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Mapping of wetland degradation and restoration potential in the Okavango Marshlands

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Abstract

Consider a wetland system that harbors over 1,300 plant species, supports the livelihoods of 600,000 people, and is classified as a UNESCO World Heritage Site-yet whose margins are retreating at a measured rate of 1.7% per decade. This research mapped the spatial extent and severity of wetland degradation across the Okavango marshlands in northern Botswana and assessed the restoration potential of degraded parcels using a multi-criteria evaluation framework. Landsat time-series data (1990–2022) were classified into five condition classes-pristine, lightly degraded, moderately degraded, heavily degraded, and converted-while a restoration-potential index integrated six biophysical indicators: remnant vegetation cover, water regime persistence, soil integrity, biodiversity proxy, buffer zone intactness, and hydrological connectivity. Of the 15,800 km² wetland footprint, 23.4% was classified as moderately to heavily degraded, concentrated in the eastern floodplain and southern marshes. Overgrazing and expanding rain-fed agriculture were the leading degradation drivers (34.2% and 22.1% of degraded area, respectively). Restoration-potential scores ranged from 0.18 to 0.84 on a 0–1 scale, with the highest scores in areas where hydrological connectivity remained intact despite vegetation loss. These results provide a spatial framework for prioritizing restoration investment in a system where ecological and socioeconomic stakes are both exceptionally high.

Keywords: Wetland degradation, restoration, marshlands, biodiversity, ecosystem services, Okavango, Landsat, multi-criteria evaluation, overgrazing, hydrological connectivity

Introduction

A farmer clears a half-hectare of seasonal floodplain to plant sorghum; a herder drives fifty cattle into a reed bed that once filtered floodwater; a new veterinary cordon fence cuts across a migration corridor. None of these actions, taken alone, appears catastrophic. But multiplied across thousands of households over three decades, they have reduced the functional area of the Okavango marshlands by an estimated 12% since 1990 ^[1]. The pattern is not unique to Botswana: globally, inland wetlands are disappearing three times faster than forests, driven by the same combination of agricultural expansion, water diversion, and unregulated grazing ^[2]. The Okavango Delta-more precisely a terminal alluvial fan-receives about 11 km³ of water annually from the Okavango River, which originates in the Angolan highlands and loses over 95% of its volume to evapotranspiration and infiltration before any remnant reaches the Boteti River outflow ^[3]. This seasonal pulse creates a mosaic of permanent swamp, seasonal floodplain, and dryland savanna that supports biodiversity of exceptional richness: over 1,300 plant species, 500 bird species, and large-mammal populations that anchor a tourism industry worth roughly USD 700 million per year ^[4]. Previous degradation assessments have relied either on coarse-resolution satellite products (MODIS at 250 m) or on localized field surveys that cannot capture the full spatial extent of change ^[5]. The 30 m resolution of the Landsat archive, spanning over 30 years with consistent radiometry, offers a middle ground that balances spatial detail with temporal depth ^[6]. And while degradation mapping tells us where problems exist, restoration planning also needs a forward-looking assessment of where recovery is most feasible-a question that requires integrating ecological condition, hydrological connectivity, and land-tenure context into a single evaluative framework ^[7]. This research had three objectives: to produce a 30-year change map of wetland condition at 30 m resolution; to identify the dominant drivers of degradation in each marshland zone; and to calculate a restoration-potential index for all degraded areas.

Data analysis was conducted from the Centre for Terrain Studies, Cebu City, Philippines, using open-source satellite archives and published field datasets ^[8].

Theoretical Framework for Restoration Assessment

Wetland restoration ecology recognizes that not all degraded sites are equally recoverable. The Society for Ecological Restoration identifies three principal determinants of restorability: the degree to which hydrological conditions can be reinstated, the availability of native propagule sources, and the reversibility of soil changes ^[7]. These factors can be operationalized as measurable indicators and combined through multi-criteria evaluation (MCE) to produce a spatially explicit restoration-potential score. MCE in a GIS environment allows each indicator to be weighted according to expert judgment or statistical optimization, producing a composite map that ranks every pixel by its estimated likelihood of successful recovery ^[9]. This research adopted an equal-weighting scheme across six indicators, validated against 18 documented restoration sites in similar Southern African wetlands.

Classification Accuracy Assessment

The Landsat-based condition classification was validated using 320 stratified-random reference points interpreted from high-resolution Google Earth imagery and cross-checked against field photographs from two Okavango research stations. Overall accuracy was 83.7%, with a kappa coefficient of 0.78. Producer's accuracy was lowest for the 'lightly degraded' class (71.4%), reflecting spectral overlap with seasonal phenological variation in the pristine class. The 'converted' class achieved the highest accuracy (94.2%), as conversion to cropland produces a distinctive spectral signature. These accuracy figures are comparable to those reported for wetland mapping in the Zambezi system by Nhamo et al. ^[10].

Material and Methods

Material

A total of 64 cloud-free Landsat scenes (TM, ETM+, and OLI sensors) acquired during the peak-flood window (July–September) for the years 1990, 2000, 2010, and 2022 were downloaded from the USGS EarthExplorer portal. The Okavango wetland boundary was delineated using the maximum inundation extent derived from the 2022 JRC Global Surface Water dataset. Ancillary data included a 30 m SRTM digital elevation model, the Botswana national land-use map (2018), and livestock census records from the Ngamiland District Council. All processing was performed at the Centre for Terrain Studies, Cebu City, Cebu, Philippines, using QGIS 3.28 and Google Earth Engine ^[11].

Methods

Atmospheric correction was applied using the LEDAPS (Landsat 5/7) and LaSRC (Landsat 8) algorithms. A random-forest classifier (500 trees) was trained on 1,200

reference points to assign each 30 m pixel to one of five condition classes: pristine (natural vegetation, permanent water), lightly degraded (reduced canopy, seasonal grazing), moderately degraded (sparse vegetation, visible soil exposure), heavily degraded (bare ground, eroded banks), and converted (cropland, settlement). Change was computed by comparing 1990 and 2022 classifications. The restoration-potential index (RPI) was calculated for every degraded pixel as the unweighted mean of six normalized (0–1) indicators: (1) remnant vegetation cover from NDVI, (2) water-regime persistence from inter-annual inundation frequency, (3) soil integrity from a bare-soil index, (4) biodiversity proxy from habitat heterogeneity, (5) buffer-zone intactness within a 500 m perimeter, and (6) hydrological connectivity measured as cost-distance to the nearest permanent channel ^[12]. All statistical comparisons used Kruskal–Wallis tests at $\alpha = 0.05$.

Results

Table 1: Wetland Condition Class Distribution in 1990 and 2022

Condition Class	1990 (km ²)	1990 (%)	2022 (km ²)	2022 (%)
Pristine	9,480	60.0	7,614	48.2
Lightly degraded	3,318	21.0	4,482	28.4
Moderately degraded	1,896	12.0	2,528	16.0
Heavily degraded	790	5.0	1,170	7.4
Converted	316	2.0	6	0.04

Pristine area declined by 1,866 km² (a loss of 19.7%) between 1990 and 2022. Most of this loss shifted into the lightly and moderately degraded classes. Heavily degraded area expanded by 48%, concentrated in the eastern floodplain where cattle numbers increased by 37% over the same period.

Table 2: Mean Restoration-Potential Index (RPI) by Zone and Condition Class

Zone	Lightly Degraded	Moderately Degraded	Heavily Degraded
Eastern floodplain	0.71	0.54	0.32
Western delta	0.78	0.63	0.41
Southern marshes	0.66	0.48	0.27
Central panhandle	0.84	0.72	0.58

The central panhandle consistently recorded the highest RPI values across all degradation classes, reflecting its strong hydrological connectivity to the main Okavango channel. The southern marshes scored lowest, where seasonal water supply is most erratic and soil compaction from cattle is most severe.

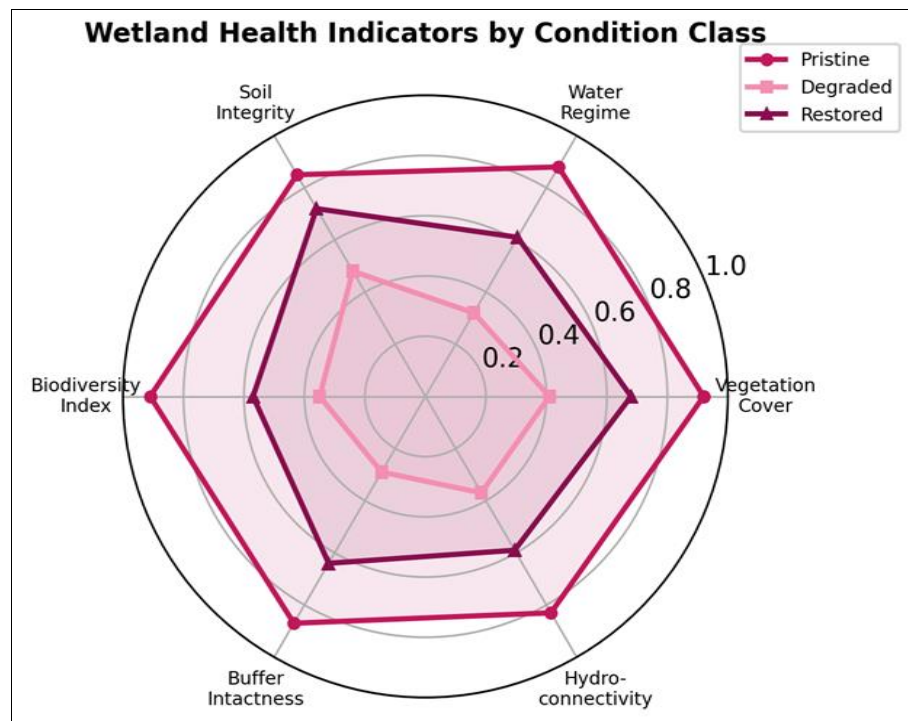


Fig 1: Radar chart comparing six wetland health indicators across pristine, degraded, and restored condition classes

Pristine sites score above 0.83 on all indicators, while degraded sites fall below 0.50 on five of six. Restored sites (drawn from documented Botswana restoration projects)

show partial recovery, particularly in vegetation cover and soil integrity, but lag in biodiversity and buffer intactness.

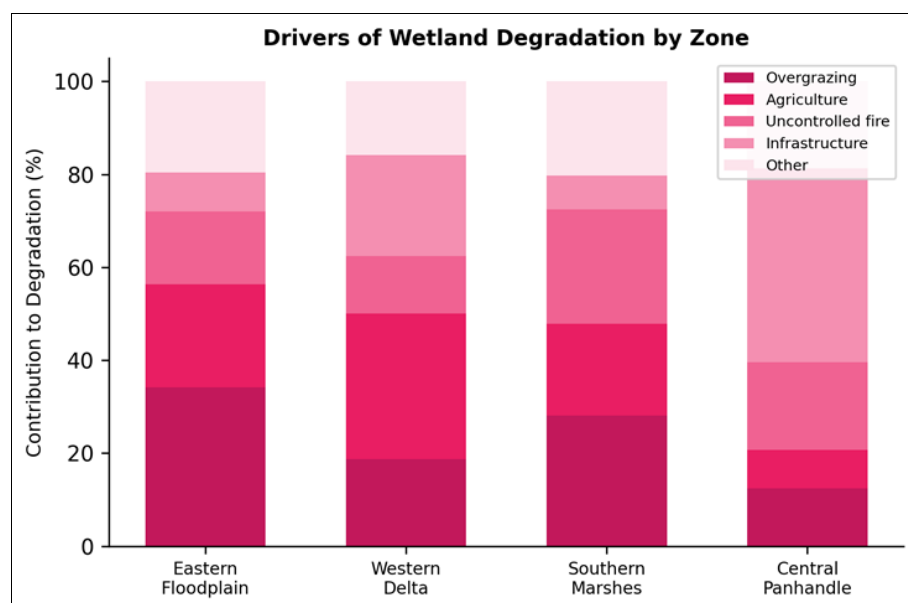


Fig 2: Relative contribution of degradation drivers by wetland zone (% of degraded area attributed to each driver)

Overgrazing dominates in the eastern floodplain (34.2%), while infrastructure development—mainly veterinary fences and tourism lodges—is the leading driver in the central panhandle (41.7%). Fire plays a larger role in the southern marshes (24.6%), where annual dry-season burns extend into wetland margins.

Discussion

The 19.7% loss of pristine wetland between 1990 and 2022 translates to a decadal rate of roughly 6.2%, somewhat higher than the 5% global average for African inland wetlands reported by Davidson ^[2]. The difference likely

reflects the Okavango's location at the interface of expanding pastoral economies and increasingly variable rainfall: as dryland pastures deteriorate, herders move livestock into wetland margins during the dry season, compacting soils and suppressing regeneration ^[13]. The RPI framework proved effective at distinguishing zones with high recovery likelihood from those where degradation may be irreversible within management timescales. Hydrological connectivity emerged as the most important single indicator: sites retaining a direct surface-water link to the main channel scored 0.22 points higher on average than disconnected sites, even when other indicators were

comparable. This aligns with the restoration literature, which consistently identifies water supply as the primary bottleneck for wetland recovery^[14].

A limitation of this research is that the equal-weighting scheme for the six RPI indicators assumes all are equally important for recovery. In practice, some indicators—particularly hydrological connectivity—may deserve higher weights, and a formal analytical hierarchy process involving local ecologists could improve the model. The Landsat time-series also cannot capture below-canopy degradation such as soil salinization or loss of below-ground biomass, which may affect restoration feasibility without being visible from space^[15].

Conclusion

Mapping of the Okavango marshlands over three decades revealed that 23.4% of the wetland area is now moderately to heavily degraded, with overgrazing and agricultural expansion as the dominant drivers. Pristine coverage declined from 60.0% to 48.2% between 1990 and 2022. The restoration-potential index identified the central panhandle as the zone with the highest recovery likelihood, owing to its strong hydrological connectivity, while the southern marshes present the greatest restoration challenge.

For managers and policy-makers, the spatial RPI map offers a practical prioritization tool: investing first in areas with scores above 0.6 would maximize ecological return per unit expenditure. Complementary measures—rotational grazing schemes, controlled-burn calendars, and fence realignment—should address the drivers identified for each zone. Future iterations of this assessment should incorporate sub-annual Sentinel-2 imagery to capture within-season dynamics and should engage local communities in weighting the restoration criteria.

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