highway. These areas indicate priority locations for conservation intervention and land-use planning. This spatial differentiation provides an MRV-compatible evidence base for targeting community forest user group investment plans under Nepal's TAL program.

3.3 Economic Valuation and REDD+ Payment Potential

The standing carbon stock of Kavre carries a notional gross asset value of approximately USD 255 million at the ERPA reference price of USD 5 per tCO, e (Table 4). However, consistent with the results-based logic of REDD+ mechanisms, payments flow only for incremental, verified emission reductions above the Forest Reference Level and not for the standing stock itself (MoFE, 2023). The projected 2.79 MtCO, e of additional sequestration yields a gross emission reduction value of approximately USD 14 million. After applying

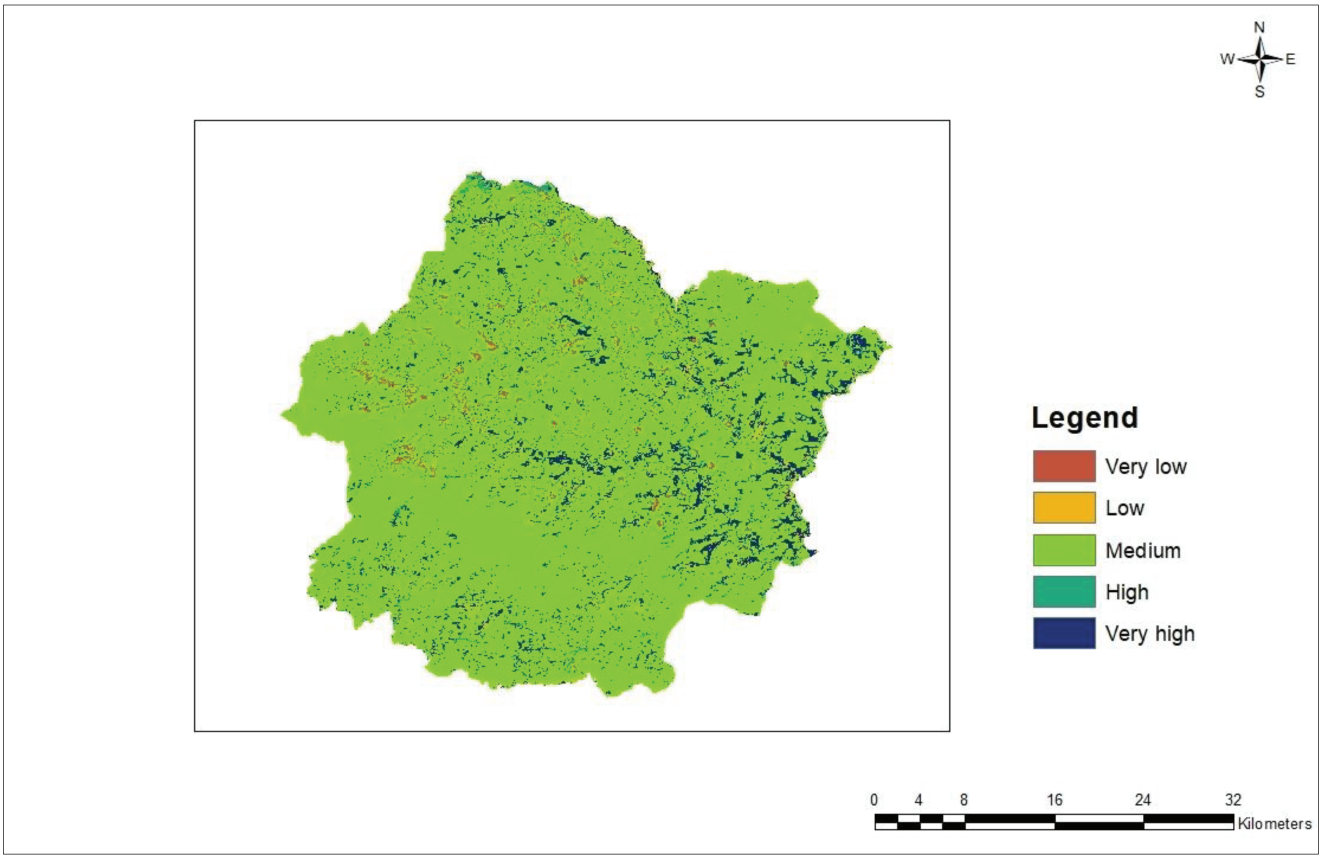

Figure 4: Map of the net present value (USD) of carbon sequestration in Kavre District between 2022 and 2032, calculated by the InVEST Carbon model. Blue zones indicate strong carbon sinks; red and orange zones indicate net carbon losses from land-use conversion

Table 5: Economic valuation of Kavre carbon stocks under REDD+ frameworks

Valuation Scenario	Carbon Quantity ($MtCO_2e$)	Estimated Value (USD)	Realizability
Standing stock value (2022)	51.0	~USD 255 million	Notional asset
Gross ER value (2022–2032)	2.79	~USD 14 million	Conditional on REDD+ enrollment
Net ER (after 23% buffer)	2.15	~USD 10.8 million	Conditional on verification
Realizable payment (after costs)	2.15	~USD 9.1–9.7 million	If performance verified

the TAL Benefit Sharing Plan's 23% uncertainty and risk reversal buffer and 15% combined operational and transaction cost deductions (MoFE, 2023), the net realizable payment envelope narrows to USD 9.1–9.7 million.

The economic valuation results further demonstrate the importance of distinguishing between ecological carbon value and realizable carbon finance. The standing carbon stock of the district represents a large notional asset value; however, results-based climate finance is generally linked to verified additional emission reductions or enhanced sequestration, not to the total standing stock. Therefore, the estimated realizable payment potential after applying uncertainty, risk reversal, and operational deductions is substantially lower than the gross carbon asset value. This distinction is critical for managing expectations among local governments and community forest user groups. Carbon finance should be communicated as a performance-based incentive for verified conservation and enhancement, rather than as a direct payment for all existing forest carbon.

The gap between the USD 255 million notional stock value and the USD 9.7 million realizable payment is not a failure of the approach but reflects the fundamental architecture of results-based climate finance: permanence, additionality, and verification requirements ensure that payment corresponds to genuine climate action rather than standing ecological capital (MoFE, 2023). This distinction is frequently misunderstood in district-level policy discussions and represents a key communication challenge for expanding community forest participation in Nepal's carbon market. Critically, these findings demonstrate that mid-hill districts such as Kavre harbor substantial potential for verifiable emission reductions. The estimated USD 9.1–9.7 million payment potential for a single mid-hill district of approximately 1,396 km² demonstrates the substantial results-based finance potential of Nepal's hilly landscapes. The recent LEAF Coalition ERPA, covering Bagmati, Gandaki and Lumbini provinces and potentially mobilizing up to USD 55 million, confirms that this opportunity is increasingly being recognized within Nepal's jurisdictional REDD+ strategy (REDD Implementation Centre, 2026). In this context, the present estimate provides district-level evidence that can support the effective scaling, prioritization and benefit-sharing design of REDD+ programmes in Nepal's mid-hill regions. (REDD Implementation Centre, 2026). WWF Nepal (2025) recently confirmed the disbursement of Nepal's inaugural REDD+ payment of USD 9.4 million from FCPF, validating the financial architecture complying Kavre's projections.

From a community forestry perspective, the TAL Benefit Sharing Plan allocates 80% of performance-based payments to CFUGs, 5% to private forest owners, and 5% to forest-dependent households (MoFE, 2023). For Kavre's CFUGs, which have demonstrated sustained forest recovery over the 2013–2032 modeling period, this creates a meaningful incentive structure provided that carbon rights are clearly assigned, MRV systems are linked to district-level LULC data of the type produced by this study, and benefit-sharing governance mechanisms are strengthened to reach women, indigenous, and marginalized household members who are currently underserved by CFUG governance structures.

The findings also have practical implications for REDD+ and subnational carbon planning in Nepal. The spatial distribution of carbon gain and loss can help identify priority zones for forest conservation, assisted natural regeneration, and control of land-use conversion. Areas showing high carbon gain may be suitable for strengthening community forest management and benefit-sharing mechanisms, while areas showing low or negative carbon values may require targeted land-use regulation, restoration, or infrastructure planning. Since Kavre lies close to rapidly urbanizing zones, integrating carbon-sensitive spatial planning into municipal land-use plans will be important to maintain long-term carbon benefits.

3.4 Uncertainty and Limitations

Despite these findings, the results should be interpreted with caution. The analysis depends on the accuracy of LULC classification, the assumptions used for projecting 2032 land cover, and the carbon pool values assigned in the InVEST model. The InVEST carbon model uses static carbon density values for each land-cover class and does not fully capture gradual biomass growth, forest age structure, management quality, degradation, or soil carbon dynamics over time. Similarly, economic valuation is sensitive to assumptions regarding carbon price, discount rate, uncertainty buffer, and transaction or operational costs. Therefore, the estimated carbon and payment values should be considered indicative planning estimates rather than exact financial or biophysical measurements.

4. Conclusion

This study provides an integrated district-level assessment of LULC dynamics, carbon stock change, and REDD+-aligned economic valuation for Kavrepalanchowk District, Nepal. The findings indicate that forest cover is projected to increase to 66.6% by 2032, while cropland is expected to continue declining. A net carbon stock gain of 762,195 Mg C, equivalent to 2.79 MtCO, e, is projected over the 2022–2032 period. After applying verification buffers and operational cost deductions, the realizable results-based payment potential under REDD+ mechanisms is estimated at USD 9.1–9.7 million.

These findings carry three direct policy implications. First, Nepal's carbon finance architecture should be extended beyond the Terai Arc Landscape to mid-hill districts with documented modeled carbon stock gain, using the MRV-compatible district-level evidence produced by this and similar studies. Second, land-use planning in Kavre must explicitly target the built-up expansion corridors along major highways, where land conversion threatens the highest-value carbon sink zones identified in the NPV spatial analysis. Third, the USD 255 million standing stock value versus USD 9.7 million realizable payment contrast should inform community-level communication strategies, ensuring that CFUGs and local governments hold realistic expectations about carbon market revenue and do not conflate ecological asset value with immediate financial returns. Future research should extend the temporal horizon to at least 2050 using ensemble climate scenarios to capture longer-term forest dynamics, and should incorporate ecosystem co-benefits like biodiversity, water regulation, and livelihood services to support holistic ecosystem service valuation for mid-hill districts of Nepal and support climate change adaptation and mitigation in the long run.

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