

Assessment of Wetland Change, Community Participation, and Nature-Based Conservation Options of Tanguar Haor, Bangladesh

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ABSTRACT

Tanguar Haor, a Ramsar Wetland of International Importance in Sunamganj District, Sylhet Division, north-eastern Bangladesh, is among the most ecologically significant freshwater wetlands in South Asia, supporting over 140 fish species, 51 or more migratory bird species, and the livelihoods of roughly 30,000 people in about 40 surrounding villages. Despite its Ramsar status, the wetland has faced sustained anthropogenic and climatic pressure. This study presents a five-period (1990, 2000, 2010, 2020, 2024) multi-temporal assessment of wetland change using Landsat 5 TM, 7 ETM+, 8 OLI, and 9 OLI imagery processed on the Google Earth Engine (GEE) cloud platform, supplemented by SRTM 30 m elevation data. Open-water extent was mapped using the Normalized Difference Water Index (NDWI), vegetation condition with the Normalized Difference Vegetation Index (NDVI), and land cover with Maximum Likelihood Classification (MLC). The results show an 84.2% decline in mapped open-water area, from 85.83 km² in 1990 to 13.54 km² in 2024, consistent with published evidence of wetland transformation across Bangladesh. Vegetation and terrain analyses confirm a low-relief basin highly sensitive to hydrological disturbance. The paper further examines community participation in wetland governance and proposes five nature-based conservation options — hydrological restoration, community fish sanctuaries, native vegetation rehabilitation, seasonal agricultural zoning, and community-linked ecotourism — arguing that GIS-based monitoring must be integrated with participatory, gender-inclusive governance for long-term conservation success.

Keywords: Tanguar Haor; wetland change detection; NDWI; Google Earth Engine; community-based management; nature-based solutions; Bangladesh

INTRODUCTION

Wetlands are among the most biologically productive ecosystems on Earth, providing flood regulation, freshwater storage, carbon sequestration, nutrient cycling, groundwater recharge, and habitat for globally threatened species (Ramsar Convention Secretariat, 2016; Zedler & Kercher, 2005). They are also fundamental to food security in developing countries, serving as nursery grounds for commercially important fish and as a livelihood source for hundreds of millions of rural people (Sultana et al., 2022; ADB, 2025). Despite this value, global wetland loss has accelerated: approximately 35% of the world's wetlands disappeared between 1970 and 2015, a rate of loss three times faster than tropical forests (Ramsar Convention Secretariat, 2016; Bangladesh Ministry of Environment, Forest and Climate Change [MoEFCC], 2024).

Bangladesh sits at the confluence of the Ganges, Brahmaputra, and Meghna rivers and contains an extensive network of rivers, floodplains, haors, baors, beels, and coastal mangroves; wetlands cover approximately 7 million hectares, or about 47% of the country's land area, though coverage is highly seasonal (Byomkesh et al., 2011; Khan et al., 2025). The haor wetlands of north-eastern Bangladesh — large bowl-shaped depressions that flood deeply during the monsoon and dry partially from November to April — are of exceptional ecological significance and function as complex socio-ecological systems in which hydrology, biodiversity, food production, and human welfare are inseparably intertwined (Islam et al., 2016; Farruq & Islam, 2025; Sultana et al., 2019).

Tanguar Haor, located in Sunamganj District, Sylhet Division, is the most internationally recognized haor wetland in Bangladesh and was designated a Ramsar Wetland of International Importance in 2000 (Ramsar Convention Secretariat, 2016). It covers approximately 9,727 hectares comprising 88 beels interconnected by channels, and is home to 141 freshwater fish species — about 54% of Bangladesh's freshwater fish diversity — and 51 or more migratory bird species, with some surveys recording over 200 bird species in total (Ahmad & Alam, 2003; NINA, 2004; Hossain et al., 2018; Sultana et al., 2022).

Remote sensing and GIS have become indispensable for wetland monitoring because they provide systematic, repeatable, and spatially comprehensive assessment of land cover change over long time horizons (Richards & Jia, 1999). The Google Earth Engine (GEE) cloud platform has transformed this work by enabling large-scale Landsat time-series analysis without local computational infrastructure, making systematic change detection accessible across the developing world (Gorelick et al., 2017; Wang et al., 2020). NDWI and NDVI are widely validated indices for water body and vegetation mapping respectively (McFeeters, 1996; Gao, 1996; Xu, 2006; Rouse et al., 1973), and Maximum Likelihood Classification remains an established baseline classifier for wetland land cover mapping in Bangladesh despite the emergence of machine-learning alternatives (Richards & Jia, 1999; Siddique et al., 2024). A 2026 study in *Communications Earth & Environment* used GEE-based Landsat analysis (2000–2024) to extract long-term wetland subclass dynamics across Bangladesh, providing national-scale context directly relevant to Tanguar Haor (Nature Communications Earth and Environment, 2026).

At the national scale, wetland degradation in Bangladesh has been driven by agricultural encroachment, urbanization, drainage, sedimentation, and overexploitation (Byomkesh et al., 2011; Khan et al., 2025; Bangladesh MoEFCC, 2024). Within haor systems specifically, population pressure has driven substantial land use and land cover (LULC) shifts, with conversion of vegetation to agricultural land emerging as a dominant transformation pathway; Siddique et al. (2024) documented that roughly 33% of vegetation cover in the comparable Hakaluki Haor was converted to agriculture between 1989 and 2017. Governance research consistently identifies elite capture of fishery resources, weak enforcement, institutional fragmentation, and gender exclusion as persistent barriers to effective co-management in Bangladesh's wetlands (Sultana et al., 2019; Khan et al., 2025).

Although a growing literature exists on Tanguar Haor's biodiversity (Ahmad & Alam, 2003; NINA, 2004; Hossain et al., 2018; NHBS, 2024) and governance (Sultana et al., 2019; GEF, 2020), no recent study has combined a five-period multi-temporal GEE-based change assessment with an integrated governance and nature-based solutions analysis. This paper addresses that gap. The specific objectives are: (1) to quantify and interpret wetland change from 1990 to 2024 using multi-temporal Landsat imagery and GEE; (2) to interpret the findings against published ecological and governance literature; (3) to examine community participation frameworks and challenges in Tanguar Haor; and (4) to propose nature-based conservation options grounded in the ecological and social realities of the wetland.

Study Area

Tanguar Haor is located in Sunamganj District, Sylhet Division, north-eastern Bangladesh, at approximately 24.83°N–25.10°N and 91.05°E–91.35°E (Islam et al., 2016), at the foot of the Meghalaya Hills of north-eastern India. Its position at the base of a large transboundary catchment makes it a highly dynamic hydrological system (Rahaman et al., 2021). The wetland covers approximately 9,727 hectares comprising 88 beels interconnected by channels and floodplain, forming a complex wetland mosaic (NINA, 2004; Ahmad & Alam, 2003).

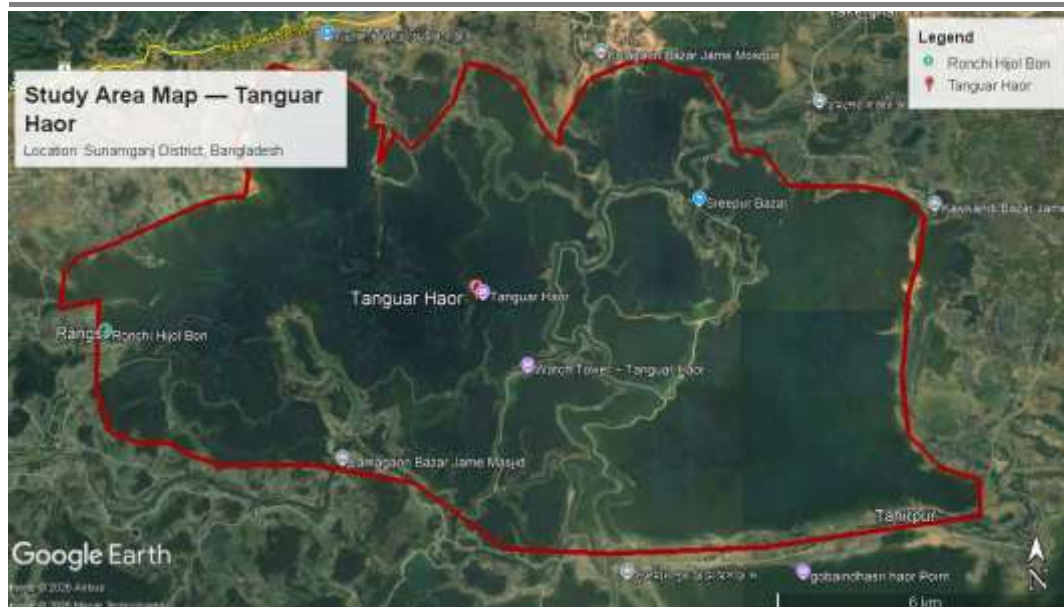


Figure 1. Study area map of Tanguar Haor, Sunamganj District, Sylhet Division, Bangladesh (24.83°N–25.10°N; 91.05°E–91.35°E). Source: Google Earth Pro imagery (2026); author's own analysis.

The climate is strongly seasonal under the South Asian monsoon system. Annual rainfall exceeds 3,000 mm, concentrated between May and September, causing deep inundation of the haor basin to depths of 4–6 m; the dry season (November–April) sees substantial water recession, exposing much of the haor floor for agriculture (Islam et al., 2016; Rahaman et al., 2021). Mean annual temperature ranges from approximately 18 °C in winter to 34 °C in summer (Rahaman et al., 2021). This seasonal hydrological dynamism underlies the ecological productivity that distinguishes haor wetlands from other freshwater habitats in the region.

Ecologically, Tanguar Haor supports 141 freshwater fish species across 35 families — about 54% of Bangladesh's freshwater fish diversity — and provides critical wintering, foraging, and roosting habitat for 51 or more migratory bird species along the Central Asian and East Asian–Australasian flyways, with some surveys recording over 200 bird species in total, including threatened species such as the Oriental Darter (*Anhinga melanogaster*) and Lesser Adjutant (*Leptoptilos javanicus*) (Ahmad & Alam, 2003; NINA, 2004; Hossain et al., 2018; Sultana et al., 2022). Native swamp forest, reed beds, floating-leaved aquatic plants, and submerged vegetation communities provide the structural habitat underpinning this biodiversity.

Socioeconomically, approximately 30,000 people in about 40 surrounding villages depend directly on wetland resources for their primary livelihoods (NINA, 2004; Rahaman et al., 2021). Fishing is the most important livelihood activity; seasonal cultivation of the haor floor during the dry season, aquatic plant collection, and livestock grazing also contribute to household income and food security (GEF, 2020; ERA Haor, 2012; Sultana et al., 2019). These communities face increasing livelihood vulnerability as wetland resources decline, climate variability intensifies, and governance constraints limit equitable resource access (Rahaman et al., 2021).

METHODOLOGY

Data Sources and Pre-Processing

Multi-temporal Landsat imagery was accessed through GEE, which provides global access to the complete Landsat archive with integrated processing tools (Gorelick et al., 2017). Five time periods approximately one decade apart were selected — 1990, 2000, 2010, 2020, and 2024 — to capture three decades of change. Landsat 5 TM Collection 2 Level-2 surface reflectance data were used for 1990 and 2000; Landsat 7 ETM+ Collection 2 Level-2 for 2010; Landsat 8 OLI Collection 2 Level-2 for 2020; and Landsat 9 OLI Collection 2 Level-2 for 2024 (Gorelick et al., 2017; USGS, 2023). All imagery was filtered to a maximum cloud cover of 10% and composited using a median approach to reduce cloud contamination and inter-scene radiometric variability. SRTM 30 m elevation data were accessed from the GEE data catalogue for terrain analysis (Farr et al., 2007). Level-2 surface reflectance products (USGS LaSRC atmospheric correction) were used throughout to ensure

radiometric consistency across sensors, and a digitized study-area boundary was used to clip all imagery and terrain data (USGS, 2023; Islam et al., 2016).

NDWI Water Mapping

The Normalized Difference Water Index was computed for each period to map open water, exploiting the high reflectance of water in the green band and its strong absorption in the near-infrared (NIR) band (McFeeters, 1996):

$$NDWI = (Green - NIR) / (Green + NIR)$$

Pixels with $NDWI > 0$ were classified as water (McFeeters, 1996). For Landsat 5/7, Green = Band 2 and NIR = Band 4; for Landsat 8/9, Green = Band 3 and NIR = Band 5. NDWI has been widely validated for water body delineation in Bangladesh wetland contexts, although shallow or turbid water can cause underestimation of true water extent (Gao, 1996; Xu, 2006), a limitation addressed in Section 7.

NDVI Vegetation Assessment

The Normalized Difference Vegetation Index was computed to characterize vegetation condition and spatial distribution (Rouse et al., 1973):

$$NDVI = (NIR - Red) / (NIR + Red)$$

NDVI ranges from -1 to $+1$; values above 0.3 indicate healthy vegetated surfaces, while values near zero or below indicate water, bare soil, or non-photosynthetic surfaces (Rouse et al., 1973). For Landsat 5/7, Red = Band 3 and NIR = Band 4; for Landsat 8/9, Red = Band 4 and NIR = Band 5 (Gorelick et al., 2017).

Maximum Likelihood Classification and Change Detection

Maximum Likelihood Classification (MLC) was applied to generate four-class land cover maps for each period: (1) deep water (permanent open water); (2) shallow water / seasonal wetland (transitional inundation zones and seasonal beels); (3) vegetation / agricultural land (terrestrial vegetation, swamp forest, crops, grassland); and (4) settlement / bare soil (built-up areas, roads, embankments, exposed sediment). MLC assigns each pixel to the class with the highest statistical probability of membership based on multivariate normal class statistics derived from training samples (Richards & Jia, 1999), and has been applied in prior Tanguar Haor and comparable haor assessments (Islam et al., 2016; Siddique et al., 2024; Rahaman et al., 2021). Post-classification change detection compared land cover maps and NDWI-derived water area across all five periods, with percentage change calculated relative to the 1990 baseline to capture both decadal transitions and cumulative long-term trends.

SRTM Terrain Analysis

The SRTM 30 m digital elevation model (Farr et al., 2007) was used to derive elevation and slope surfaces for Tanguar Haor, characterizing the low-relief basin morphology relevant to hydrological sensitivity and the spatial distribution of water retention zones (Rahaman et al., 2021).

Field-Based Validation Framework for Future Research

Although primary field surveys were not conducted in this study, a complementary field protocol for future work would include stratified-random vegetation quadrat surveys (Islam et al., 2016), point-count and transect-based bird surveys during the October–February migratory season (Hossain et al., 2018), water quality measurement (pH, dissolved oxygen, turbidity, conductivity, temperature; Rahaman et al., 2021), and semi-structured household surveys documenting livelihood dependence and governance perceptions (Sultana et al., 2019). Such data would provide ground truth for classification accuracy assessment and strengthen ecological interpretation beyond remote sensing evidence alone.

RESULTS AND DISCUSSION

Water Area Change Across Five Time Periods

Table 1 presents NDWI-derived open-water area for Tanguar Haor across the five study periods. The results document a major long-term contraction in open water extent, from 85.83 km² in 1990 to 13.54 km² in 2024 — an overall reduction of 84.2% (Figure 2; Figure 5).

Table 1. Mapped water area in Tanguar Haor, 1990–2024 (NDWI-based, GEE).

Year	Sensor	Water Area (km ²)	Change from Previous Period (km ²)	Cumulative % Change from 1990
1990	Landsat 5 TM	85.83	—	Baseline
2000	Landsat 5 TM	59.71	−26.12	−30.4%
2010	Landsat 7 ETM+	67.34	+7.63	−21.5%
2020	Landsat 8 OLI	10.97	−56.37	−87.2%
2024	Landsat 9 OLI	13.54	+2.57	−84.2%

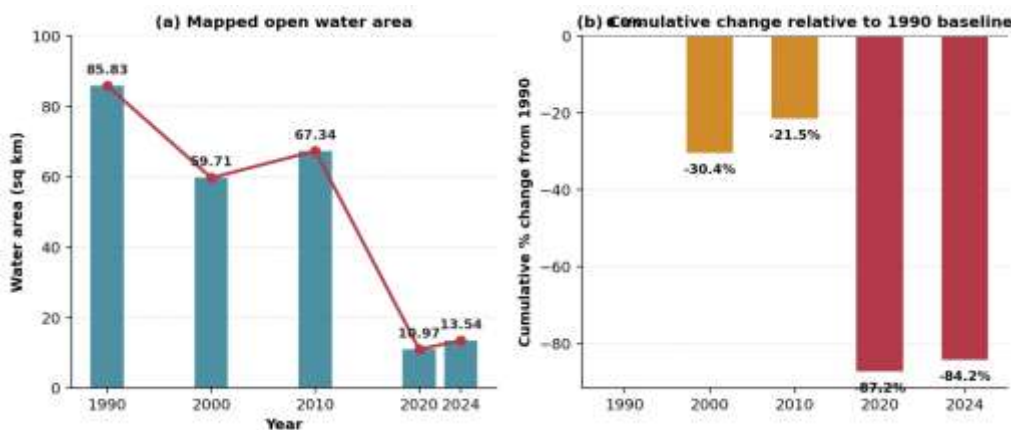


Figure 5. Trend in NDWI-derived water area in Tanguar Haor, 1990–2024: (a) mapped open-water area; (b) cumulative percentage change relative to the 1990 baseline.

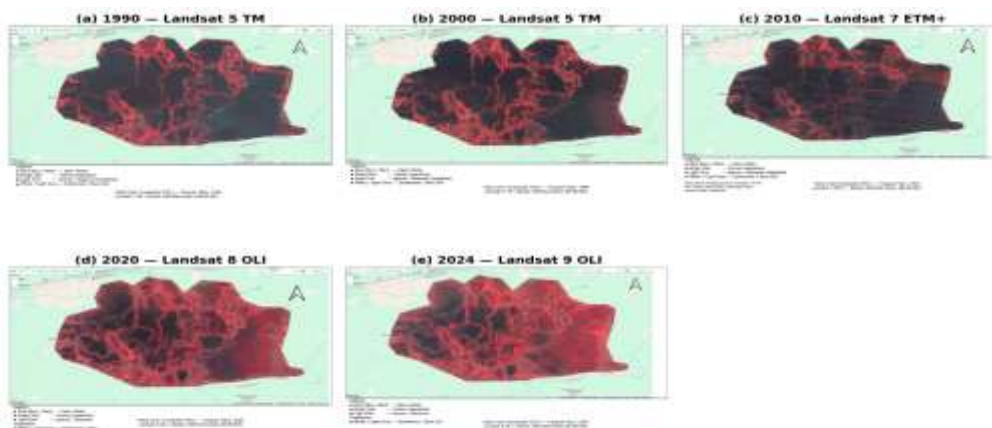


Figure 2. False Colour Composite (FCC) images of Tanguar Haor, 1990–2024, derived from Landsat 5 TM, 7 ETM+, 8 OLI, and 9 OLI imagery via Google Earth Engine. Source: author's own analysis (USGS, 2023; Gorelick et al., 2017).



Figure 3. NDWI-derived open-water extent in Tanguar Haor, 1990 vs. 2024 (NDWI > 0 threshold). Source: author's own analysis (McFeeters, 1996; Gorelick et al., 2017).

Interpreting the Trend: Decline, Partial Recovery, and Renewed Loss

The 30.4% decline in water area between 1990 and 2000 (85.83 to 59.71 km²) is consistent with documented intensification of anthropogenic pressure on Tanguar Haor during the 1990s (Islam et al., 2016; Rahaman et al., 2021). Population growth in Sunamganj District increased demand for agricultural land, fishery resources, and building materials, while a pre-2000 government leasing system allocated fishing rights to wealthy outsiders rather than local communities, encouraging intensive, unsustainable harvesting and land grabbing at wetland margins (Sultana et al., 2019; GEF, 2020). These trends align with national-scale wetland loss documented over the same period (Byomkesh et al., 2011; Khan et al., 2025).

The apparent partial recovery between 2000 and 2010 (59.71 to 67.34 km², +12.8%) should be interpreted cautiously. Substantial inter-annual hydrological variability in haor systems means that a wetter seasonal window in the 2010 composite relative to 2000 could partly explain the difference (Islam et al., 2016). The introduction of community-based co-management following the 2000 Ramsar designation may also have reduced localized extractive pressure (Sultana et al., 2019; ERA Haor, 2012; GEF, 2020), but published literature does not document a systematic ecological improvement during this decade, and overall degradation pressure remained intense (Islam et al., 2016; Siddique et al., 2024).

The 2010–2020 decline (67.34 to 10.97 km², a loss of 56.37 km²) is the most dramatic change in the series. A seasonal acquisition effect cannot be excluded — a drier seasonal window in the 2020 composite would inflate the apparent decline (Richards & Jia, 1999; Wang et al., 2020) — but the magnitude exceeds what seasonal variation alone can explain. Real degradation processes documented during this period include accelerating sedimentation from the Indian hill catchment, unauthorized embankment construction, and continued drainage and encroachment that governance arrangements were unable to fully arrest (Rahaman et al., 2021; Sultana et al., 2019; GEF, 2020), consistent with the national picture of accelerating wetland loss (Bangladesh MoEFCC, 2024; Nature Communications Earth and Environment, 2026).

The marginal 2020–2024 increase (10.97 to 13.54 km², +2.57 km²) is ecologically insignificant relative to the 1990 baseline and should not be read as evidence of meaningful restoration; it more plausibly reflects inter-annual hydrological variability or a relatively wetter acquisition period in 2024 (Gorelick et al., 2017; McFeeters, 1996). The overall 84.2% water-area loss over the study period is consistent with the broader literature documenting severe wetland contraction in Tanguar Haor and north-east Bangladesh (Islam et al., 2016; Siddique et al., 2024; Khan et al., 2025).

Vegetation Change: NDVI Analysis

NDVI maps for 1990 and 2024 (Figure 4) show that areas of low NDVI consistent with bare soil, degraded wetland surface, or exposed sediment are markedly more extensive in 2024, qualitatively consistent with published evidence of vegetation loss in comparable haor systems (Rouse et al., 1973; Islam et al., 2016).

Siddique et al. (2024) documented that approximately 33% of vegetation cover in Hakaluki Haor converted to agricultural land between 1989 and 2017 — a trend plausibly mirrored in Tanguar Haor given a similar pressure regime. Loss of native wetland vegetation (swamp forest, reed beds, floating-leaved and submerged plant communities) reduces fish nursery habitat, bird foraging and nesting sites, shoreline stability, and water-quality buffering capacity (Ahmad & Alam, 2003; Sultana et al., 2022; Hossain et al., 2018).

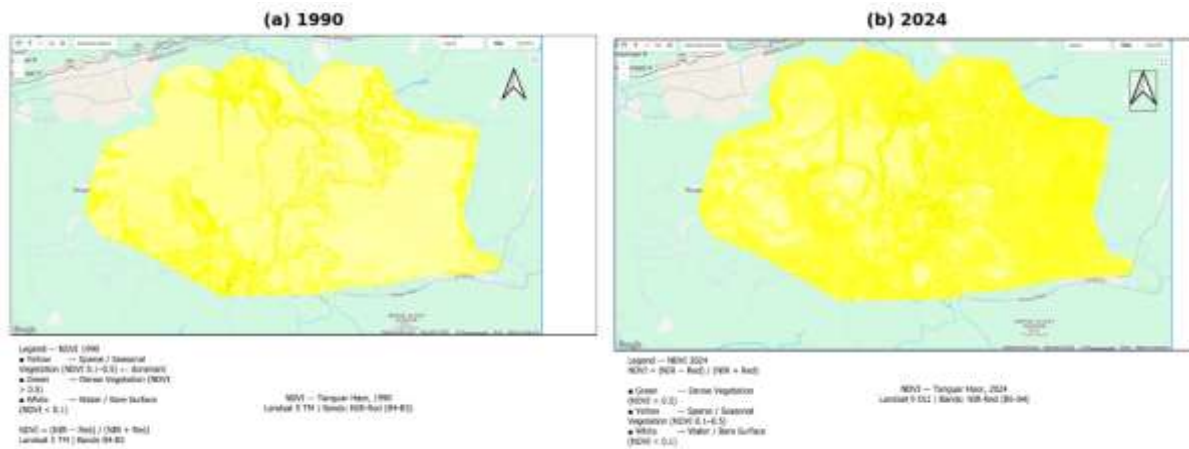


Figure 4. NDVI-derived vegetation condition in Tanguar Haor, 1990 vs. 2024. Source: author's own analysis (Rouse et al., 1973; Gorelick et al., 2017).

Terrain Analysis: SRTM Findings

The SRTM elevation and slope surfaces (Figure 6) confirm the extremely low-relief character of the Tanguar Haor basin, with most of the haor floor lying within a very narrow elevation range and gentle slope values typical of haor systems in north-eastern Bangladesh (Farr et al., 2007; Rahaman et al., 2021). This low-relief morphology means that even small alterations to drainage — unauthorized embankment construction, canal diversion, or progressive sedimentation — can substantially alter the extent and depth of seasonal flooding across the basin (Rahaman et al., 2021; Islam et al., 2016), reinforcing the importance of maintaining the natural hydrological regime and pursuing watershed-scale sediment management in any long-term conservation strategy.

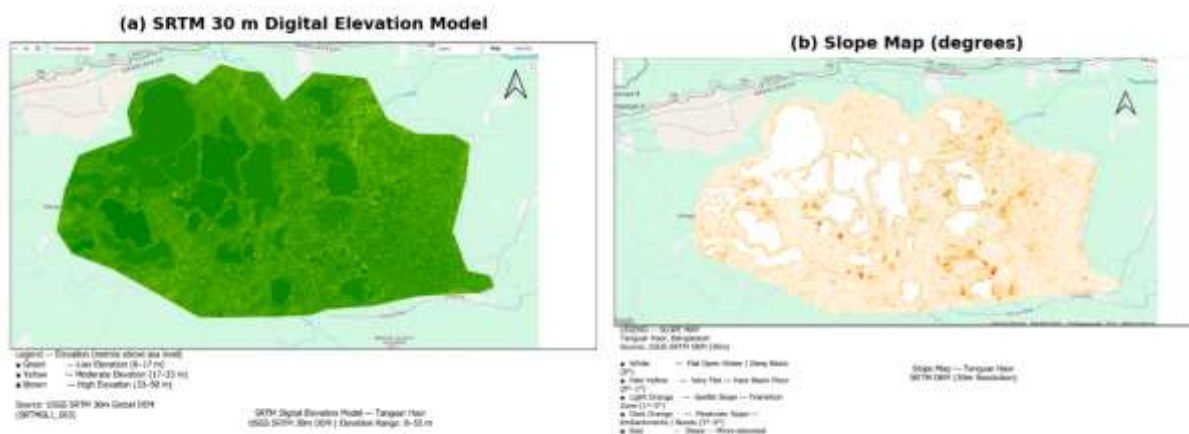


Figure 6. Terrain characteristics of Tanguar Haor: (a) SRTM 30 m digital elevation model; (b) slope map. Source: author's own analysis (Farr et al., 2007; Gorelick et al., 2017).

Comparison with Published Literature

The 84.2% water-area reduction documented here is directionally consistent with published literature, though direct comparison of magnitudes requires caution given differences in imagery, classification approach, and area definitions across studies. Islam et al. (2016) documented substantial land cover change including water body

contraction in Tanguar Haor from 1980 to 2015; Rahaman et al. (2021) confirmed major LULC shifts between 1989 and 2017; and Siddique et al. (2024) documented large-scale vegetation conversion in the comparable Hakaluki Haor system. At the national scale, Byomkesh et al. (2011) and Bangladesh MoEFCC (2024) confirm that Tanguar Haor's trajectory is part of a systemic national trend of wetland loss driven by population pressure, governance failure, and climate change, a picture reinforced by the 2026 Communications Earth & Environment national GEE analysis (Nature Communications Earth and Environment, 2026).

Community Participation in Wetland Governance

Importance and History of Co-Management

Community participation in wetland management is both an ethical necessity and a practical requirement in socio-ecological systems like Tanguar Haor (Sultana et al., 2019; ADB, 2025). With approximately 30,000 people directly dependent on haor resources, any governance system that excludes local communities cannot realistically enforce conservation rules, monitor ecological conditions, or ensure equitable distribution of benefits (NINA, 2004; Sultana et al., 2019); local ecological knowledge accumulated by fishing and farming communities over generations is an irreplaceable monitoring and management asset (GEF, 2020; ERA Haor, 2012).

Tanguar Haor's governance history illustrates a transition from state-controlled open-access exploitation toward co-management. Prior to 2000, fishing rights were auctioned to wealthy outsiders through a government leasing system that generated revenue but delivered few local benefits and permitted intensive overexploitation (Sultana et al., 2019; ERA Haor, 2012). Following the 2000 Ramsar designation and subsequent civil-society advocacy, community-based co-management was formally promoted from 2003 onward: the Community-Based Sustainable Management of Tanguar Haor Project (supported by USAID, implemented with IUCN and local partners) established community wetland management committees and formal local governance structures (ERA Haor, 2012), while the UNDP Community-Based Adaptation project provided further support for capacity building and climate adaptation (UNDP, 2011).

Governance Challenges

Despite institutional progress, governance remains challenged by persistent obstacles. Elite capture — disproportionate control of resource benefits by wealthy, politically connected community members — is consistently identified as a major barrier to equitable co-management (Sultana et al., 2019). Limited enforcement capacity of community committees constrains action against illegal fishing gear, wetland drainage, and encroachment, particularly where offenders hold political or economic power (GEF, 2020; ERA Haor, 2012). Institutional fragmentation among the Department of Environment, the Department of Fisheries, the Bangladesh Forest Department, and local government creates coordination gaps (Sultana et al., 2019; Khan et al., 2025), while inadequate gender inclusion means that women wetland users — despite significant roles in fish processing, plant collection, and household food security — remain largely excluded from decision-making (Sultana et al., 2019). Weak monitoring, including limited use of GIS and remote-sensing evidence in management decisions, keeps governance largely reactive rather than proactive (Islam et al., 2016; Gorelick et al., 2017).

Recent International Conservation Initiatives

International engagement with Tanguar Haor has intensified recently. In May 2025, UNDP Bangladesh and the Ministry of Environment, Forest and Climate Change launched a five-year, USD 4.05 million community-led wetland conservation project at Tanguar Haor, funded through the Global Environment Facility, with components addressing governance strengthening, biodiversity monitoring, livelihood diversification, and ecological restoration (UNDP Bangladesh, 2025; GEF, 2020). In parallel, the Asian Development Bank's 2025 regional assessment recommends sustained investment in community-based wetland governance as a cost-effective strategy for biodiversity conservation and climate resilience across Asia and the Pacific (ADB, 2025).

Nature-Based Conservation Options

Nature-based solutions work with natural ecological processes to address societal and environmental challenges while delivering co-benefits for biodiversity and human well-being (Ramsar Convention Secretariat, 2016; ADB, 2025). For Tanguar Haor, such solutions must be ecologically grounded, compatible with the livelihoods of wetland-dependent communities, and institutionally feasible within the existing co-management context (Sultana et al., 2019; GEF, 2020). Figure 7 summarizes five complementary options proposed on the basis of this study's findings and the published literature.

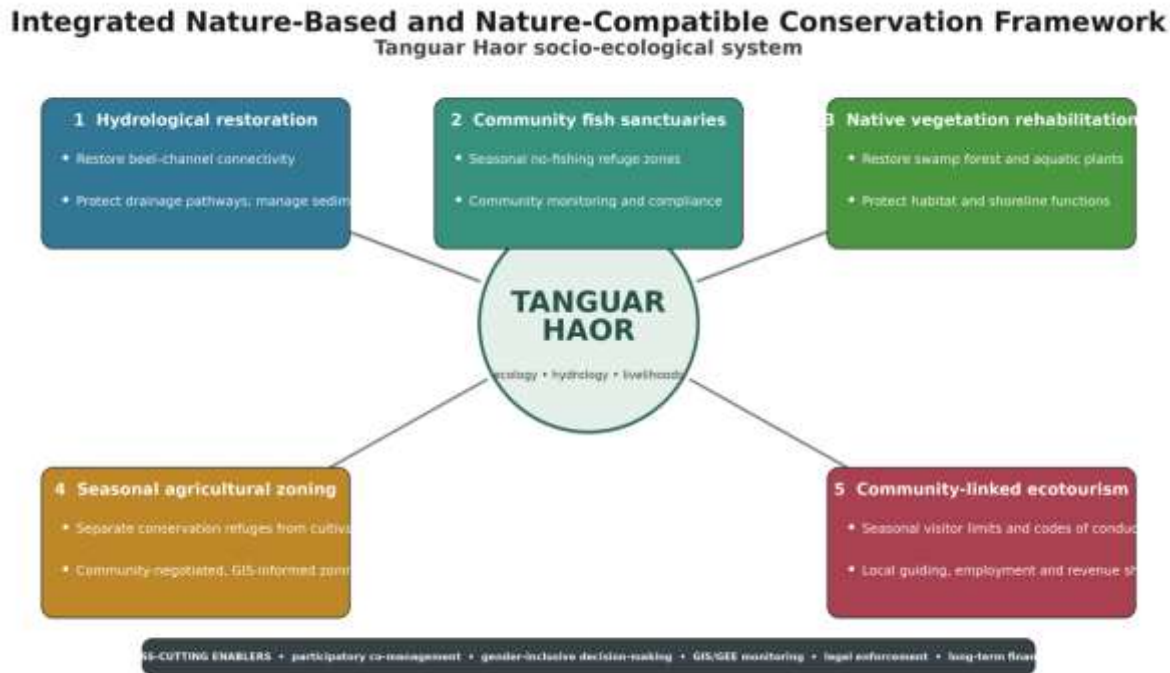


Figure 7. Nature-based conservation options proposed for Tanguar Haor.

Hydrological Restoration

Protecting and restoring natural hydrological connectivity is the most fundamental conservation priority, given the extreme sensitivity to hydrological modification demonstrated by the SRTM terrain analysis (Section 4.4; Farr et al., 2007; Rahaman et al., 2021). Priority measures include removing unauthorized embankments that disrupt seasonal connectivity between beels and the main haor basin, protecting natural drainage channels from encroachment, and instituting watershed-scale sediment management to slow the infilling of open water bodies.

Community Fish Sanctuaries

Designating no-fishing sanctuary zones within key beels, particularly during the breeding season, can help rebuild depleted fish stocks and support the nursery function on which the wetland's exceptional fish diversity depends (Sultana et al., 2022; Farruq & Islam, 2025). Community-managed sanctuaries, rather than externally imposed closures, have the strongest track record of sustained compliance in comparable Bangladeshi wetland contexts (Sultana et al., 2019).

Native Vegetation Rehabilitation

Native swamp forest, reed beds, floating-leaved plants (e.g., *Nymphaea*, *Nelumbo*), and submerged aquatic vegetation provide the habitat structure underpinning fish spawning and nursery function, bird foraging and nesting, shoreline stabilization, nutrient retention, and carbon storage (Ahmad & Alam, 2003; Sultana et al., 2022; Hossain et al., 2018). Community-led rehabilitation programmes establishing native-plant nurseries in surrounding villages can supply restoration plantings while generating income for participants (GEF, 2020; ERA

Haor, 2012); protection of remaining swamp-forest patches and aquatic vegetation beds from clearing should be institutionally enforced as a non-negotiable conservation rule (Sultana et al., 2019).

Seasonal Agricultural Zoning

Spatially explicit seasonal zoning, developed through community consultation and formalized in local management plans, can balance dry-season cultivation of the haor floor with habitat conservation (Sultana et al., 2019; Rahaman et al., 2021). The land cover classification outputs from Section 3.4 can support GIS-based spatial planning that distinguishes permanent or seasonal wetland refuges from areas where cultivation is compatible with conservation objectives (Gorelick et al., 2017; Islam et al., 2016). Zoning that is perceived as fair, and accompanied by technical support for improving productivity within designated cultivation areas, is more likely to achieve sustained community compliance (Sultana et al., 2019; GEF, 2020).

Community-Linked Ecotourism

Tanguar Haor's biodiversity, migratory bird spectacle, and distinctive landscape make it a potentially valuable nature-based tourism destination (Hossain et al., 2018; NINA, 2004; NHBS, 2024). A community-linked ecotourism model — with strict seasonal visitor limits (particularly during the October–February migratory season), revenue sharing with wetland-dependent households, local employment as guides, and an environmental code of conduct — can generate conservation-compatible income while building a public constituency for wetland protection (UNDP Bangladesh, 2025; GEF, 2020), provided it is accompanied by regular monitoring of visitor impacts on birds and fish (Hossain et al., 2018).

Policy and Institutional Recommendations

Effective long-term conservation requires enabling conditions beyond the site level: long-term, predictable financing for co-management institutions to replace short project cycles (UNDP Bangladesh, 2025; GEF, 2020); credible, consistently applied legal enforcement against encroachment, unauthorized drainage, and destructive fishing (Sultana et al., 2019); formal integration of haor conservation into Bangladesh's National Adaptation Plan and climate resilience frameworks, recognizing the role of haor wetlands in flood regulation and rural food security (Rahaman et al., 2021; Bangladesh MoEFCC, 2024); institutionalization of GIS-based GEE monitoring as a routine government and community function, with results made publicly available (Gorelick et al., 2017; Islam et al., 2016); and gender-transformative approaches ensuring women's meaningful participation in governance design (Sultana et al., 2019).

LIMITATIONS

Several methodological limitations affect the precision, though not the overall direction, of the findings. The most important is the absence of full seasonal harmonization across the five time periods: Tanguar Haor's strong seasonal hydrological dynamics mean that NDWI-based water area varies substantially between peak-inundation and dry-season conditions (McFeeters, 1996), so differences between years may partly reflect acquisition timing rather than permanent hydrological change (Gorelick et al., 2017; Wang et al., 2020) — a concern particularly relevant to the very low 2020 estimate. No formal accuracy assessment (error matrix, overall accuracy, Kappa coefficient) was conducted for the land cover classifications, so classification error rates for mapped-area statistics remain unknown (Richards & Jia, 1999); future studies should collect independent ground-truth reference points for formal accuracy assessment. Water area was estimated using a single NDWI threshold of zero, which may misclassify highly turbid shallow water as non-water and thus underestimate total water area; testing with the Modified NDWI (substituting SWIR for NIR) could improve performance in turbid conditions (Xu, 2006). Finally, the study did not include primary field data collection, limiting the ability to validate satellite-derived results against ground conditions (Hossain et al., 2018; Sultana et al., 2022); full implementation of the field-based framework described in Section 3.6 would substantially strengthen future assessments. Despite these limitations, the overall finding of an 84.2% decline in mapped water area is consistent in direction and magnitude with the published literature on Tanguar Haor and comparable haor systems (Islam et al., 2016; Siddique et al., 2024; Rahaman et al., 2021), and can be interpreted with reasonable confidence as evidence of significant long-term change.

CONCLUSION

This study documented a substantial 84.2% decline in mapped water area in Tanguar Haor, from 85.83 km² in 1990 to 13.54 km² in 2024, using multi-temporal Landsat imagery processed on Google Earth Engine and NDWI-based water mapping. The overall trajectory is consistent with published evidence of sustained land cover transformation, vegetation loss, and ecological degradation in Tanguar Haor and comparable haor systems (Islam et al., 2016; Siddique et al., 2024; Rahaman et al., 2021; Khan et al., 2025). The sharp 2010–2020 decline likely reflects a combination of real wetland degradation and seasonal acquisition effects, and the slight recovery to 13.54 km² by 2024 does not indicate meaningful ecological restoration relative to the 1990 baseline.

This study also demonstrates the value of GEE as an accessible platform for wetland change detection, enabling a 34-year multi-temporal analysis without local data infrastructure (Gorelick et al., 2017), while the SRTM terrain analysis confirmed the low-relief character and hydrological sensitivity of the haor basin (Farr et al., 2007; Rahaman et al., 2021). However, technical monitoring evidence alone is insufficient to reverse degradation: conservation outcomes depend on translating this evidence into effective participatory governance, legally enforced habitat protection, and nature-based restoration strategies compatible with the livelihoods of the approximately 30,000 people who depend on the wetland (Sultana et al., 2019; NINA, 2004; Rahaman et al., 2021). The institutional framework provided by the 2025 UNDP–GEF project, building on earlier co-management experience (GEF, 2020; ERA Haor, 2012; UNDP, 2011), offers an important platform for renewed conservation effort — whether it proves sufficient will depend on sustained political will, adequate funding, genuine community empowerment, and evidence-based adaptive management informed by the kind of GIS monitoring demonstrated in this study (Gorelick et al., 2017; Sultana et al., 2019; Islam et al., 2016).

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