Volume 22, Issue 1: KUS: 1329: 25-37: 05122024: 2025

KHULNA UNIVERSITY
STUDIES

journal homepage: www.kus.ku.ac.bd

Research article

Assessment and Future Scenario Analyses of Land Use and Land Cover Changes in Co-Managed Forest: The Case of Chunati Wildlife Sanctuary in Bangladesh

Md Sarowar Hossain[1], Shaikh Mahfuz Alam[2]*, Rezaul Hasan Bhuiyan[3] and Muhammad Moniruzzaman[3]

[1]*Department of Natural Resource Systems, University of Twente, Netherlands*
[2]*Department of Architecture, Premier University, Chittagong-4203, Bangladesh*
[3]*Department of Natural Resource Systems, University of Twente, Netherlands*
[3]*Department of Environmental Science and Disaster Management, Noakhali Science and Technology University, Noakhali-3814, Bangladesh*

ABSTRACT

The co-management approach has emerged as a significant strategy for forest and wildlife conservation, aiming to balance ecological preservation with the socio-economic needs of local communities. Despite its adoption in several protected areas in Bangladesh, including the Chunati Wildlife Sanctuary (CWS), forest degradation and anthropogenic pressures persist. This study investigates the effectiveness of co-management in mitigating land use and land cover (LULC) changes in CWS and explores future land use scenarios to inform sustainable management strategies. Specifically, the study seeks to (1) assess the spatio-temporal dynamics of LULC changes in CWS from 2004 to 2021, (2) project future LULC changes under natural development and ecology preservation scenarios using the CLUE-s model, and (3) assess the effectiveness of current co-management strategy in conserving CWS forested area.The findings reveal a steady decline in forest cover, particularly in beats near forest boundaries, despite reforestation efforts. Agricultural expansion and settlement development were identified as primary drivers of degradation. Projections indicate that stringent conservation measures under the ecology preservation scenario could lead to significant recovery in forest and wetland areas by 2030, whereas the natural development scenario predicts continued ecological degradation. These results highlight the limitations of the current co-management framework and underscore the need for tailored interventions, enhanced governance, and community engagement to achieve sustainable conservation goals. This study contributes to the broader discourse on adaptive co-management strategies and their potential to reconcile conservation and development objectives in tropical developing regions.

ARTICLE INFO

Article timeline:
Date of Submission:
05 December, 2024
Date of Acceptance:
20 April, 2025
Article available online:
24 April, 2025

***Keywords*:**
CLUE-s model
Co-management
Forest change detection
Forest management

Introduction

Co-management of protected areas has emerged as a crucial strategy for balancing conservation goals with local community needs (Plummer & Fitzgibbon, 2004), particularly in developing countries where human pressures on natural resources are high. In Bangladesh, where forest cover has declined significantly over the past century, co-management was introduced in several protected areas, including Chunati Wildlife Sanctuary (CWS), to address the limitations of traditional exclusionary conservation approaches (Thompson et al., 2018). This governance model emphasizes shared responsibilities among government agencies, local stakeholders, and communities, and has been adopted worldwide as a strategy to address the shortcomings of exclusionary management approaches (Plummer & Fitzgibbon, 2004). However, the effectiveness of co-management varies significantly depending on its implementation and the socio-political and ecological contexts.

Implemented in 2004, co-management in CWS aims to integrate conservation efforts with socio-economic incentives, engaging local populations in forest

*Corresponding author: <archmahfuz@gmail.com>
DOI: https://doi.org/10.53808/KUS.2025.22.01.1329-ls

management and offering alternatives to land-dependent livelihoods (Islam et al., 2019). Despite these efforts, CWS continues to face threats from illegal encroachment, agricultural expansion, and settlement development, particularly near forest boundaries. Agricultural practices, including betel leaf cultivation and brick kilns, have been identified as major drivers of deforestation in the region (Rashid & Khan, 2014).

Over the years, several co-management projects have been undertaken to address the ecological and social challenges in CWS. The Nishorgo Support Project (2004–2009) developed a functional model of co-management by establishing co-management councils and committees (DeCosse, 2012). This initiative aimed to conserve biodiversity and replace monoculture plantations with indigenous species while promoting sustainable livelihoods and capacity development. Subsequently, the Integrated Protected Area Co-management (IPAC) project (2009–2012) emphasized creating a national network of co-managed protected areas while raising awareness about integrated conservation approaches (IPAC, 2010). The Climate Resilient Ecosystems and Livelihoods (CREL) project (2013–2017) strengthened collaboration between communities and governments, focusing on biodiversity protection, climate resilience, and alternative livelihoods (CREL, 2018). The most recent SUFAL project (2019–2023) sought to enhance collaborative forest management by improving institutional capacity, monitoring systems, and community engagement through alternative income-generating activities (SUFAL, 2018). Despite these efforts, persistent land use changes, driven by agricultural expansion, settlement development, and unsustainable resource use, continue to threaten the sanctuary's ecological integrity.

While co-management has garnered local support, but the persistence of forested land conversion suggests that significant challenges remain. Previous studies have highlighted ongoing deforestation trends and the expansion of agricultural lands within CWS, indicating that the current co-management model may be struggling to fully address local pressures on forest resources (Islam, et al., 2018; Rahman et al., 2016; Rahman et al., 2017). However, there is a lack of comprehensive understanding of how co-management has influenced land use and land cover (LULC) changes at a fine spatial scale within CWS. Additionally, little is known about the potential future trajectories of LULC under different management scenarios. This knowledge gap hinders the development of targeted, effective strategies for enhancing the co-management approach in CWS and similar protected areas in Bangladesh.

To address these gaps, this study aims to assess the spatio-temporal dynamics of LULC changes in CWS from 2004 to 2021, focusing on the smallest administrative units (beats) within the sanctuary. Furthermore, it seeks to project future LULC scenarios under different management approaches, providing insights into potential outcomes of sustained co-management efforts. The study addresses the following research questions:

1. How have LULC patterns changed across different beats of CWS since the implementation of co-management in 2004?
2. What are the projected LULC changes in CWS by 2030 under natural development and ecology preservation scenarios?
3. How do these projections inform the effectiveness of current co-management strategies and potential areas for improvement?

By analyzing past and projected land cover dynamics in CWS, this study contributes to the broader discourse on co-management's viability as a conservation strategy in tropical developing countries. The findings are intended to offer actionable insights for policymakers, suggesting specific areas where intervention may help to strengthen conservation outcomes in CWS and similar protected areas in Bangladesh.

Materials and Methods

Study Area

Chunati Wildlife Sanctuary is located in the southeastern region of Bangladesh, was selected in this study regarding its heterogeneous land use types. The geographical position of CWS extends from 21° 40′N latitude and 92° 07′E longitude (figure 1) (Islam, et al., 2018; Rahman et al., 2016; Rahman et al., 2017). The average annual temperature ranges between 14°C and 32°C and the annual average precipitation are about 3000mm (M. M. Rahman et al., 2017). It comprises an approximate area of 7764 ha and falls into the tropical mixed evergreen forest category (BFD, 2015). The sanctuary has become significant due to its conservation focus on the “Critically Endangered” species named *Elephas maximus* besides its diverse floral and faunal resources (Islam et al., 2020). The presence of gullies (shallow and deep) and creeks (gravelly and stony beds) have triggered the formation of wetlands in the protected area which facilitated opportunities for agricultural activities (BFD, 2015; Nath et al., 2016). The unsustainable way of survival (e.g. habitat destruction, encroachment and over-exploitation of forest reserves) exhibited by the inhabitants of CWS raises environmental concerns which have led to several development initiatives (forest co-management) for biodiversity and habitat restoration of the sanctuary (Islam et al., 2020).

Data Sources and Processing

LULC change in the CWS region was characterized using remotely sensed data including Landsat 5 Thematic Mapper (TM) for 2004 and Landsat 8 Operational Land Imager (OLI) for 2015 and 2021. Spring time imagery for each year was collected from United States Geological Survey (https://usgs.gov/) platform. The imagery collection was planned for spring to reduce cloud cover and severe rainfall effects. Arial cloud cover in all images was less than 0.5 percent. The obtained data were atmospherically and topographically adjusted "Landsat collection 2 level 2" products, appropriate for reliable land characterization (Pinto et al., 2020).

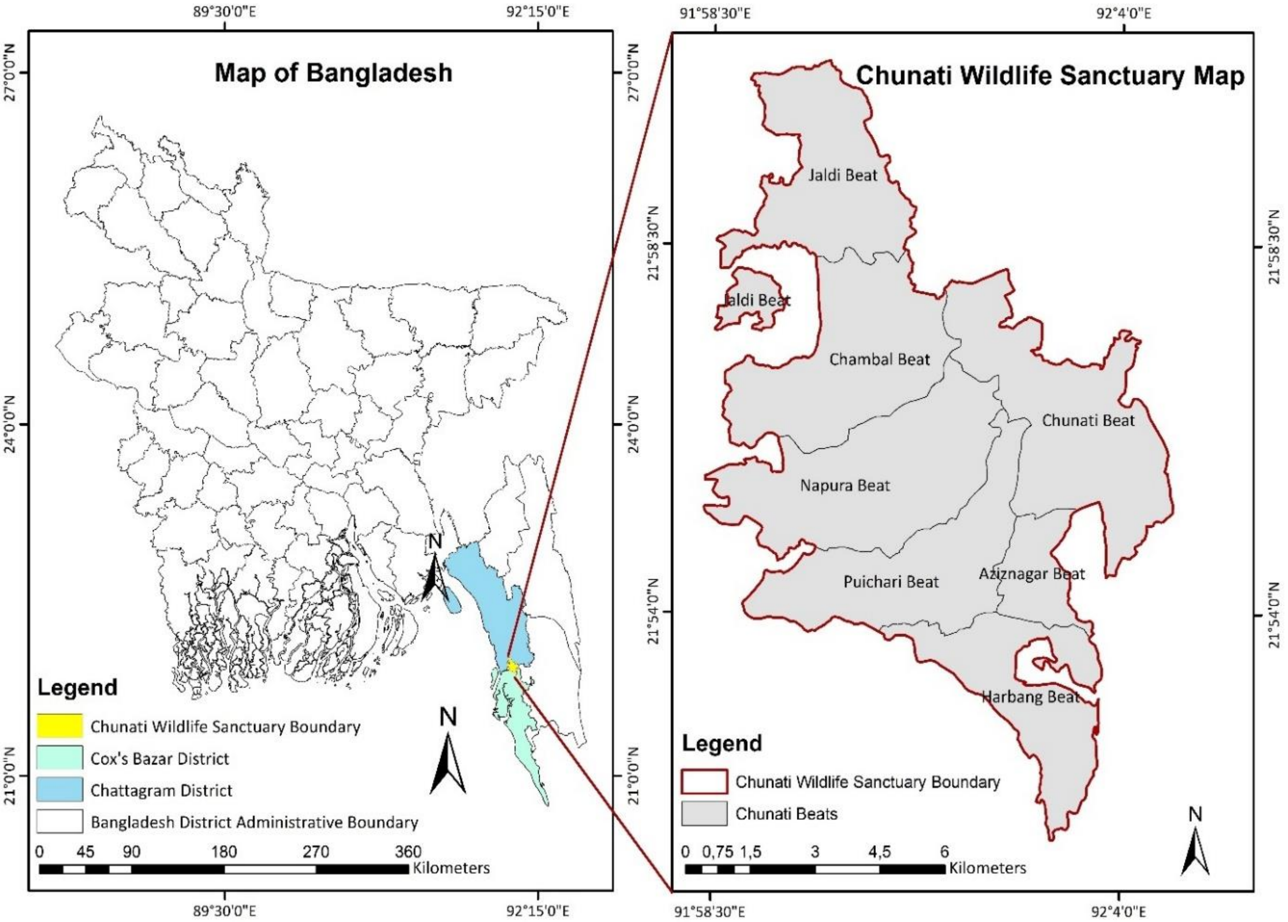

Figure 1: Map of the study area, showing the administrative boundary of CWS outlined in red and the smallest administrative units (beats) delineated in black.

The CWS area was categorized into several LULC classes based on major land features identified during field visit in 2021. Six LULC classes were defined: forest, degraded forest, plantation, agricultural lands, settlements and wetlands. Forest class was defined as vegetation patches greater than 0.5 ha having canopy cover more than 10 percent (Booth & Saunders, 1985), while degraded forests were vacant lands and forests impacted by stressors. Plantation included afforested areas with immature trees. Some surface features like roadways and irrigation canals were categorized as relevant land categories due to spatial resolution limitations. The Random Forest (RF) algorithm was used for classification and visual interpretation aided in defining land use categories. Accuracy of 2021 classified image was assessed using 127 ground truth points. Forests covered 39 points, while wetlands accounted for 13. Validation for 2004 and 2015 images involved 220 randomly generated points verified using Google Earth Pro historical imagery, similar to Mtui et al. (2017) and Wu et al. (2020). Kappa statistics quantified image classification accuracy, estimated at 0.74, 0.87 and 0.84 for 2004, 2015 and 2021, respectively (Table S1). A kappa coefficient of 0.7 or greater indicates substantial agreement and high accuracy (Monserud & Leemans, 1992). Our LULC classification exhibited remarkable alignment with observed land cover classes, with an average kappa coefficient of 0.82, signifying strong compatibility for land use change analysis.

Besides Landsat imageries, other meteorological, topographic and biophysical data were collected as location characteristics for future simulation of land use based on their influencing relationships. Ten location characteristic variables were chosen based on the CWS LULC map in 2015, considering availability, usability, and actual condition of the study region. Driving variables included: 1) two meteorological variables, 2) three terrain variables, 3) four accessibility variables and 4) one biophysical variable. These variables are considered probable factors of land use suitability and their names and sources are given in table 2. Biophysical data such as soil type were converted into spatial map using inverse distance weighted interpolation method. All driving variables data were kept in 30m resolution to match with the spatial resolution of Landsat images.

Spatio-Temporal Land Use change assessment

We assessed LULC changes using the 'post-classification comparison' approach, where classified images are compared pixel by pixel over time. This method identifies specific land use transitions for each changed pixel, providing both "from" and "to" class information (Fichera et al., 2012). LULC transitions were analyzed using ENVI photogrammetric software's change detection algorithm. Transitions across LULC classes were computed for two-time intervals (2004-2015; 2015-2021

Table 1: Driving factors of LULC used in CLUE-s model for future simulation

Input Data	Source	Resolution
Land Surface Temperature (LST)	Landsat thermal bands	30m
Precipitation	Bangladesh Meteorological Department (http://live3.bmd.gov.bd/)	
Altitude	SRTM (https://earthexplorer.usgs.gov/)	30m
Slope	SRTM elevational data	30m
Aspect	SRTM elevational data	30m
Distance to coast	National Encyclopedia of Bangladesh	30m
Distance to town	National Encyclopedia of Bangladesh	30m
Distance to roads	WFP	30m
Distance to stream	National Encyclopedia of Bangladesh	30m
Soil type	National Encyclopedia of Bangladesh	30m

Simulation of Future Land Use using CLUE-s

The future land use dynamics of CWS area were simulated using Conversion of Land Use and Its Effects (CLUE-s) model. CLUE-s is a scenario-based model projecting and visualizing spatial patterns of land use changes expected under various scenarios (Overmars et al., 2007; Verburg & Veldkamp, 2004). The CLUE-s version offers capability to portray land change across scales, leveraging high-resolution data where each pixel is characterized by a single land use type. This version has been employed in local to regional case studies with resolutions from 20 to 1000 m (Verburg et al., 2006; Verburg & Veldkamp, 2004). The model is based on dynamic modeling of competition between land uses, while spatial allocation criteria are established according to empirical analysis, user-provided decision rules, neighborhood features, or combinations thereof (Luo et al., 2010). Actual allocation is determined by user-defined constraints and preferences related to land use type features or expected procedures and constraints pertinent to the scenario (Verburg & Overmars, 2007).

Table 2: a) Conversion elasticity and b) conversion settings defined for 2030 LULC simulation under natural development scenario

a)				b)	Future LULC							√ - Conversion possible	X -Conversion not possible		
		Elasticity		Current LULC		1	2	3	4	5	6				LULC Classes
	1	0.7			1	✓	✓	✓	✓	✓	✓			1	Forest
	2	0.3			2	✓	✓	✓	✓	✓	✓			2	Degraded Forest
	3	0.5			3	✓	✓	✓	✓	✓	✓			3	Plantation
	4	0.3			4	✓	✓	✓	✓	✓	✓			4	Agricultural land
	5	0.8			5	✓	✓	✓	✓	✓	✓			5	Settlement
	6	0.6			6	✓	✓	✓	✓	✓	✓			6	Wetlands

Two scenarios including natural development scenario and ecology preservation scenario were developed for 2030 land use simulation using the requirements of land used demands, location characteristics and suitability, spatial policies and restrictions, and land use specific conversion settings. The selection of these scenarios was based on understanding how existing trends in agricultural and settlement growth, and the implementation of forest conservation objectives, would affect future land use distribution. Before simulating future LULC using CLUE-s, the simulation accuracy needs validation. Therefore, based on the land use trend from 2005 to 2015, the spatial distribution of LULC for 2021 was predicted for each scenario. The accuracy of predicted LULC of 2021 under both scenarios was evaluated by comparing with observed LULC of 2021 using kappa statistics (table S2).

Table 3: a) Conversion elasticity and b) conversion settings defined for 2030 LULC simulation under ecology preservation scenario

a)				b)	Future LULC										
		Elasticity		Current LULC		1	2	3	4	5	6	✓ -Conversion possible	X -Conversion not possible		LULC Classes
	1	0.9			1	✓	✓	✓	X	X	✓			1	Forest
	2	0.3			2	✓	✓	✓	✓	✓	✓			2	Degraded Forest
	3	0.5			3	✓	✓	✓	✓	X	✓			3	Plantation
	4	0.5			4	✓	✓	✓	✓	✓	✓			4	Agricultural land
	5	0.7			5	✓	✓	✓	✓	✓	✓			5	Settlement
	6	0.9			6	✓	✓	✓	X	X	✓			6	Wetlands

Natural Development Scenario

In this scenario, no policy restrictions would limit the demand for land use in CWS area in near future. We anticipated that the trend of LULC conversion would be consistent with the change pattern from 2015 to 2021. For simulating 2030 land use distribution under this scenario, the demand for each LULC class area in 2030 was estimated using the Markov model, obtaining the area transition probability matrix of each year from 2021 to 2030 and the starting matrix used was the proportion of the LULC areas in 2015. Another requirement for CLUE-s is location suitability as a determining factor of competitive capacity of various LULC types at a certain location. The location suitability is determined by empirical analysis of historical and present location preferences in relation to location characteristics and their suitability depending on scenario-specific decision rules (Verburg et al., 2004). Ten location characteristics (Table 2) were used to estimate the contribution of different location characteristics to the suitability of a certain pixel to be converted to a land use type using logistic regression model, following:

$$Log\left(\frac{P_i}{1-P_i}\right) = \beta_0 + \beta_1 X_{1,i} + \beta_2 X_{2,i} + \cdots\cdots\cdots\cdots\cdots + \beta_n X_{n,i} \quad (2)$$

Where, P_i is the likelihood of a specific cell to be claimed by land use type i and X are the driving factors. Receiver operating characteristics (ROC) was utilized to assess the accuracy of the regression analysis results. The ROC value ranges from 0.5 to 1 and a value more than 0.7 indicates that the selected factor has a good explanatory power (Pontius and Schneider, 2001). Therefore, location characteristics having less explanatory power for each land use type had been eliminated from the model (table S3).

The last criteria for CLUE-s modeling are Land use specific conversion settings, where land use type specific conversion setting was designated and the conversion follows the relative elasticity of land use change capability defined in the model (Luo et al., 2010). Elasticity values range from 0 to 1, with higher values indicating greater difficulty for land use conversion. In this study, land use conversions were frequent between 2004 to 2021. For natural development scenario, conversion elasticity was defined by observing the land use trend from 2015 to 2021. The implemented conversion elasticity values for simulating land use of 2030 under natural development scenario are given in table 3.

Ecological Preservation Scenario

In ecology preservation scenario, land use demand for 2030 was determined by current forest conservation goal in CWS area, set by Bangladesh Forest Department. This goal aimed at preserving ecological lands such as forest and wetlands, restricting the conversion of human-driven land use types like settlements and agricultural lands. Plantation in degraded forest areas was expected to be preserved for conversion into forested area, reducing degraded forest areas in future.

The suitability of land use types for conversion was determined by Eq. 1, similar to the natural development scenario. Expert opinions from forest department and local government were collected to define land use conversion settings and elasticity for this scenario. The defined conversion settings and relative elasticity are given in table 4.

Results and discussion

Trend in LULC changes in CWS area from 2004 to 2021

LULC change analysis in CWS from 2004 to 2021 reveals distinct patterns of change across six primary categories: forest, degraded forest, plantation, agricultural land, settlement, and wetland. As shown in table 5 and figure 2, a clear downward trend in forest cover was observed, with the decline occurring more rapidly from 2015 to 2021. During this period, agricultural land expanded considerably, covering around 14% of the total area by 2015—a more than threefold increase since 2004, prior to the sanctuary's co-management interventions. Settlement areas also grew gradually, underscoring ongoing anthropogenic pressures that drive LULC changes within CWS. Degraded forest areas declined sharply from 19.60% to 5.68%, predominantly transitioning into agricultural land and plantations. Notably, plantation areas expanded significantly from 3.25% to 23.02%, indicating active reforestation efforts. Wetland areas showed a decreasing trend until 2015 but later increased by 2.48% by 2021.

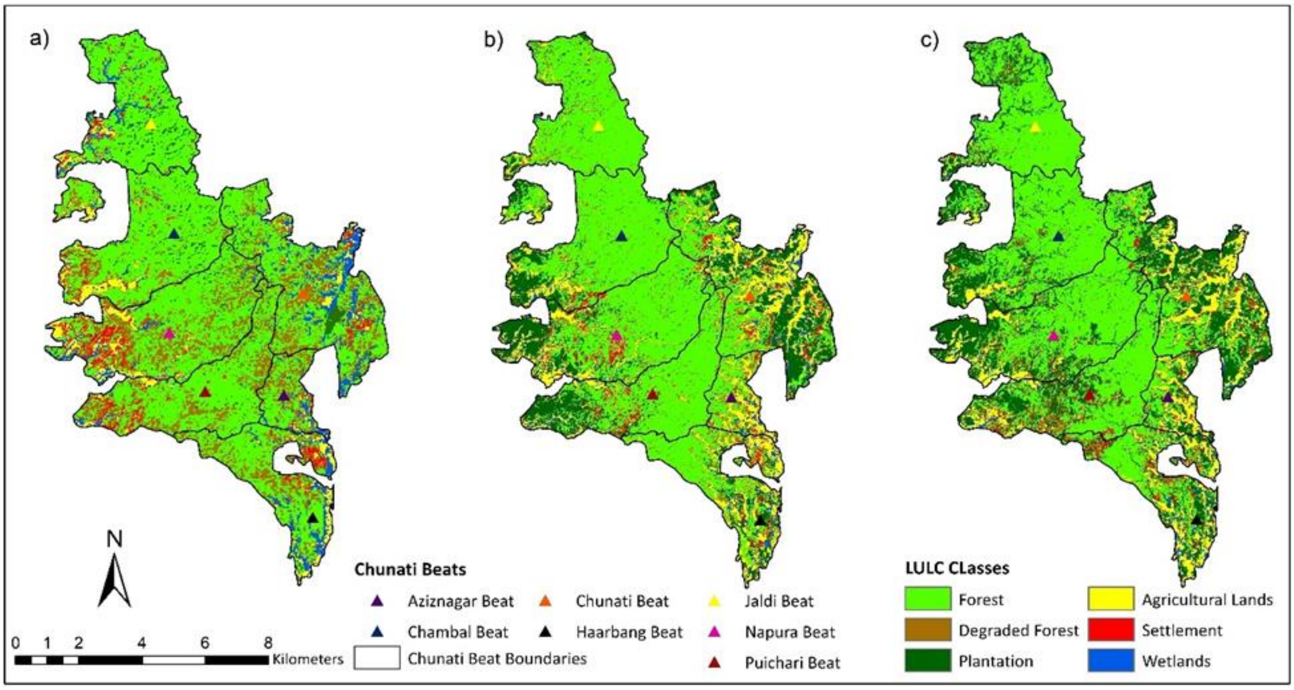

Figure 2: LULC maps of CWS for the year a) 2004, b) 2015 and c) 2021

Beat wise LULC changes in CWS area from 2004 to 2021

Spatial patterns within CWS beats further highlight the uneven distribution of LULC changes. As illustrated in Figure 2 and table 6, in 2004, Chambal beat contained the highest forest cover (75.6%) among the seven beats of CWS, while Aziznagar had the lowest (51%). Higher concentrations of degraded forests were found in Napura and Chunati beats (approximately 25% and 23%, respectively). Limited agricultural and plantation activity was observed initially, with Jaldi showing the largest plantation coverage (6%) and Haarbang the highest agricultural land use (8%).

Table 4: Changes in extent of LULC classes from 2004 to 2021 in CWS. The table displays the area (in hectares) and corresponding percentage of total area for each LULC category

LULC classes	Year 2004		Year 2015		Year 2021	
	Area (ha)	Area (%)	Area (ha)	Area (%)	Area (ha)	Area (%)
Forest	5238.88	62.07	4870.96	57.72	4410.40	52.26
Degraded Forest	1653.96	19.60	595.68	7.06	479.70	5.68
Plantation	274.28	3.25	1439.00	17.05	1942.60	23.02
Agricultural Lands	408.44	4.84	1106.44	13.11	1142.32	13.54
Settlements	292.20	3.46	264.12	3.13	255.60	3.02
Wetlands	571.88	6.78	163.44	1.94	209.02	2.48

By 2015, Chunati beat experienced severe forest loss, reducing to 28.10% coverage, while Jaldi retained the largest proportion (81%). The period from 2015 to 2021 saw further shifts, including expanded plantations across all beats, particularly in Chunati (33%) and Napura (18%), as well as substantial growth in agricultural land in Chunati (24%). Settlement expansion was most pronounced in Aziznagar (7%). Overall, while forest cover generally declined, only Napura beat demonstrated an increase in forest area (58%) over the study period, driven largely by intensified plantation initiatives and reduced agricultural activity in certain beats. By 2021, plantations were highest in Chunati (33%), followed by Napura (27%) and Chambal (22%). Meanwhile, agricultural expansion dominated Aziznagar (43%), Haarbang (29%), and Chunati (25%), with agricultural reductions noted only in Jaldi, Chambal, and Napura beats.

LULC conversion dynamics in CWS beats

LULC conversion dynamics between 2004–2015 and 2015–2021 reveal prominent transitions among land use classes, as illustrated in Figure 3. From 2004 to 2015, agricultural and plantation land expanded substantially, converting degraded forest, forest, and wetland areas, with Chunati experiencing the highest conversion. During 2015–2021, while forest losses continued across beats, targeted plantation efforts aimed to restore forest cover in degraded areas. However, agricultural expansion persisted in Chunati, Puichari, Aziznagar, and Haarbang beats, where settlements also grew, increasing pressure on forested and plantation zones.

Table 5: Changes in LULC class extents across various beats of CWS from 2004 to 2021. The table provides the area (hectares) and percentage of total area for each LULC category

		Forest		**Degraded Forest**		**Plantation**		**Agricultural Lands**		**Settlements**		**Wetlands**	
	Beat Names	Area	%	Area	%	Area	%	Area	%	Area	%	Area	%
2004	*Jaldi*	953.00	74.35	78.36	6.11	82.04	6.40	53.32	4.16	36.64	2.86	78.40	6.12
	Chambal	1051.32	75.59	146.88	10.56	59.44	4.27	70.64	5.08	41.20	2.96	21.40	1.54
	Napura	880.24	54.98	403.32	25.19	38.92	2.43	115.36	7.21	97.72	6.10	65.52	4.09
	Chunati	857.64	53.45	376.08	23.44	64.80	4.04	46.44	2.89	37.84	2.36	221.84	13.82
	Puichari	801.64	65.25	310.08	25.24	23.72	1.93	31.28	2.55	38.96	3.17	22.80	1.86
	Aziznagar	188.76	51.48	116.36	31.73	1.36	0.37	11.80	3.22	7.36	2.01	41.04	11.19
	Haarbang	506.28	52.40	222.88	23.07	4.00	0.41	79.60	8.24	32.48	3.36	120.88	12.51
2015	*Jaldi*	1035.84	80.81	58.08	4.53	121.68	9.49	59.08	4.61	3.68	0.29	3.40	0.27
	Chambal	1033.32	74.29	77.20	5.55	172.84	12.43	78.16	5.62	17.52	1.26	11.84	0.85
	Napura	965.64	60.31	96.64	6.04	288.60	18.03	167.12	10.44	64.28	4.01	18.80	1.17
	Chunati	450.84	28.10	109.56	6.83	530.12	33.04	384.24	23.95	68.84	4.29	61.04	3.80
	Puichari	810.68	65.99	66.80	5.44	221.00	17.99	77.64	6.32	38.76	3.16	13.60	1.11
	Aziznagar	161.60	44.07	38.40	10.47	17.88	4.88	108.52	29.60	26.92	7.34	13.36	3.64
	Haarbang	413.04	42.75	149.00	15.42	86.88	8.99	231.68	23.98	44.12	4.57	41.40	4.29
2021	*Jaldi*	913.96	71.31	55.72	4.35	258.60	20.18	33.04	2.58	8.24	0.64	12.20	0.95
	Chambal	959.06	68.95	54.30	3.90	303.16	21.80	51.64	3.71	11.48	0.83	11.24	0.81
	Napura	926.48	57.87	72.96	4.56	433.52	27.08	110.72	6.92	26.68	1.67	30.72	1.92
	Chunati	395.86	24.67	148.16	9.23	523.24	32.61	393.52	24.52	87.72	5.47	56.14	3.50
	Puichari	700.44	57.02	86.32	7.03	276.84	22.54	86.68	7.06	56.72	4.62	21.48	1.75
	Aziznagar	115.04	31.37	12.88	3.51	38.28	10.44	159.36	43.46	32.68	8.91	8.44	2.30
	Haarbang	399.56	41.36	49.36	5.11	108.96	11.28	277.36	28.71	62.08	6.43	68.80	7.12

Chunati beat showed the most significant changes, with substantial reductions in forest and degraded forest areas (primarily replaced by agricultural land and plantations). Between 2015 and 2021, Chunati lost an additional 54.88 ha of forest, largely transitioning into degraded forest (38.6 ha) and settlements (18.8 ha). In Napura beat, extensive plantation efforts reclaimed approximately 306.68 ha of degraded forest, with a portion also transitioning to forest between 2004 and 2015. Similarly, agricultural land expansion in Aziznagar from 2004 to 2015 resulted in the conversion of forest, degraded forest, and wetland areas.

Future Changes in LULC of CWS

Table 7 and Figure 4 illustrate projected changes in forest and wetland areas across Chunati Wildlife Sanctuary (CWS) from 2021 to 2030 under both the natural development and ecology preservation scenarios. Under both scenarios, forest and wetland areas in most beats are expected to increase, reflecting an interest in maintaining ecological land uses that support essential ecosystem functions. However, agricultural land continues to expand, with a projected growth of up to 18.07% in Chunati beat under the natural development scenario and 10.48% under the ecology preservation scenario. Degraded forests and plantation areas show a consistent decline across all beats, likely due to ongoing agricultural encroachment and the potential transformation of 2021 plantations into forested areas over time. Additionally, conservation restrictions on settlement expansion in core forest zones are projected to retain much of the existing ecological land, allowing some abandoned areas to be reclaimed by forest or agriculture. Forest area increases more substantially under the ecology preservation scenario than the natural development scenario, while agricultural expansion is slightly reduced under the ecology-focused approach. This reduction in agricultural expansion may be attributable to targeted conservation goals by the Bangladesh Forest Department (BFD) and enhanced awareness programs within CWS.

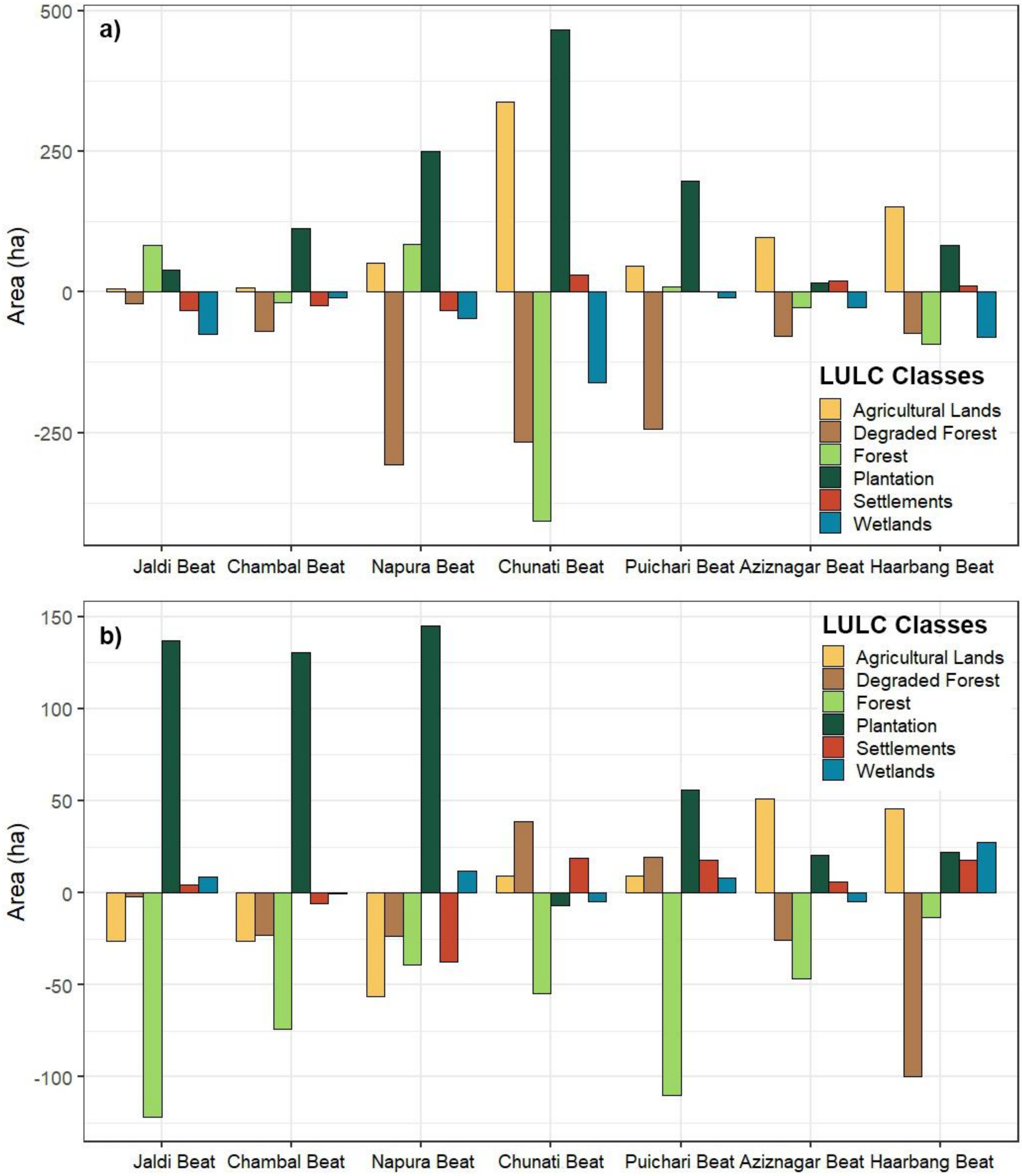

Figure 3: Area gains and losses in LULC categories, showing transitions between classes during (a) 2004 to 2015 and (b) 2015 to 2021 across different beats in CWS

Under the natural development scenario (Table 7, Figure 5), Chunati and Aziznagar beats experience the highest levels of LULC change, with significant increases in agricultural land (18.07% and 9.93%, respectively), which overtakes large portions of plantation areas. These two beats also exhibit the most pronounced declines in wetland area (by 2.07% and 2.39%) and modest increases in forest degradation (1.94% in Chunati and 2.19% in Aziznagar). Proximity to regional roads and marketplaces may contribute to the increased LULC dynamics and loss of ecological land in these areas. Conversely, Jaldi and Chambal beats maintain relative ecological stability, with forest cover expanding by 6.32% and 8.39%, and wetlands by 2.16 ha and 3.0 ha, respectively. In Napura and Puichari beats, agricultural activity also rises (5.98% and 3.96%, respectively); however, these areas concurrently experience increases in forest cover (8.29% and 7.01%) through the conversion of degraded and plantation areas. In Harbang beat, notable wetland expansion (18.92 ha) and modest forest area growth occur alongside increases in settlements (1.76%) and agricultural land (6.45%).

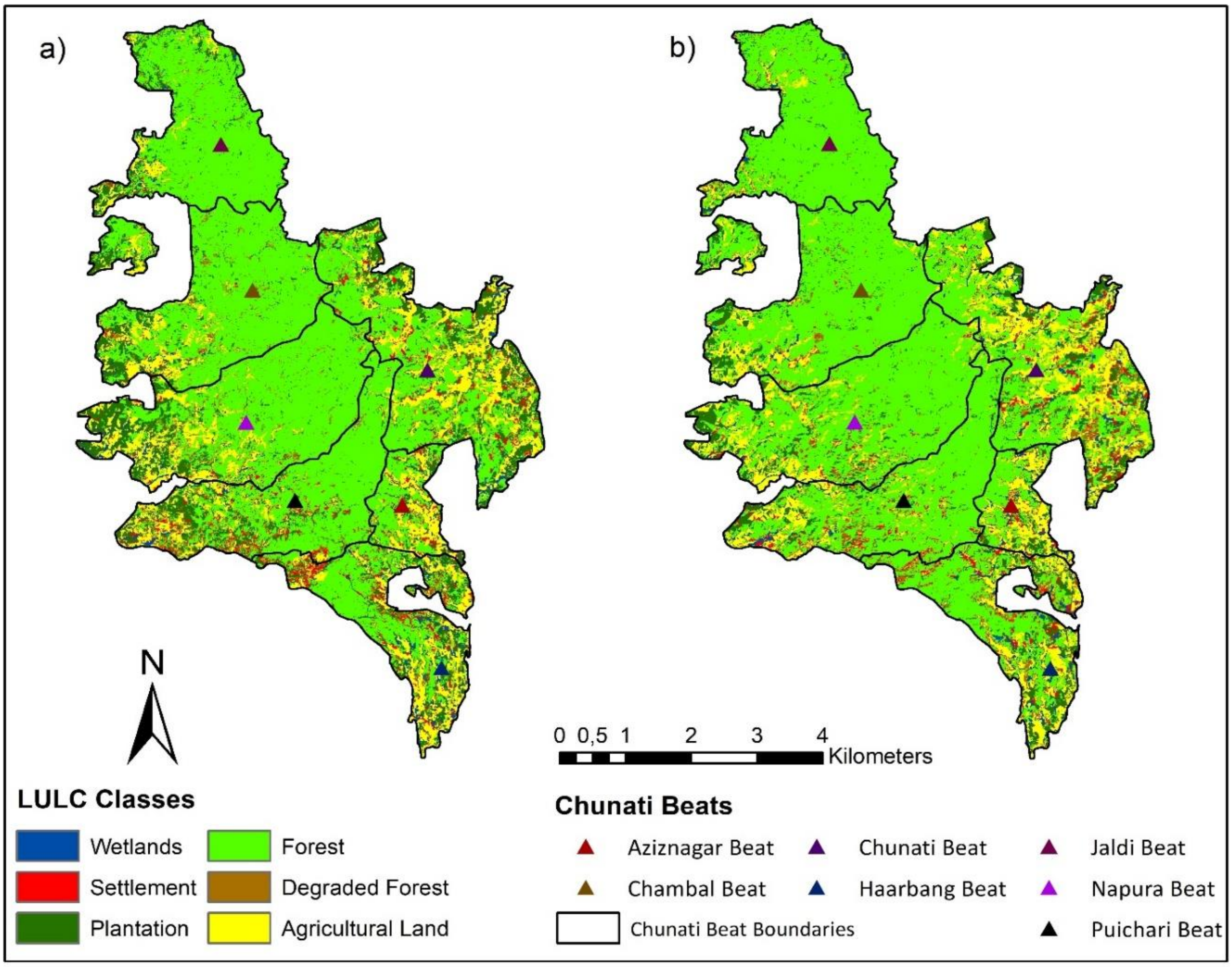

Figure 4: LULC simulation maps in 2030 under a) natural development and b) ecology preservation scenario

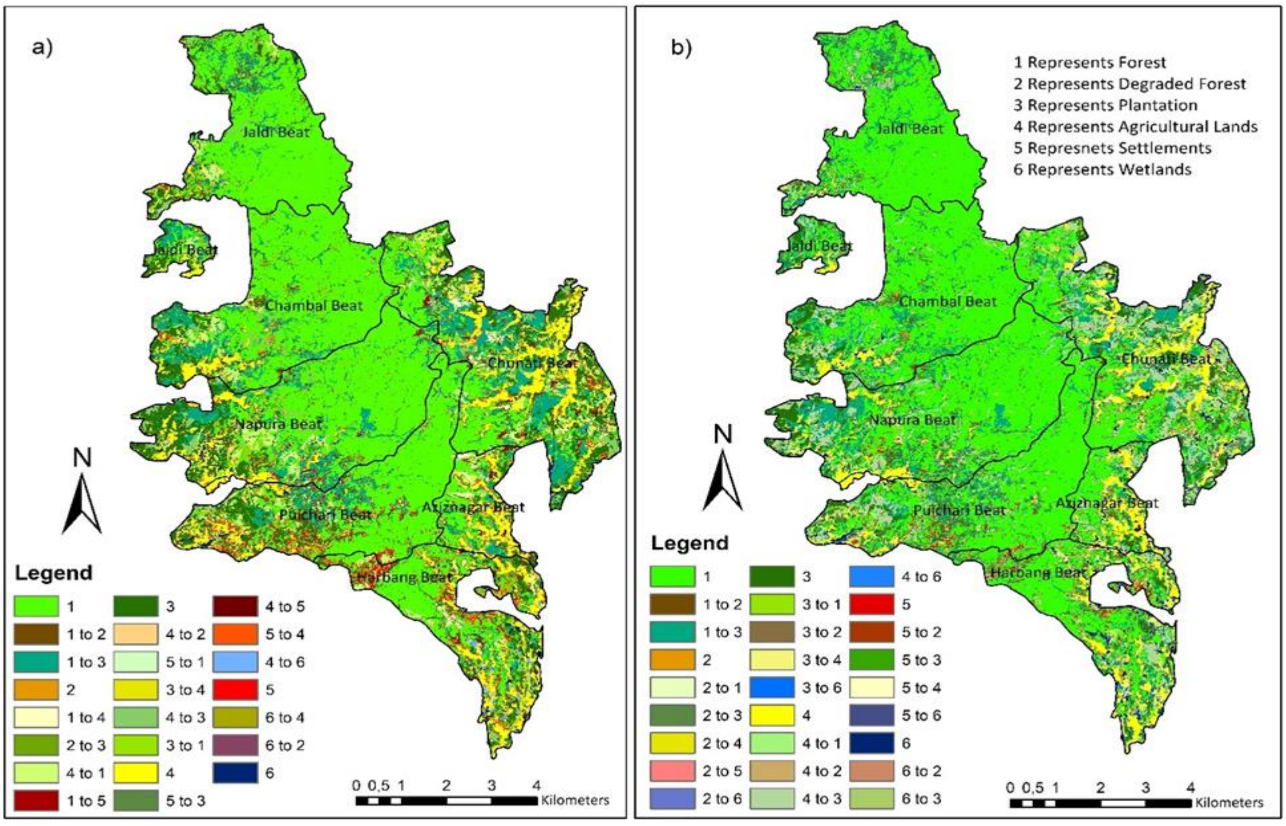

Figure 5: Land use dynamics under a) natural development and b) Ecology preservation scenario from 2021 to 2030

Under the ecology preservation scenario, LULC transitions generally mirror those seen in the natural development scenario, although changes are more conservative due to stricter conservation measures. Forest and plantation reductions occur at a faster rate in this scenario, except in Chunati and Aziznagar beats, where human activity remains high. Chunati beat experiences the most substantial wetland loss (15.28 ha) under this scenario. Forest expansion rates in Chunati and Aziznagar beats are slower, attributed to increased human encroachment (notably, settlement growth by 27.80 ha in Chunati and 10.36 ha in Aziznagar, alongside agricultural land growth of 168.16 ha and 13.96 ha, respectively). Across other beats, the ecology preservation scenario achieves a forested area increase of approximately 14% by 2030, particularly in Jaldi, Chambal, Napura, and Puichari beats. This suggests that strict regulation of human activity contributes positively to ecological land preservation in these areas.

Table 6: Shifts in Land use types under a) natural development and b) Ecological protection scenario from 2021 to 2030

a)		**Forest**		**Degraded Forest**		**Plantation**		**Agricultural Lands**		**Settlements**		**Wetlands**	
	Beat Names	**Area**	**%**	**Area**	**%**	**Area**	**%**	**Area**	**%**	**Area**	**%**	**Area**	**%**
Natural Development scenario	Jaldi	80.96	6.32	-15.56	-1.21	-114.60	-8.94	51.36	4.01	-3.28	-0.26	2.16	0.17
	Chambal	116.68	8.39	2.72	0.20	-183.88	-13.22	62.44	4.49	5.12	0.37	3.08	0.22
	Napura	132.80	8.29	-10.68	-0.67	-228.04	-14.24	95.72	5.98	-15.84	-0.99	5.64	0.35
	Chunati	16.80	1.05	31.12	1.94	-331.24	-20.64	289.92	18.07	18.64	1.16	-33.24	-2.07
	Puichari	86.08	7.01	-28.20	-2.30	-115.56	-9.41	48.60	3.96	11.08	0.90	2.00	0.16
	Aziznagar	2.56	0.70	8.04	2.19	-46.40	-12.65	36.40	9.93	8.16	2.23	-8.76	-2.39
	Harbang	17.28	1.79	-0.08	-0.01	-50.60	-5.24	62.32	6.45	17.00	1.76	18.92	1.95
b)		**Forest**		**Degraded Forest**		**Plantation**		**Agricultural Lands**		**Settlements**		**Wetlands**	
		Area	**%**	**Area**	**%**	**Area**	**%**	**Area**	**%**	**Area**	**%**	**Area**	**%**
Ecological Development scenario	Jaldi Beat	188.16	14.68	-30.64	-2.39	-182.44	-14.23	28.64	2.23	-0.89	-0.07	1.00	0.08
	Chambal	183.40	13.19	-32.36	-2.33	-212.68	-15.29	54.72	3.93	7.56	0.54	0.64	0.05
	Napura	221.52	13.84	-42.72	-2.67	-304.80	-19.04	85.56	5.34	-22.80	-1.42	12.36	0.77
	Chunati	67.16	4.19	3.80	0.24	-213.64	-13.31	168.16	10.48	27.80	1.73	-15.28	-0.95
	Puichari	172.28	14.02	-44.76	-3.64	-198.20	-16.13	55.72	4.54	-14.76	-1.20	9.80	0.80
	Aziznagar	11.84	3.23	-0.24	-0.07	-30.80	-8.40	13.96	3.81	10.36	2.83	5.12	1.40
	Harbang	95.60	9.90	16.80	1.74	-103.44	-10.71	26.64	2.76	9.60	0.99	25.20	2.60

Discussions

This study offers a detailed assessment of LULC changes in the Chunati Wildlife Sanctuary (CWS) under a co-management framework and projects future trajectories under natural development and ecology preservation scenarios. The findings underscore significant challenges in achieving ecological stability amidst ongoing anthropogenic pressures. While co-management has facilitated some progress, the persistence of forest degradation and agricultural expansion indicates critical gaps in the current approach.

Effectiveness of co-management in addressing forest loss

Despite over a decade of co-management implementation, forest cover in CWS has steadily declined, particularly between 2015 and 2021. This period saw the most pronounced losses in Chunati and Aziznagar beats, regions characterized by proximity to markets and infrastructure, which facilitate agricultural and settlement expansion. These results align with prior studies on co-managed forests in Bangladesh and beyond, which indicate that co-management often struggles to counteract economic pressures when governance structures are weak or poorly enforced (Thompson et al., 2018; Ullah et al., 2022).

Joint Forest Management (JFM) practices globally have demonstrated that success depends heavily on robust institutional frameworks and clear land use regulations (Shono et al., 2007). In CWS, the inadequacy of enforcement mechanisms and lack of alternative livelihoods for local communities exacerbate the situation, allowing agricultural encroachment to persist. For instance, betel leaf cultivation and other land-intensive activities have been identified as significant contributors to deforestation, echoing trends observed in other co-managed tropical forests where economic incentives override conservation goals (Bhuiyan et al., 2019).

Localized Management and Beat-specific Challenges

The spatial variability of LULC changes highlights the need for tailored management strategies. Jaldi and Chambal beats retained higher forest cover due to limited human encroachment, whereas Chunati and Aziznagar experienced substantial agricultural and settlement expansion. These disparities suggest that a one-size-fits-all co-management approach may be insufficient to address localized challenges. Research on JFM in India and Ethiopia has shown that adapting management plans to local socio-economic contexts improves conservation outcomes (Solomon et al., 2017; Katju, 2018). For CWS, beat-level interventions, including stricter enforcement of land use regulations and targeted reforestation programs, could help address these localized pressures.

Reforestation Efforts and Plantation Dynamics

The increase in plantation areas, particularly in Chunati and Napura beats, highlights the efforts of reforestation initiatives. However, the reliance on plantations, often dominated by monocultures, raises concerns about biodiversity and ecological functionality. Unlike natural forests, plantations generally fail to support diverse ecosystems, limiting their value in long-term ecological restoration (Shono et al., 2007). Assisted natural regeneration (ANR) and enrichment planting with native species have proven more effective in restoring degraded tropical forests (Bhuiyan et al., 2019). Integrating these strategies into CWS's co-management framework could enhance biodiversity conservation and ecosystem resilience.

Future Scenarios and Policy Implications

The projected scenarios reveal contrasting trajectories for CWS's ecological future. Under the natural development scenario, continued agricultural and settlement expansion is anticipated, particularly in high-pressure beats such as Chunati and Aziznagar. This highlights the limitations of the current co-management framework in regulating land conversion. By contrast, the ecology preservation scenario suggests that stringent conservation measures, including restrictions on agricultural and settlement growth, could significantly enhance forest recovery and wetland preservation. These findings align with global JFM experiences, which emphasize the need for enforceable land use policies and strong institutional support to achieve conservation goals (Rashid & Khan, 2014).

Conclusion

The analysis of land use and land cover (LULC) changes in Chunati Wildlife Sanctuary (CWS) from 2004 to 2021 reveals significant spatial and temporal variations driven by anthropogenic activities and management interventions. Forest cover declined consistently during the study period, with the most substantial losses observed between 2015 and 2021. This decline was particularly pronounced in Chunati and Aziznagar beats, where agricultural expansion and settlement development were prominent. These findings highlight the ongoing challenges posed by human encroachment and inadequate enforcement of land-use regulations.

Reforestation efforts, evidenced by the substantial increase in plantation areas, particularly in Chunati and Napura beats, have shown localized success in reducing degraded forest cover. Additionally, The localized success in Napura beat, which experienced a net increase in forest cover, underscores the potential of targeted conservation interventions when coupled with effective co-management practices.

Future scenario modeling indicates that ecological restoration is achievable under an ecology preservation scenario, with projected increases in forest and wetland areas by 2030. However, the natural development scenario suggests continued agricultural and settlement expansion, particularly in high-pressure beats, which may further degrade ecological land. These contrasting trajectories emphasize the importance of stringent conservation measures and adaptive co-management approaches to achieve sustainable land use in CWS.

The findings of this study demonstrate that while co-management has facilitated reforestation efforts, its effectiveness remains inconsistent across different beats. Tailored strategies that address local socio-economic pressures are critical to mitigating further forest degradation. These results provide actionable insights for policymakers and stakeholders to refine co-management frameworks and prioritize interventions in the most vulnerable areas of CWS.

Acknowledgment

The study question and its substance are the authors' original ideas, and the information presented in this paper is accurate to the best of each author's knowledge. The authors conducted a physical survey to gather all of the data. The Authors are liable for any potential instances of misinformation. As long as they provide acknowledgment to each other for creating the paper. This paper's contents may only be duplicated for academic purposes without the authors' express written approval.

Conflict of Interest

The authors declare no conflict of interest

References

BFD, 2015. Management Plan for Chunati Wildlife Sanctuary. Bangladesh Forest Department.

Bhuiyan, M. K. A., Hossain, M. A., Kamal, A. K. I., Hossain, M. K., Jashimuddin, M., & Uddin, M. K. (2019). Climate resilience through natural regeneration in degraded natural forests of South-Eastern Hilly region of Bangladesh. *Bangladesh Journal of Botany, 48*(3), 417–425.

Booth, T. H., & Saunders, J. C. (1985). Applying the FAO Guidelines on land evaluation for forestry. *Forest Ecology and Management, 12*(2), 129–142.

CREL, 2018. Final Performance Report (2012 –2018). Climate-Resilient Ecosystems and Livelihoods (CREL) and United States Agency for International Development (USAID), Dhaka, Bangladesh.

DeCosse, P.J. ed., 2012. Protected area co-management where people and poverty intersect: Lessons from Nishorgo in Bangladesh. USAID.

Fichera, C. R., Modica, G., & Pollino, M. (2012). Land Cover classification and change-detection analysis using multi-temporal remote sensed imagery and landscape metrics. *European Journal of Remote Sensing, 45*(1), 1–18.

Islam, K., Jashimuddin, M., Nath, B., & Nath, T. K. (2018). Land use classification and change detection by using multi-temporal remotely sensed imagery: The case of Chunati wildlife sanctuary, Bangladesh. *The Egyptian Journal of Remote Sensing and Space Science, 21*(1), 37–47.

Islam, K., Jasimuddin, M., Nath, B., & Nath, T. K. (2016). Quantitative Assessment of Land Cover Change Using Landsat Time Series Data: Case of Chunati Wildlife Sanctuary (CWS), Bangladesh. *International Journal of Environment and Geoinformatics, 3*(2), 45–55.

Islam, K. N., Rahman, M. M., Jashimuddin, M., Hossain, M. M., Islam, K., & Faroque, M. Al. (2019). Analyzing multi-temporal satellite imagery and stakeholders' perceptions to have an insight into how forest co-management is changing the protected area landscapes in Bangladesh. *Forest Policy and Economics, 101*, 70–80.

Islam, K. N., Rahman, M. M., Jashimuddin, M., Islam, K., & Zhang, Y. (2020). Impact of co-management on tree diversity and carbon sequestration in protected areas: Experiences from Bangladesh. *Trees, Forests and People, 2*, 100033.

Islam, K., Nath, T. K., Jashimuddin, M., & Rahman, M. F. (2019). Forest dependency, co-management and improvement of peoples' livelihood capital: Evidence from Chunati Wildlife Sanctuary, Bangladesh. *Environmental Development, 32*, 100456.

IPAC, 2010. Third Annual Work Plan (June 1, 2010 – May 31, 2011) Integrated Protected Area Co-management Program (IPAC) and United States Agency for International Development (USAID), Dhaka, Bangladesh.

Islam, K., Rahman, M. F., & Jashimuddin, M. (2018). Modeling land use change using Cellular Automata and Artificial Neural Network: The case of Chunati Wildlife Sanctuary, Bangladesh. *Ecological Indicators, 88*, 439–453.

Katju, D. (2018). The Political Ecology of Non-Compliance: Encroachment, Illicit Resource Extraction, and Environmental Governance in the Manas Tiger Reserve (India).

Luo, G., Yin, C., Chen, X., Xu, W., & Lu, L. (2010). Combining system dynamic model and CLUE-S model to improve land use scenario analyses at regional scale: A case study of Sangong watershed in Xinjiang, China. *Ecological Complexity, 7*(2), 198–207.

Monserud, R. A., & Leemans, R. (1992). Comparing global vegetation maps with the Kappa statistic. *Ecological Modelling, 62*(4), 275–293.

Mtui, D. T., Lepczyk, C. A., Chen, Q., Miura, T., & Cox, L. J. (2017). Assessing multi-decadal land-cover – land-use change in two wildlife protected areas in Tanzania using Landsat imagery. *PLOS ONE, 12*(9), e0185468.

Nath, T. K., Jashimuddin, M., Kamruzzaman, M., Mazumder, V., Hasan, M. K., Das, S., & Dhali, P. K. (2016). Phytosociological characteristics and diversity of trees in a comanaged protected area of Bangladesh: Implications for conservation, 35(8), 562–577.

Overmars, K. P., Verburg, P. H., & Veldkamp, T. (A). (2007). Comparison of a deductive and an inductive approach to specify land suitability in a spatially explicit land use model. *Land Use Policy, 24*(3), 584–599.

Pinto, C. T., Jing, X., & Leigh, L. (2020). Evaluation Analysis of Landsat Level-1 and Level-2 Data Products Using In Situ Measurements. *Remote Sensing 2020, Vol. 12*, Page 2597, 12(16), 2597.

Plummer, R., & Fitzgibbon, J. (2004). Co-management of natural resources. A proposed framework. *Environmental Management, 33*(6), 876–885.

Pontius, R. G., & Schneider, L. C. (2001). Land-cover change model validation by an ROC method for the Ipswich watershed, Massachusetts, USA. *Agriculture, Ecosystems & Environment, 85*(1–3), 239–248.

Rahman, F., Jashimuddin, M., Islam, K., & Nath, T. (2016). Land Use Change and Forest Fragmentation Analysis: A Geoinformatics Approach on Chunati Wildlife Sanctuary, Bangladesh. *Journal of Civil Engineering and Environmental Sciences, 2*(1), 020–029.

Rahman, M. M., Mahmud, M. A. Al, & Ahmed, F. U. (2017). Restoration of degraded forest ecosystem through non-forestry livelihood supports: experience from the Chunati Wildlife Sanctuary in Bangladesh, 13(3), 109–115.

Rashid, M. A. Z. M., & Khan, N. A. (2014). Role of Co-management Organizations in Protected Area Governance: Some Observations from the Chunati Wildlife Sanctuary. 181–200.

Shono, K., Cadaweng, E. A., & Durst, P. B. (2007). Application of Assisted Natural Regeneration to Restore Degraded Tropical Forestlands. *Restoration Ecology, 15*(4), 620–626.

Solomon, N., Birhane, E., Tadesse, T., Treydte, A. C., & Meles, K. (2017). Carbon stocks and sequestration potential of dry forests under community management in Tigray, Ethiopia. *Ecological Processes, 6*(1), 1–11.

SufaL, 2018. Resettlement policy framework for the sustainable forests & livelihood (Sufal) project. Bangladesh Forest Department, Dhaka, Bangladesh.

Thompson, P. M., Mohaiman Chowdhury, R., Shams Uddin, M., & Dutta, U. (2018). Capacity and sustainability of co-management organizations.

Ullah, S. M. A., Tani, M., Tsuchiya, J., Rahman, M. A., & Moriyama, M. (2022). Impact of protected areas and co-management on forest cover: A case study from Teknaf Wildlife Sanctuary, Bangladesh. *Land Use Policy, 113*, 105932.

Verburg, P. H., & Overmars, K. P. (2007). Dynamic Simulation of Land-Use Change Trajectories with the Clue-S Model. *GeoJournal Library*, *90*, 321–337.

Verburg, P. H., Schot, P. P., Dijst, M. J., & Veldkamp, A. (2004). Land use change modelling: current practice and research priorities. *GeoJournal 2004* 61:4, 61(4), 309–324.

Verburg, P. H., Schulp, C. J. E., Witte, N., & Veldkamp, A. (2006). Downscaling of land use change scenarios to assess the dynamics of European landscapes. *Agriculture, Ecosystems & Environment*, *114*(1), 39–56.

Verburg, P. H., & Veldkamp, A. (2004). Projecting land use transitions at forest fringes in the Philippines at two spatial scales. *Landscape Ecology 2004 19:1*, *19*(1), 77–98.

Wu, X., Wang, K., Li, Y., Liu, K., & Huang, B. (2020). Decadal Urban Land Use/Land Cover Changes and Its Impact on Surface Runoff Potential for the Dhaka City and Surroundings Using Remote Sensing. Remote Sensing 2021, Vol. 13, Page 83, 13(1), 83.