Building Socio-Ecological Resilience in Inle Lake: Post-Disaster Environmental Assessment and Rehabilitation Plan following twin disasters

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Abstract

Inle Lake, a UNESCO Biosphere Reserve and one of Myanmar's most important freshwater ecosystems, experienced a compounded disaster during 2024–2025 when severe flooding associated with Typhoon Yagi was followed by a magnitude 7.7 earthquake. This paper synthesizes findings from post-disaster environmental assessments and evaluates cumulative impacts on ecosystems, livelihoods, infrastructure, and governance systems. Using a multidisciplinary impact assessment framework that integrates geospatial analysis, water quality monitoring, structural assessments, and community consultations, the study identifies key environmental and socio-economic consequences. Results indicate significant sedimentation, habitat degradation, damage to floating gardens, disruption of fisheries and tourism, and increased vulnerability of lakeside communities. Recovery efforts have been constrained by fragmented governance arrangements, limited monitoring systems, and resource limitations. The paper proposes an integrated rehabilitation framework based on ecosystem restoration, climate adaptation, community participation, resilient infrastructure, and coordinated governance. The findings demonstrate the importance of cumulative impact assessment and resilience planning in environmentally sensitive regions facing increasing climate and disaster risks. A five-pillar rehabilitation roadmap is proposed, emphasizing nature-based solutions, seismic-resilient infrastructure, and a unified management authority to secure the lake's future as a sustainable biosphere.

Introduction

Inle Lake is the second-largest freshwater lake in Myanmar and a globally recognized socio-ecological system. Located in Southern Shan State at approximately 880 meters above sea level, the lake supports more than 150,000 people through fisheries, floating gardens, tourism, transportation, and ecosystem services. UNESCO designated Inle Lake as a Biosphere Reserve in in recogintion of its ecological significance and cultural heritage (UNESCO, 2015).

Despite its importance, Inle Lake has experienced environmental degradation for decades. Deforestation, watershed erosion, sedimentation, nutrient loading, invasive species, and unsustainable resource use have progressively reduced ecosystem resilience. These pressures created conditions in which natural disasters could generate more severe and long-lasting impacts.

The flood of September 2024 and the earthquake of March 2025 represented a compounded disaster. Rather than acting as isolated events, they interacted with existing environmental and institutional vulnerabilities. This paper examines these cumulative impacts and proposes a rehabilitation strategy focused on long-term resilience rather than short-term recovery alone.

Study Area and Existing Vulnerabilities

The Inle Lake watershed contains mountains, agricultural lands, wetlands, and densely populated villages. Traditional floating gardens represent one of the most distinctive agricultural systems in Southeast Asia. However, expansion of cultivated areas and increasing sediment inflow have contributed to shrinking open-water areas.

Prior to the disasters, environmental studies documented declining water quality, reduced biodiversity, and increasing sediment accumulation. Economic dependence on tourism, fisheries, and agriculture also increased sensitivity to external shocks. Governance responsibilities were distributed among multiple institutions, creating coordination challenges for environmental management and disaster response.

Figure 1. Location of Inle Lake and Assessment Areas

Methodology

A multidisciplinary impact assessment approach was adopted. Environmental assessments included field observations, water quality sampling, habitat surveys, and ecological evaluations. Geospatial analysis was conducted using satellite imagery to evaluate flood extent, sediment deposition, and landscape changes.

Infrastructure assessments examined housing, transportation networks, tourism facilities, and public buildings. Structural observations focused on vulnerability of stilt-house communities and flood-affected settlements.

Socio-economic assessments included stakeholder consultations, focus group discussions, and household interviews. Information was collected regarding livelihood losses, recovery priorities, institutional challenges, and community perceptions of environmental change.

The analysis focused on cumulative impacts by examining interactions among environmental degradation, disaster events, governance limitations, and socio-economic vulnerabilities.


Figure 2. Water Quality Monitoring Locations

The assessment comprised four main components:

- Field Observations and Geospatial Analysis: Mapping 150-170 villages to assess the extent of the 16 km long lake's shrinking and the impact of sediment deposition.
- Socio-Economic Surveys: Data collection from damaged households to understand livelihood loss.
- Environmental Quality Testing: Systematic water quality monitoring (pH, EC, Turbidity) across multiple stations and biodiversity surveys focusing on endangered species like the Sarus Crane.
- Stakeholder Consultation: Key Informant Interviews (KIIs) with local CSOs, NGOs, and technical experts from MEAA and E Guard.

The water quality assessment indicates that pH values remained within the national surface water quality standards, while dissolved oxygen levels were generally close to the minimum threshold for aquatic ecosystems. Low turbidity and TSS values suggest relatively good water clarity at the sampled locations. However, the presence of ammonium and elevated oil and grease concentrations at selected stations highlights the need for continued monitoring and pollution control measures to maintain ecological integrity.

Table 1. Water Quality Test Results at Selected Monitoring Locations in Inle Lake

Item	Unit	INL-SW (20° 28' 02" N 96° 54' 37" E)	INL-AG (20° 28' 57" N 96° 54' 49" E)	INL-RS (20° 27' 27" N 96° 54' 28" E)	National Surface Water Quality Standard III
Temp	°C	24.9	24.9	24.9	-
DO	mg/L	3.98	3.99	4.01	>4
pH	-	6.99	7.14	7.17	6.0-9.0
EC	uS/cm	369	355	350	-
Turbidity	NTU	1.62	1.34	1.05	
Secchi depth	m	2	1.9	2.1	
TSS	mg/L	1.2	5	3	75
COD (Mn/Cr)	mg/L	5.2	3.6	6.4	13.0
BOD	mg/L	0.87	1.1	0.88	8.0
Ammonium	mg/L	0.4	0.4	Nil	0.5
Nitrate	mg/L	-	1.5	-	-
Nitrite	mg/L	-	1.0	-	-
Total Kjeldah1 Nitrogen	-	-	Nil	-	-
E. coli (MF)	-	-	-	Nil	-
Oil & Grease	mg/L	10	-	-	NA

Cumulative Impacts of the Twin Disaster

Environmental Degradation

The 2024 flood brought massive volumes of sediment and organic waste (water hyacinth) into the lake. The assessment found significant deterioration in water quality, leading to eutrophication and threats to endemic fish species.

Damage to Cultural and Physical Infrastructure

The March 2025 earthquake caused structural damage to iconic heritage sites, including the Phaung Daw Oo Pagoda and the Indein stupa complex. Furthermore, traditional stilt houses—the hallmark of Inle architecture—proved vulnerable to the combined force of water saturation and seismic activity.

Livelihood and Socio-Economic Stress

Floating gardens (Kyunn-myaw), the primary source of income for the region, were uprooted or buried under silt. The tourism sector, already fragile, faced a total standstill due to the perceived instability of the region.

Results and Discussion

Environmental impacts were substantial throughout the lake system. The flood transported large quantities of sediment into the lake, reducing water depth and affecting aquatic habitats. Sediment deposition altered ecological conditions and accelerated lake shallowing. Water quality deterioration was observed through increased turbidity and suspended solids.

The earthquake generated additional disturbances. Shoreline instability, localized slope failures, and infrastructure damage increased environmental stress. Saturated soils contributed to instability of foundations in several lakeside communities. The interaction between flood and earthquake impacts amplified overall damage.

Floating gardens experienced widespread losses. Many cultivated areas were physically damaged or displaced. Farmers reported reduced productivity and increased recovery costs. Fisheries were affected by habitat degradation, water quality changes, and disruption of breeding areas.

Tourism suffered significant impacts. Damage to jetties, accommodation facilities, cultural sites, and transportation services reduced visitor activity. Because tourism represents an important source of income, economic consequences extended beyond directly affected households.

Community infrastructure experienced varying levels of damage. Housing, sanitation systems, roads, and public facilities required rehabilitation. Health risks increased because of sanitation failures and reduced water quality.

Governance challenges emerged as a major factor affecting recovery effectiveness. Multiple institutions shared responsibilities for environmental management and disaster response, resulting in overlapping mandates and coordination difficulties. Limited environmental monitoring systems reduced the availability of timely information for decision-making.

Monitoring and Evaluation (M&E) findings further highlighted governance-related challenges affecting post-disaster recovery. Stakeholder consultations identified coordination gaps among government agencies, local organizations, and development partners, leading to overlapping responsibilities and implementation delays. Lessons learned from the rehabilitation process emphasized the importance of establishing a unified coordination mechanism, strengthening information-sharing systems, and enhancing community participation in environmental monitoring and decision-making. These findings suggest that institutional capacity and governance effectiveness are critical determinants of long-term resilience and sustainable recovery in the Inle Lake region (MEAA, 2025; MESDI, 2025).

Figure 3. Rehabilitation Activities Conducted Following the 2024 Flood and 2025 Earthquake (Hyacinth Removal and Dredging Activities)

Rehabilitation activities implemented following the flood and earthquake included water hyacinth removal, dredging of sediment-affected waterways, and restoration of navigation channels. These interventions contributed to improving water circulation, reducing environmental pressures, and supporting local livelihoods dependent on fisheries, transportation, and tourism (MEAA, 2025).

Long-term risks were also identified. Continued sedimentation may accelerate ecological degradation and reduce ecosystem productivity. Declining environmental conditions could negatively affect fisheries, agriculture, and tourism. Climate change is expected to increase the frequency and intensity of extreme events, making resilience planning increasingly important.

The assessment demonstrates that cumulative impacts are more significant than the effects of individual events. Environmental degradation, institutional weaknesses, and socio-economic vulnerability interact to create feedback mechanisms that can undermine recovery if not addressed through integrated planning.

Rehabilitation and Resilience Framework

Five strategic priorities are proposed.

- Integrated Governance: Establish a coordinated mechanism that improves planning, implementation, monitoring, and communication among agencies and stakeholders.
- Nature-Based Solutions: Promote reforestation, watershed restoration, wetland conservation, erosion control, and sediment management to reduce future environmental risks.
- Climate-Resilient Infrastructure: Reconstruct critical infrastructure using designs that consider flood and seismic hazards.
- Community-Based Resource Management: Strengthen local participation in environmental monitoring, fisheries management, watershed protection, and disaster preparedness.
- Environmental Monitoring and Early Warning Systems: Develop monitoring networks that integrate hydrological, environmental, and disaster-risk information. Additional priorities include livelihood diversification, capacity building, environmental education, and research programs supporting adaptive management. Sustainable recovery requires balancing ecological restoration with economic development and social well-being.

Conclusion

The Inle Lake post-disaster assessment demonstrates that the 2024 flood and 2025 earthquake were not isolated events, but cumulative shocks interacting with environmental degradation, livelihood dependence, fragile infrastructure, and fragmented governance. These conditions exposed the vulnerability of Inle Lake as a sensitive socio-ecological system and shows that recovery must extend beyond physical reconstruction to strengthen ecosystem resilience, institutional coordination, and capacity.

The findings highlight the role of impact assessment in identifying connected environmental, social, economic, and governance risks after disasters. Sedimentation, water quality concerns, damage to floating gardens, disruption of fisheries and tourism, sanitation risks, and heritage impacts require integrated rehabilitation based on ecosystem restoration, resilient infrastructure, environmental monitoring, livelihood recovery, and community participation.

The Inle Lake case shows that cumulative impact assessment can link immediate recovery needs with long-term resilience planning. Its lessons can inform future disaster recovery in Myanmar and other ecologically sensitive regions of Southeast Asia.

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