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An Integrated Geospatial Assessment to Evaluate Factors Affecting Sustainability of Ecosystem Services of Urban Wetlands Due to Fragmentation: A Case study of Bellanwila-Attidiya Wetland in Sri Lanka

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Abstract: Urban wetlands are crucial ecosystems that offer a wide range of ecosystem services, including flood mitigation, biodiversity support, and climate regulation. However, in rapidly urbanizing areas, the sustainability of these services is increasingly compromised by land fragmentation. The objective of this research was to identify ecosystem services provided by the Bellanwila-Attidiya Wetland and to analyse spatial and temporal changes of wetland fragmentation and to evaluate the drivers of loss of ecosystem services provided by the Bellanwila-Attidiya Wetland due to wetland fragmentation. A geospatial assessment was carried out using Landsat satellite images acquired in 1995, 2011 and 2024 to assess spatial and temporal changes of fragmentation. Fragmentation parameters such as the Number of Patches, Patch Density, Mean Patch Area, and Edge Density were estimated using QGIS to assess wetland fragmentation that affects the sustainability of ecosystem services. Then factors affecting the loss of ecosystem services due to fragmentation was assessed. The data were collected through key informant interviews with experts and focus group discussions with local residents of the wetland. The results indicated that the Bellanwila-Attidiya Wetland provides vital ecosystem services including flood regulation, biodiversity conservation, water purification, air pollution control recreational opportunities and health benefits for residents and people living in surrounding region. Spatial analysis from 1995 to 2024 reveals a significant reduction in wetland cover from 60% to 38% accompanied by increased fragmentation, with the number of wetland patches rising from 16 in 1995 to 141 in 2024. Household surveys and interviews revealed that unregulated housing expansion (70%), inadequate enforcement of environmental laws (68%), and infrastructure development (65%) as the primary factors of wetland fragmentation that have affected the sustainability of ecosystem services in Bellanwila-Attidiya Wetland. The survey data revealed that 67% of respondents have observed a noticeable decline in water quality over the past decade. Biodiversity indicators, including bird and amphibian presence, were reported to have decreased by 45% since 2000, based on observational and community-reported data. The findings of the research highlight the need for stronger conservation efforts. Implementing clear land-use policies, restoration programs, and better enforcement can be recommended to sustain the Bellanwila-Attidiya Wetland's ecosystem services.

Keywords: Ecosystem services, Environmental sustainability, Fragmentation, Geospatial analysis, Urban wetlands

Introduction

Wetlands are distinctive ecosystems that have water either at all times or seasonally that helps sustain different flora and fauna adapted to the saturated soils. These are mangroves, swamps, marshes, and peat lands [8]. Wetlands play very essential ecological roles that are beneficial to the environment and human beings. Wetlands provide essential ecosystem services like water purification, flood management, erosion, and carbon sequestration, which contribute to environmental health and disaster risk mitigation [11].

Wetlands also serve as natural sponges, where they absorb the excess rain water and decrease the magnitude of floods, alleviating the flood impacts. They control the amount of water and assist in stabilizing the groundwater level [9]. In addition, wetlands are able to treat water by removing pollutants and sediments in water [2]. In addition, wetlands are very important habitats to a vast variety of species such as birds, amphibians, insects, fish and plants. They house numerous species as well as being a feeding and breeding area of many species particularly of migratory birds [12].

And wetlands can store large quantities of carbon in their plants and soils, contributing to controlling carbon levels in the atmosphere and reducing the effects of climate change [9]. Besides, wetlands have aesthetic, spiritual, recreation, and tourism values, which are significant to the well-being of people and local economies [7]. Moreover, wetlands provide irrigation and drinking water, food and other aquatic organisms, raw materials in the form of reeds and medicinal plants [10].

Fragmentation of wetlands has caused a significant problem in the ecosystem services of wetlands. The division of a previously undivided landscape into small units can be described as wetland fragmentation. Fragmentation affects wetland landscapes by dividing them into small, sporadic fragments, this minimizes their capacity to deliver much needed ecosystem services efficiently [5].

Fragmentation minimizes the ability of the wetlands to store and filter water resulting in escalated runoffs, downstream flooding, and low water quality. This prevents the purification of wetland as a natural purifier of water [4]. Moreover, small isolated wetlands are not effective to maintain a variety of wildlife, leading to loss of biodiversity and poor quality of habitat [6].

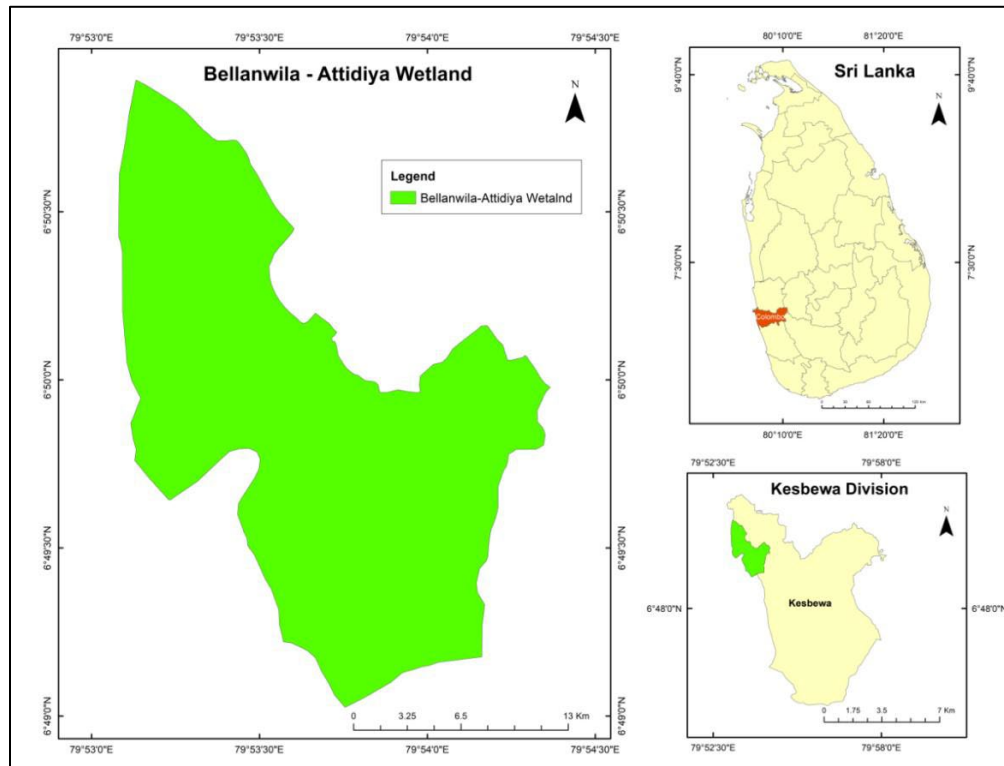
Despite the well-recognized importance of wetlands, there is still a limited understanding of how fragmentation specifically affects the long-term sustainability of ecosystem services in urban wetlands, particularly in rapidly developing regions like Sri Lanka. While many global studies have focused on wetland loss in general, fewer have examined the spatial dynamics of fragmentation and its direct impact on services such as flood regulation, water purification, and habitat provision at a local scale. The Bellanwila–Attidiya Wetland, located in the heart of Colombo's urban landscape, is under increasing pressure from urbanization and land-use change, yet comprehensive geospatial assessments that integrate both ecological and community perspectives remain scarce. This research therefore seeks to fill that gap by evaluating factors that have altered the sustainability of ecosystem services in the Bellanwila–Attidiya wetland fragmentation.

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Materials and methods

Study area

Figure 1: Study area map of Bellanwila Attidiya Wetland



Source: Compiled by the author

The study area of Bellanwila-Attidiya Wetland is located at $6^{\circ} 52' 0''$ N and $79^{\circ} 52' 0''$ E to $6^{\circ} 48' 0''$ N and $79^{\circ} 56' 0''$ E. It belongs to the Keskewa District Secretariat Division of Colombo District in the western province of Sri Lanka. The study area consists of an extent of 372 hectares and it is protected under the Department of Wildlife as a wildlife sanctuary.

Spatial data collection and pre-processing

To assess the spatial and temporal changes of fragmentation in the Bellanwila- Attidiya Wetland area, Landsat images from the years 1995, 2011, and 2024 were used. The images with 10% or less cloud cover were selected. The details of the Landsat images are illustrated in Table 1.

Table 1: Satellite data used for the research

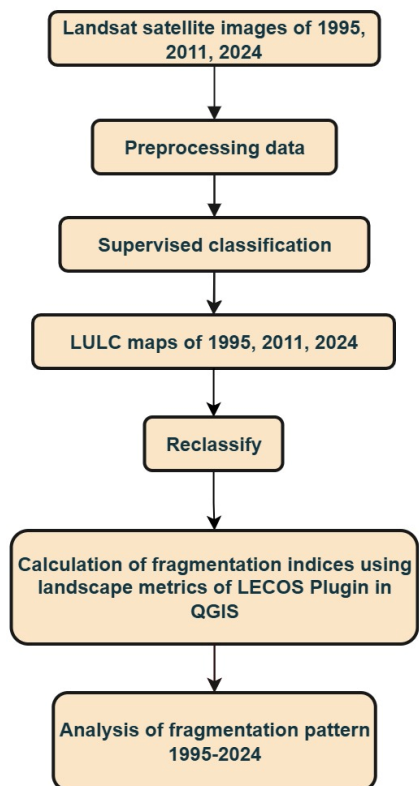
Sensor	Acquisition Date	Source
Landsat-5 TM	1995.12.10	https://earthexplorer.usgs.gov
Landsat-5 TM	2011.11.13	https://earthexplorer.usgs.gov
Landsat-8OLI/TIRS	2024.03.05	https://earthexplorer.usgs.gov

Source: Compiled by author based on data from United States Geological Survey (USGS), Available at: <https://earthexplorer.usgs.gov>

A spatial analysis was conducted using Arcgis and QGIS to identify fragmentation pattern of the study area. To identify the fragmentation levels, first, the overall LULC changes of the study area between 1995-2024 has been analyzed by classifying the downloaded satellite images using supervised classification.

Then the LULC maps of study area were reclassified as wetland and non-wetland areas (built-up areas and open areas) to identify the level of fragmentation between 1995-2024.

Figure 2: Fragmentation analysis of Bellanwila Attidiya Wetland from 1995-2024



Source: Compiled by the author

Quantification of wetland fragmentation is done by using landscape metrics of Lecos plugin of QGIS. The landscape metrics of Number of Patches, Patch Density, Mean Patch Area, and Edge density were used as fragmentation indices to quantify the level of wetland fragmentation of Bellanwila-Attidiya Wetland.

Table 2: Landscape Metrics Used to Assess Wetland Fragmentation

Metric	Explanation	Formula
Number of Patches (NP)	Total number of wetland patches identified in each grid.	$NP = \sum m_i$ $m_i = \text{number of patches}$
Patch Density (PD)	Number of patches of a given type divided by the total landscape area (m^2), standardized to 100 ha. Indicates the degree of fragmentation.	$PD = \frac{\sum(M_i)}{A}$ $n = \text{number of landscape types}$ $M_i = \text{number of patches in the } i\text{-th type}$ $A = \text{total area of the landscape}$

Mean Patch Area (AREA_MN)	Average patch size of a given type, calculated by dividing the sum of patch areas by the number of patches.	$MA = \sum(a_{ij})/n_i \times (1/1000)$ a_{ij} = area (m ²) of the j-th patch in the i-th landscape n_i = number of patches of type i
Edge Density (ED)	Ratio of total edge length to the total landscape area. Higher values indicate greater landscape heterogeneity.	$ED = (1/A) \sum(P_{ij})$ P_{ij} = perimeter of patch j A = total area

Source: compiled by author based on data from [1], [3] and [13].

Evaluation of Drivers of Ecosystem Service Loss

The study employed a mixed-methods approach combining household surveys, key informant interviews, and spatial analysis. The target population comprised households residing in three Grama Niladhari Divisions adjacent to the wetland. A stratified random sampling technique was applied to ensure representation across different community clusters, and a total of 55 households were surveyed. Structured questionnaires were used to assess residents' perceptions of ecosystem services and the factors contributing to their decline. Quantitative data from household surveys were analyzed using descriptive statistics, including frequencies, percentages, and mean scores, to summarize respondents' perceptions of ecosystem services. Pearson correlation analysis was employed to examine the relationships between identified drivers of fragmentation and the perceived decline in ecosystem services. Significance was tested at the 0.01 level.

Key informant interviews were conducted with officials from the Department of Wildlife Conservation, the Central Environmental Authority, and local community leaders to supplement household data with institutional and policy-level perspectives. Secondary data sources, including government reports and published studies, were also reviewed to contextualize the findings.

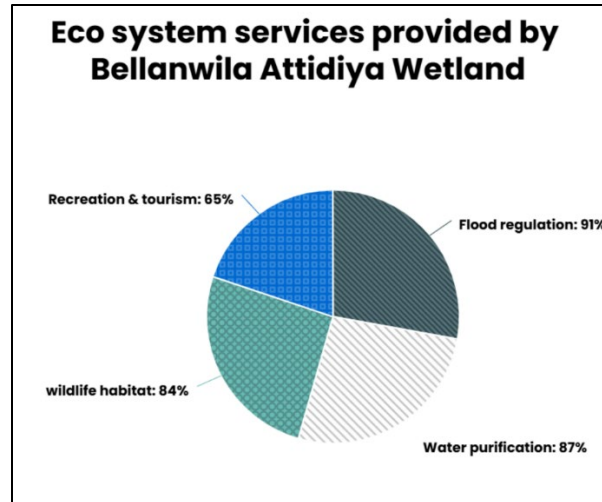
Results and discussion

Ecosystem services provided by Bellanwila Attidiya wetland

As illustrated in Figure 3, the questionnaire data indicates a high level of public awareness regarding the ecosystem services of the Bellanwila Attidiya Wetland. The most widely recognized service was flood regulation, identified by 91% of respondents. This suggests that the community predominantly values the wetland for its protective function, likely due to the tangible benefits of reduced flooding in an urban setting.

Other services were also highly rated, though to a slightly lesser extent. Water purification (87%) and the provision of a wildlife habitat (84%) were clearly acknowledged, reflecting an understanding of the wetland's ecological health and biodiversity value. The strong recognition of recreation and tourism (85%) positions the wetland as not just an ecological asset but also an important community space for well-being.

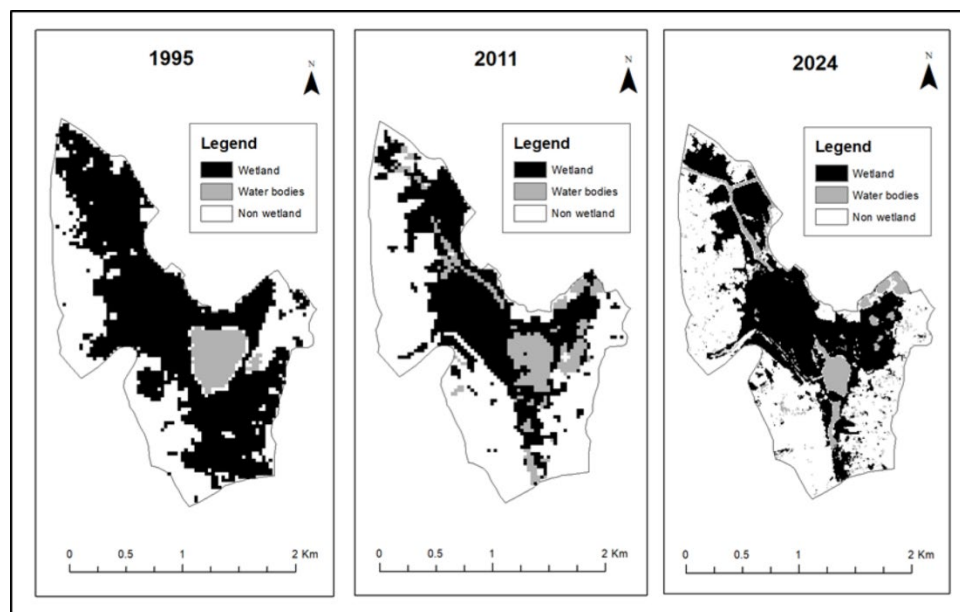
Figure 3: Ecosystem services provided by Bellanwila Attidiya Wetland according to the questionnaire survey



Source: Compiled by the author

Spatial analysis of wetland fragmentation in Bellanwila Attidiya wetland from 1995-2024

Figure 4: Spatial and temporal variation of fragmentation in Bellanwila Attidiya Wetland 1995-2024



Source: Compiled by the author

According to Figure 4, the comparison of the land covers in 1995-2024 indicates that there is a major trend of landscape fragmentation in the Bellanwila Attidiya Wetland. The spatial and temporal analysis reveals that the integrity of wetland has significantly declined during the 29 year period, and it is mainly related to anthropogenic pressure.

The wetland in 1995 was defined by a very large and integrated core area. Non-wetland land cover classes such as built-up and open areas were also present but represented a small percentage of the landscape, occurring as an isolated inclusion within the prevailing wetland matrix. This structure implied highly functional and structurally strong ecosystem.

The landscape structure had been significantly changed by 2024. A significant portion of the wetland cover that was previously large has been broken up and the landscape now comprises of isolated wetland areas that are now embedded

into a dominant matrix of non-wetlands. The increase in these non-wetland lands, especially the built-up lands, is a clear sign of the increasing urbanization.

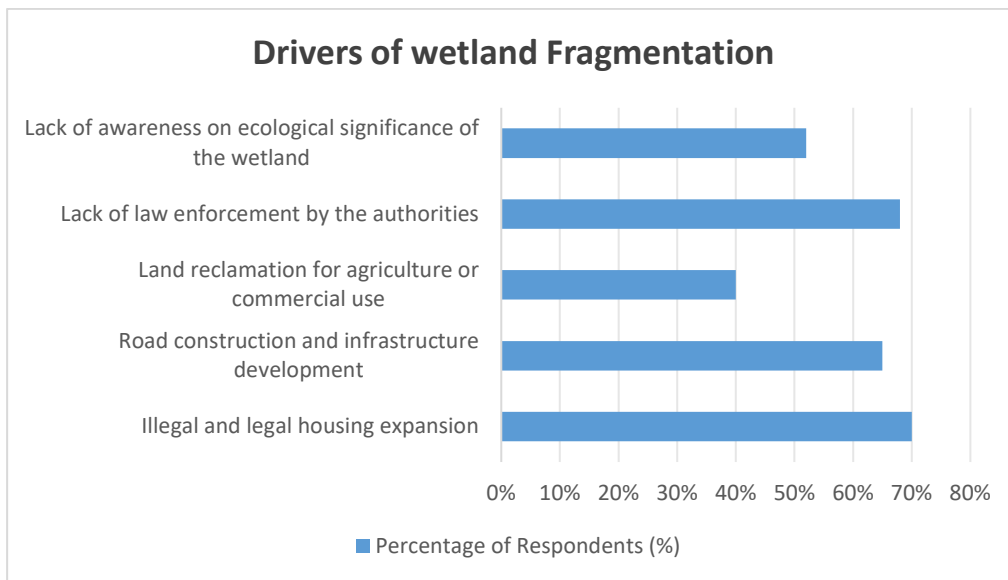
Table 3: Calculation of fragmentation indices for Bellanwila Attidiya Wetland

Year	Number of Patches	Patch Density	Mean Patch Area (sqm.)	Edge Density
1995	16	0.000004192	139556.25	0.008032697
2011	28	0.000009533	48310.71	0.004109195
2024	141	0.000036784	10288.65	0.01343525

Source: Compiled by the author

According to Table 3, number of wetland patches increased from 16 in 1995 to 28 in 2011, and further to 141 in 2024. This represents an increase of 75% between 1995 and 2011, and a dramatic 403.6% increase from 2011 to 2024 which indicates a significant level of fragmentation. The increase in patch density also suggested a high number of wetland patches per unit of area meaning that contiguous wetland cover of Bellanwila Attidiya wetland has been significantly fragmented by 2024. The 65.4% reduction of mean patch area between 1995 and 2011, and a further 78.7% decline from 2011 to 2024. The overall reduction of 92.6% across the study period indicates that patches have become progressively smaller and more fragmented. The edge density has been fluctuated during the selected time period. But compared to 1995, edge density has been increased significantly indicating an irregularity of patches, which is consistent with fragmentation processes.

Figure 5: Factors Affecting Sustainability of Ecosystem Services of Urban Wetlands Due to Fragmentation (Based on questionnaire results)



Source: Compiled by the author

The findings of the questionnaire survey identified several socio-economic and institutional forces that led to the fragmentation of wetlands in the Bellanwila Attidiya Wetland that ultimately caused the depletion of ecosystem services generated by the Bellanwila Attidiya Wetland as indicated in Figure 5. Both illegal and legal housing expansion was found to be the most important driver among them with 70 percent of them reporting it. This indicates the growing demand of residential land in cities, which results in both legal and illegal activities of encroachment into wetland ecosystems.

Weaknesses in law enforcement by authorities were noted by 68 percent of respondents, which signifies that weak policy implementation have compounded land-use violations. In close association with this, road construction and development of infrastructure was noted by 65 percent of the respondents, which indicated that urban expansion initiatives were directly linked to fragmentation and degradation of wetlands.

Furthermore, 52 percent of the respondents claimed not to be aware of the ecological importance of wetlands, which shows that local communities and stakeholders did not understand the importance of wetlands in offering essential

ecosystem services. Lastly, 40% of the respondents identified land reclamation to farmland or commercial land as a driver, and this represented the reclamation of wetlands to other economic-friendly activities at the cost of the ecological integrity.

Table 4: Correlation analysis of drivers of wetland fragmentation that affect the sustainability of ecosystem services in Bellanwila Attidiya Wetland

Factor	Pearson Correlation (r)
Lack of law enforcement	0.875
Illegal & legal housing expansion	0.884
Road construction & infrastructure	0.884
Lack of ecological awareness	0.844
Land reclamation (agriculture/commercial)	0.605

Source: Compiled by the author

The correlation analysis in Table 4 demonstrates that all identified drivers are positively and significantly correlated ($p < 0.01$) with the loss of ecosystem services in the Bellanwila–Attidiya Wetland. Among these, illegal and legal housing expansion ($r = 0.884$) and road construction and infrastructure development ($r = 0.884$) show the strongest correlations. This indicates that urban development pressures are the most influential factors accelerating wetland fragmentation and the subsequent decline in ecosystem services.

The lack of law enforcement ($r = 0.875$) and lack of ecological awareness ($r = 0.844$) also demonstrate strong correlations. These findings suggest that institutional weaknesses and governance gaps, together with limited public understanding of wetland ecological value, play a critical role in exacerbating degradation.

In contrast, land reclamation for agricultural or commercial use ($r = 0.605$) exhibits a comparatively weaker, yet still significant, correlation. While it is less influential than urban expansion and governance-related factors, its moderate association indicates that agricultural conversion remains a relevant contributor to wetland loss.

Impact of Fragmentation Drivers on Ecosystem Services

The results of the surveys clearly indicated that significant losses of ecosystem services have been caused by wetland fragmentation in Bellanwila Attidiya Wetland. Most respondents (76%), had reported increased frequency of flooding events, which indicates that the loss of wetland connectivity has decreased the natural capacity of the system to control excess water.

On the same note, 67% of respondents came up with a clear observation that water quality has declined significantly in the last decade, which they attribute to the growth of infrastructure and sewage discharge. Consistent with this, a similar percentage (67%) felt that water was much cleaner a decade ago, which further strengthened the notion of increasing levels of water pollution in the wetland among the community. In the interviews, the respondents also indicated that two decades ago, wetlands water was used in activities such as laundry and drinking water to domestic animals. However, it has become almost impossible to utilize the wetland water in such purposes because of the high pollution rates that it has reached.

The respondents also stated how roads and new settlements have dispersed the wetland into smaller and disconnected units of land. They believed that this has destroyed valuable areas which animals used to breed and forage. About 82% of the people surveyed have observed that the number and species of birds have declined while 60% have observed that migratory birds are losing their usual nesting and breeding areas.

Conclusion and recommendations

The results of this research demonstrated that not only has wetland fragmentation decreased the total area of the Bellanwila Attidiya Wetland, but that it has further strained the capacity to deliver essential ecosystem services. Urban expansion, expansion of legal and illegal housing, inadequate implementation of environmental rules have over the years become the most urgent reasons that underlie this shrinkage. The wetland landscape has been transformed by these forces, fragmenting habitats into smaller and less interconnected pieces.

These changes are already observable in the decreasing water quality, the increasing number of floods, and the observable depletion of biodiversity. The loss of breeding grounds of birds, loss of vegetation cover and aquatic organisms are signs that there is a serious threat to the long-term sustainability of this wetland. When such trends persist, the capacity of the wetland in controlling floods, filtering water and sustaining wildlife will be greatly compromised.

A number of measures are suggested to deal with these challenges. Existing environmental laws need to be more vigorously enforced to prevent the illegal encroachments and limit the harmful changes to the land use. The conservation of wetlands should also be included in the urban development plans, and planning authorities must ensure that the emerging development does not work against the health of the environment. Also, the role of the community is critical in creating ecological awareness among the local population would foster a more responsible utilization of the wetland resources. To restore ecological balance, restoration programs, like planting native vegetation, creating buffer strips and better water management would be useful.

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