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Ithai Barrage and Environmental Sustainability: A Case Study of Loktak Lake

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ABSTRACT

As humankind uses natural resources to satisfy their needs, the exploitation and exploration of different resources have increased incredibly. With the advent of the Industrial Revolution, the choices to increase their standard of living surpassed their necessities. This has resulted in the creation of many infrastructures. Among them is the Ithai Barrage erected in 1983 primarily to generate electricity and Manipur's gross domestic product (GDP). This has taken a toll on the natural flow of the environment. This analysis analyzes the pre - Ithai Barrage and post - Ithai Barrage environmental sustainability through land use and land cover change is using the Environment Sustainable Index. It is found that even before the event of the Ithai Barrage sustainability was low. The earlier phase after the Ithai Barrage erection shows an increase in sustainability but the later phase witnesses lower Environmental Sustainability than the pre-Ithai condition.

Key words: Land Use Sustainability Index, Weightage Environment Index, Environment Sustainable Index, Khodrak Canal, Ungamel Canal

INTRODUCTION

Since the dawn of human civilization, humankind has exploited natural resources to fulfill their desire from minor to greatest. The sheer scale of exploitation increases exponentially with the increase in population. Since humans influence 83% of terrestrial surfaces to form their cultural landscape, it has become a keystone species. Before the Industrial Revolution, the consumption of resources was minimal because of the lack of machinery. The post-industrial revolution period marked a significant change in resource consumption. The increased medical facilities resulted in increased life expectancy, and fertility rates. This, coupled with decreased mortality, made consumption even faster. The increased choices of men resulted in the acceleration of resource consumption and exploitation. This supports rapid economic growth, and the material standards of many countries have increased. This has resulted in the depletion of natural resources faster than their regeneration. The exploitation of natural resources will soon be overloaded. Thus, conventional economic development results only in the degradation of natural resources, soil, and water, along with the diversity of nature.

Since terrestrial activity mainly comprises land activities, it changes land use and land-cover patterns. As human beings are sentient, there is a need for an in-depth study of sustainability principles and their analysis for the assessment of land use and land cover. When sustainability raised its prominence immediately after the publication of the Brundtland report (Brundtland 1987), it emphasised the need to understand ecological balance without compromising the socio-economic growth of a place. The sustainability of land use practices is of utmost importance with increasing pressure from the over-utilisation of Earth's resources due to human activities and, thus, rapid development and transformation. Changing land cover through various human activities needs to be viewed in terms of ecological processes, biodiversity, and availability of natural resources. Just as land use and environmental sustainability are reciprocal, changing land use decisions can negatively affect the environment. This clearly shows the importance of land use and cover, and its assessment can identify numerous loopholes in identifying plans for sustainable development. Indices created for sustainable analysis can have a more holistic approach in their quantification and access progress toward sustainability. Among the many indices created to simplify sustainability, the Land Use Sustainability Index (LUSI) created by Gardi et al. (2010) is worth mentioning. The index integrates various social, ecological, and economic indicators, leading to a comprehensive assessment of land-use sustainability. It recognises that understanding land use sustainability cannot be achieved when studied through isolated matrices; instead, it requires the consideration of multiple dimensions through composite analysis. This index evaluates the importance of land use practices in the environment and the need for local communities. Simultaneously, stakeholders are important in decision-making regarding sustainable assessment. The involvement of local communities and stakeholders in the decision-making process, whereby diverse perspectives are considered, leads to more effective and relevant sustainable plans.

The ecological footprint of Wackernagel (1993), ecological integrity, and the problem of achieving economic growth by Daly (2007) and Costanza (1992) are some of the different ways that sustainability was measured. Sustainable decision-making became the center stage (Schleicher 1993), while Narodoslawsky (1996) brought to the agenda the Sustainable Process Index (SPI) to evaluate industrial process sustainability. Guinée et al. (1993) have further enriched the concept of sustainability analysis by using life cycle assessment and ecological balance. Gao et al. (2019) emphasize integration's social, ecological, and economic dimensions. Haberl et al. (2004) describe the complexity of interdisciplinary approaches, while Baral and Holmgren (2015) outline localized and sustainable metrics for outcome assessment. The approaches lack a holistic approach in comparison to LUSI and SPI. Using multi-criteria decision analysis (MCDA) in sustainability assessment improves ecological governance by giving important details about changes in the landscape and how they affect ecosystems. This leads to long-term ecological balance.

For instance, the barrages constructed like the Ithai Barrage in Loktak Lake have caused several adverse impacts because of extreme land use and cover alteration. The change has resulted in enhanced habitat fragmentation, leading to a huge biodiversity loss. In addition, ecological services like water purification, carbon sequestration, and soil binding have also declined due to such alterations. The shift from diversified natural income sources to monocultural farming practices often implemented for higher income input has further deteriorated water and soil quality. This ultimately increases the vulnerability of such land to erosion, thereby reducing its long-term productivity. Land use and land cover changes have also disrupted the seasonal fluxes of floods - the essence of ecology. To overcome these challenges, the development of a land use sustainable index or environment sustainable index used in the study and the enhancement of interdisciplinary cooperation among the stakeholders is necessary. Active engagement by all participants can spur the development of various effective land management practices. The priority between ecological well-being and socio-economic development is important for achieving sustainable results that benefit the environment and communities. Analyzing the interaction between Ithai Barrage and Loktak Lake requires awareness of and focus on its land use/cover. Knowledge of this will transform the environment surrounding the Loktak Lake ecosystem into a possible factor, promoting the lake landscape and fostering its ecological and socio-economic resilience.

STUDY AREA

Loktak Lake, the Kohinoor of Manipur, is famous for its heritage of social, cultural, political, economic and geographical importance. It is the largest fresh natural water lake in Northeast India. It lies between 24°25′ to 24°40′ N latitudes and 93°45′ to 93°55′ E longitudes (Fig. 1). Ithai Barrage has converted it into a natural reservoir for the Loktak Hydro Electric Project. The lake is oval with a significant depression. It is drained directly and indirectly by 34 rivers from the western hills, including the Imphal, Iril, Thoubal, Sekmai, and Khuga Rivers, which are worth mentioning. Khodrak and Ungamel connect the lake with the Imphal River. It serves as both an inlet and an outlet of water. The lake basin has a direct catchment area of 980 km^2 and an indirect catchment of 7157 km^2. The lake is famous for a mass of floating

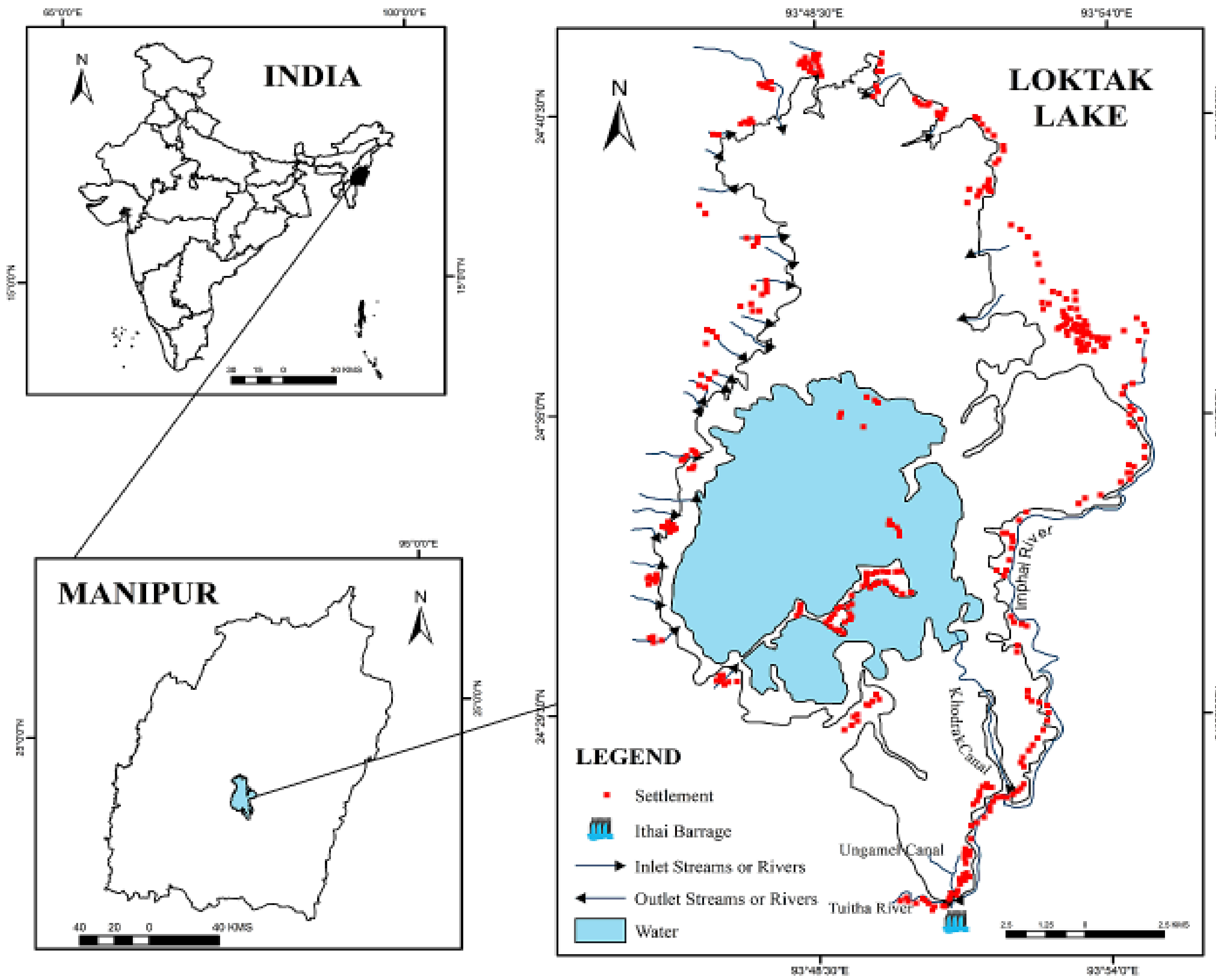

Figure 1. Study area

island weeds or macrophytes called Phumdi. They are the heterogeneous mass of soil, vegetation and organic matter. The southern part forms the habitat of Sangai Deer, which is known as Keibul Lamjao National Park. The establishment of Ithai Barrage made many changes to the Loktak Lake. There have been changes in the hydrological regime, inundation of agricultural land, displacement of people from submerged land, and loss of fish population and diversity. There is a decrease in weed thickness in the Keibul Lamjao National Park which is consequent to ecological changes, thereby threatening the survival of Sangai Deer (Nabakumar Singh 2008).

MATERIALS AND METHODS

The methodology used in the analysis incorporates elements from the Land Use Sustainability Index (LUSI) by Gardi et al. (2010) and the Weighted Environment Index (WEI) by Sánchez-González et al. (2024) to create a new Environment Sustainable Index (ESI) that addresses the drawbacks of LUSI while leveraging the merits of WEI. Like LUSI and WEI, this index uses land use and land cover classes from data generated using the Landsat series of the base years 1977, 2000 and 2024 using supervised classification on the Remote sensing data platform ERDAS. According to Gardi et al. (2010), land use and socio-economic metabolism are closely linked regarding material and energy flows, and this trend has been maintained. However, modifications were made, beginning with the selection of indicators. In this study area, as most people rely on agricultural activities for their livelihood, and the intensity of agricultural activities is not adequately represented

in previous trends, Agricultural Intensity and Industrial Indicator Indexes have been removed. However, Natural and Biodiversity Indicators remain, with the Biodiversity Indicator normalized according to Gardi et al. (2010). When integrating the indicators into a final index, varying weightings were applied. The factors considered by Sánchez-González et al. (2024), such as the natural characteristics of activities on the lake (F1), water needs associated with each feature (F2), soil degradation resistance (use of chemicals) (F3), environmental sustainability of land use (ecosystem stability) (F4), and the landscape value of activities in the analyzed area (F5), were included (Table 1, Fig. 2). These factors collectively help calculate the final weights using the Analytical Hierarchical Process (AHP) for each feature affecting environmental sustainability.
The equation is as follows

$$ESI = (BI*13+AI*27+NI*60)*NorBio$$

where, ESI - Environment Sustainable Index, BI - Built-up Index, AI - Agricultural Index, NI - Natural Index, NorBio- Normalised Biodiversity.

This analysis considers the entire study area a whole, making biodiversity singular; therefore, Nor-Bio is taken as 1. The weighting process assigns varying importance to different features. Given the significance of each feature and its impact on the environment, the relative weights for different factors are assessed. Agricultural land is assigned the highest impact when analyzed individually; followed by water, thin phumdis, and thick phumdis, with the least weight given to built-up land. Among the land use classifications, thick phumdis, thin phumdis, and water are included in Biodiversity indicators, which thus occupy 60 % of the total weight distribution. This highlights the importance of biodiversity. Since an increase in biodiversity enhances environmental sustainability, this factor is used as a multiplier in the equation. It is also noteworthy that the concept of environmental sustainability arises mainly in response to human interference with the environment, so the idea of complementarity suggested by Gardi et al. (2010) is not applied here. The value of ESI is divided into five types namely: 0-30 (very low), 30-45 (low), 45-60 (moderate), 60-75 (high) and 75-100 (very high).

Table 1. Factor wise allocation of weightage for different features

Features	F1	F2	F3	F4	F5	Mean
Agricultural land	0.14	0.23	0.58	0.24	0.15	0.27
Built-up land	0.05	0.15	0.30	0.10	0.06	0.13
Thick Phumdis	0.30	0.08	0.05	0.24	0.20	0.17
Thin Phumdis	0.21	0.19	0.04	0.14	0.25	0.17
Waterbodies	0.30	0.32	0.03	0.28	0.34	0.25

RESULTS AND DISCUSSION

Loktak Lake, the largest freshwater lake in Manipur and the Northeast, is linked with ecological and cultural sites in Manipur. Loktak Lake sustains the lives of thousands of people through agriculture, fishing, and its thick floating mass of macrophytes called phumdis, ultimately known as the Lifeline of Manipur. The floating macrophytes, or phumdis, support biodiversity and serve as a home to the endangered Sangai deer (Randhir Singh et al. 2000), enhancing nutrient cycling (Paonam and Chatterjee 2023) and water quality. To enhance hydroelectric power and irrigation services, the Ithai Barrage was constructed in 1983. Before its construction, the ecosystem was in a stable condition. The landscape was comparatively undisturbed by human activities. In 1977, agricultural land accounted for about 26% of the total study area, i.e., 73.54 km^2. It primarily concentrates in the northern and northeastern parts of the study area. Moderate dispersion was seen across the western part of the study area. Upon analysis from the core of the lake, i.e. from the middle part of the lake, the agricultural land remains a considerable distance away from the core. It shows the significant relationship between the balanced integration of agricultural activities and the natural landscape. The inhabitants were accustomed to traditional paddy cultivation, relying on seasonal flooding and drying of the lake. This was an integral part of the local economy. Nutrient-rich silt from the cycle of natural and seasonal flooding during the monsoon season allowed soil rejuvenation during the dry season. This agrarian economy enabled the communities around the lake to grow traditional crops without needing artificial fertilizers, maintaining agricultural productivity that was

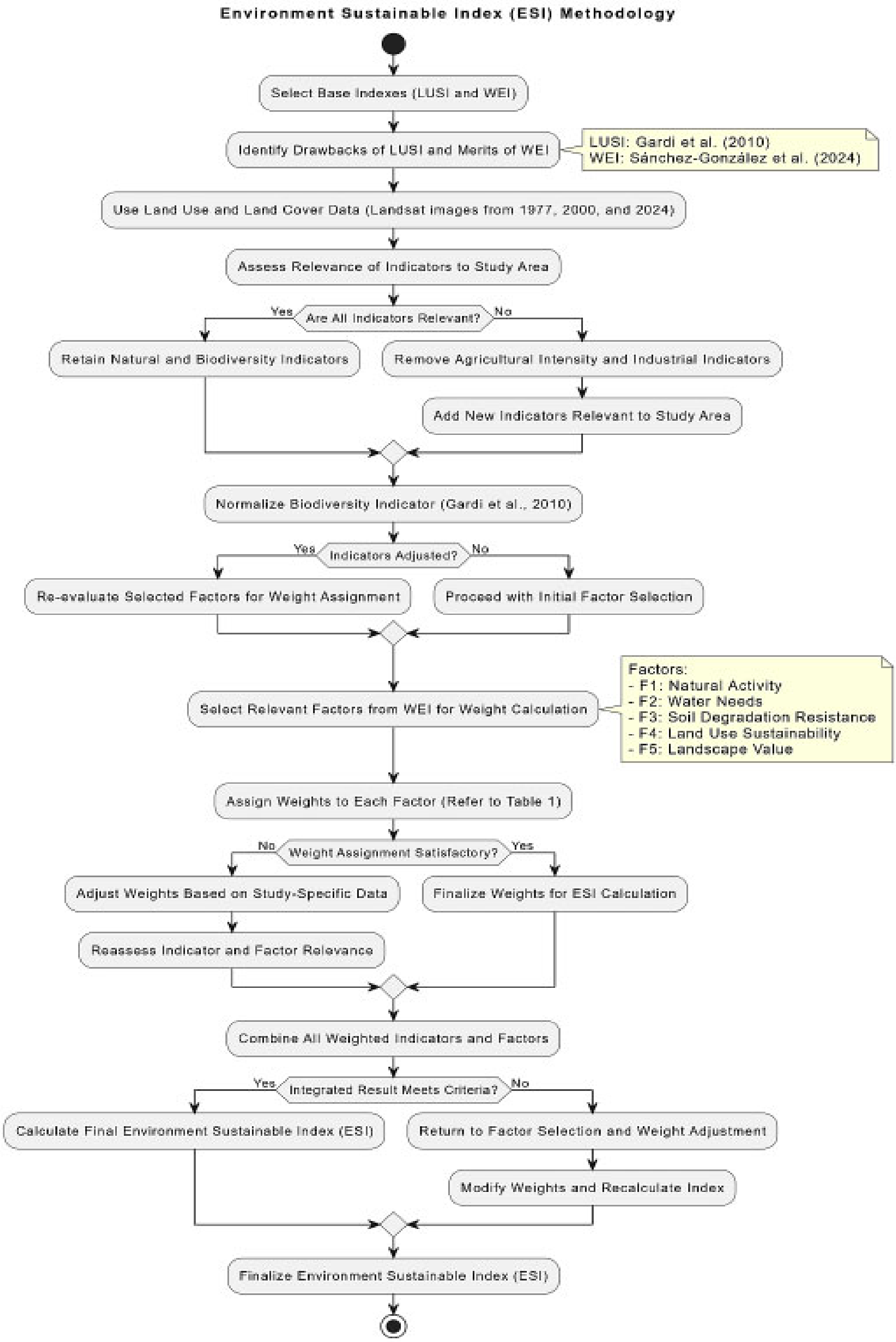

Figure 2. Methodology

reliable, productive, and sustainable.

Additionally, water bodies are mainly concentrated in the south-central part and southeastern parts of the study area. It formed a substantial part of the study area occupying about 20%, supporting diverged fish species that mainly preferred shallow water. Fishing practices were traditional, and due to the lake's plentiful nature, people had limited knowledge of fish farming, respecting its natural replenishment cycle. This contributed to the sustainability of both fish populations and biodiversity in the lake. The unique floating macrophytes, or phumdis, covered about 44% of the total study area in 1977. These floating macrophytes consist of organic and inorganic matter and vary in size and thickness. Thin phumdis occupied the majority, accounting for about 33%, while thick phumdis accounted for 11%. The phumdis acted as a natural filtration system, helping maintain water quality and providing a habitat for the Sangai deer. Before the advent of the Ithai Barrage, the phumdis absorbed nutrients from the lake's bed during the lean season, which helped increase their thickness and stability. This also provided sufficient nutrients for various plants consumed by local people (Sharma and Meitei 2020). With all these features combined, the Environment Sustainable Index was around 46.7% (moderately sustainable), indicating a moderate balance between human activities and the lake's natural processes.

The construction of the Ithai Barrage brought significant changes in the later part of the study. Initially, it was constructed to conserve the lake. It was expected to diminish due to continuous natural and anthropogenic factors through various land use changes and climatic variations, with predictions that it would last only 50 years (Khumukcham 2018). It was also constructed to generate sufficient electricity and create stable water reservoirs for irrigation. It indeed generated enough electricity (105 MW), with 35 MW being used in Manipur itself and the remaining 70 MW sold to neighboring states, earning 21–22 crore Indian rupees annually. It was also intended to irrigate 25,000 ha of cultivated land and provide employment opportunities for 2,000 people (Khumukcham 2018, Singh 2021).

By 2000, the effects of the Ithai Barrage on the hydrological regime became visible. The inundation of nearby agricultural land began slowly, reducing agricultural land to around 16% or 45.49 km^2. This forced the inhabitants to move to higher ground, making it unsafe for agricultural activities and the construction of houses. In other cases, inundation and flooding led people to build huts on the floating phumdis. After the construction of the Ithai Barrage, as water levels remained high throughout the year, the migration of indigenous fish halted as they preferred shallow waters. Local communities were forced to shift from traditional fishing to fish farming for commercial purposes to compensate for the demand for fish. This shift made the people economically independent and steadily increased the Environment Sustainable Index to 49.2% (moderately sustainable). Nevertheless, the long-term environmental costs are high, putting a strain on Loktak Lake and beginning to compromise its sustainability.

Due to obstruction by the Ithai Barrage, the maintained steady water level has led to an increase in the proliferation of phumdis. With increased fish farming, numerous infrastructures began to be constructed very fast. Fishing intensification in the lake also increased. The rise of new athaphums, especially for fish farming, led to the expansion of thin phumdis, which the Khodrak and Ungamel canals (Maril) toward the Imphal River should carry away. However, a reversal in water flow contributed to the overall spread of thin phumdis by 2000.

Built-up areas also increased from 10 to 12%, or 33.99 km^2, by 2000. As the increase in infrastructure affected the overall hydrology, the phumdis began to decline due to the lack of seasonal fluctuation, which impacted nutrient absorption and decomposition. This reduced the overall natural filtration capacity, thereby lowering water quality. Over time, the severity of the Ithai Barrage's impact on Loktak Lake has intensified. By 2024, agricultural land suddenly increased to 31%, almost double from 2000 including paddy fields and fish farms. It has expanded so much in such a way that it continuously surrounds the lake particularly the northern, eastern and southern regions. Since the agricultural expansion has made the cultivation near the edge of the lake, it affects the overall natural buffer zones thereby increasing potential direct nutrient runoff and pollution towards the lake. Upon close inspection,

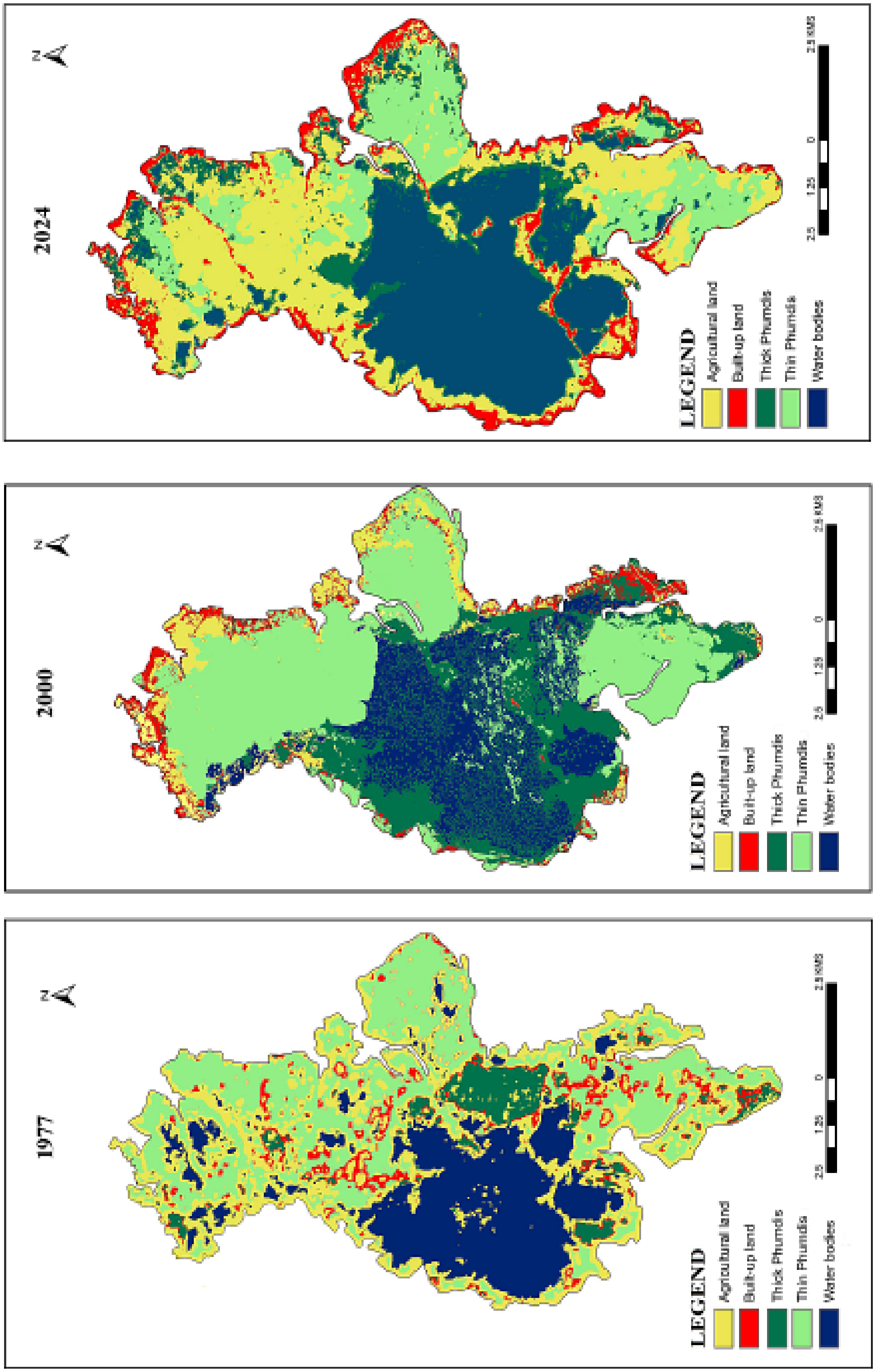

Figure 3. Land use and Land cover of Loktak Lake

fish farms increased to a great extent when compared to the paddy field. This shift has caused profound changes in land use around the lake, making traditional practices rare. Dependence on traditional fishing is now concentrated only in the Thanga and Karang areas. The consistently high water levels have accelerated the thinning of phumdis, affecting the natural habitats of the Sangai deer (Fig.3, Table 2).

On the other hand, athaphums, artificially crafted from natural phumdis specifically for fish rearing, contribute to the outward detachment of thin phumdis. However, this comes at a cost. Thin phumdis also decrease due to a lack of nutrients, reducing to 16%, or 47.21 km^2, of the total study area. Concurrently, built-up areas have accelerated, putting further pressure on the natural environment, fragmenting habitats, and reducing open spaces essential for ecosystem stability. Thick phumdis, which provide a critical habitat for the Sangai deer, were reduced to 5%. Thereby, the structural integrity has suffered. Without access to nutrients from the lake bed, the fragility of these phumdis has increased, leading to accelerated thinning. This deterioration has compounded the Sangai population challenges (Kangabam et al. 2019).

As the overall phumdis have weakened, so has the ecological stability. The increased siltation rate from the Khodrak and Ungamel canals has led to fluctuations in water levels of only 1.4 m during the lean and rainy seasons, compared to 3.1 m before the Ithai Barrage was constructed. This could push the lake's water level past its carrying capacity (Anand et al. 2024). It is also estimated that the lake now holds only 75% of its total capacity due to increased siltation, with an estimated 336,325 tons of silt deposited annually (Thakur 2023). However, the total sediment load has reached 650,000 metric tons (Rai and Raleng 2012).

Table 2. Temporal extent for each feature (in km^2)

Features	1977	2000	2024
Agricultural land	73.54	45.49	89.81
Built-up land	29.72	33.99	62.95
Thick Phumdis	31.97	35.54	13.49
Thin Phumdis	93.54	103.75	47.21
Waterbodies	58.23	68.23	73.54
Total area	287.00	287.00	287.00

Consequently, the lake's navigational benefits have also been compromised. This decline has led to a drop in the Environment Sustainable Index to 39.4% (low sustainability) highlighting the lake's reduced resilience and struggle to fulfill ecological functions and human needs. Once used as grazing grounds, elevated areas within and around the lake have become inundated, leading to long-term destruction (Oinam and Khoiyangbam 2017). This has caused significant damage to cattle and buffalo grazing areas, prompting a reduction in livestock. Consequently, local inhabitants have shifted towards fish farming. Although fish farming initially boosted the local economy, the decline in the lake's environment makes this industry vulnerable. Due to intensive activity, nutrient-rich runoff from agricultural activities and fish farms (Anand and Oinam 2019, Talini and Kalota 2018) has led to eutrophication, degrading water quality and causing frequent algal blooms. These blooms deplete oxygen levels, creating dead zones that harm farmed and wild fish. This affects the foundation of the local economy, threatening livelihoods and food security. The changes have also affected the cultural practices of communities around Loktak Lake. The submergence of traditional grazing grounds and seasonal farmland has disrupted traditional practices, often leading to conflicts with traditional stewardship and conservation, further distancing people from their cultural heritage. This shift has transformed the once harmonious relationship between communities and the lake into a more utilitarian approach, resulting in resource overutilization and undermining the deep cultural identity rooted in their heritage.

CONCLUSIONS

The proposed methodology used in this study provides a satisfactory assessment of environmental sustainability from the perspective of land use and land cover. The Ithai Barrage has affected the overall sustainability of the lake, where sustainability initially remained low at 46.7%. However, it increases to 49.2%. Ultimately, the aftermath of the Ithai Barrage reduces the lake's sustainability to 39.4%, demonstrating its overall impact. This decrease in sustainability cannot be overlooked. Even though the methodology is applied in a smaller context, it can be extended to the larger context of any area. To ensure long-term sustainability in the study area, the changes around the lake must align with the preferred weightage set in this study. Other features must compensate for any change in the area to maintain environmental sustainability. Future research could focus on adding new factors affecting the environment and obtaining more detailed land use and land cover data. The analysis could also be expanded to areas with multiple settlement boundaries, allowing for a clearer understanding of sustainability differences and the impact of biodiversity on the overall equation.

Authors' contributions: Luckychand collected and generated the data, did necessary literature reviews. He also drafted the article. Pikeshwor assisted Luckychand to create the Environment Sustainable Index and undertook the critical revision for any inconsistency, Luckyson analysed the data, Soreimi interpreted the data and did the overall revision.

Conflict of interest: The authors reported no potential conflicts of interest.

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