

Assessing the Impacts of Urbanisation on Land Use Changes and Avian Fauna in Wetlands of Tamil Nadu, India

Evaluación de los Impactos de la Urbanización en los Cambios de Uso del Suelo y la Fauna Aviar en los Humedales de Tamil Nadu, India

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Abstract

Wetlands are vital ecosystems that sustain diverse biodiversity, offering crucial resources like water, food, and habitats for numerous species. However, rapid urbanization and associated human activities have led to significant wetland degradation and loss, particularly in Tamil Nadu, India. Their integration aids in maintaining the food chain and ecological balance. However, rapid urbanization and human activities are causing significant degradation and loss of wetland areas. This study uniquely integrates decade-long satellite-based LULC and NDVI analyses with migratory bird census data to reveal how urbanization, pollution, and land use changes have directly degraded the Karaivetti Bird Sanctuary's wetland habitat and caused a sharp decline in bird populations. By precisely linking environmental changes to biodiversity loss, it provides novel, data-driven insights and practical conservation recommendations, offering a valuable model for wetland management and biodiversity protection in rapidly developing regions. The study employed Land Use Land

Cover (LULC) analysis and satellite imagery to monitor changes in wetlands from 2013 to 2023. The findings of the present research indicated substantial reductions in vegetation cover and water quality due to industrial discharges, sewage, and agricultural runoff. These alterations have negatively impacted habitats, resulting in a decrease in migratory bird visits and overall biodiversity. Wetlands provide invaluable ecological services and support rich biodiversity. The degradation of these ecosystems due to anthropogenic activities threatens the species that rely on them. The present research recommends the minimization of fishing activities during migratory seasons, establishing silent zones to reduce disturbances, and enforcing stringent measures against illegal dumping of construction debris. Henceforth, implementation of these measures aids in mitigating the adverse impacts on wetlands and promotes the sustainability of these essential ecosystems.

Keywords: Wetlands, LULC, Karaivetti, Vegetation cover, Migratory bird, Anthropogenic, Ecosystem

JEL code: R0 General, Q0 General

Resumen

Los humedales son ecosistemas vitales que sustentan una biodiversidad diversa y ofrecen recursos cruciales como agua, alimentos y hábitats para numerosas especies. Su integración ayuda a mantener la cadena alimentaria y el equilibrio ecológico. Sin embargo, la rápida urbanización y las actividades humanas están causando una degradación y pérdida significativa de áreas de humedales. Esto es particularmente evidente en la disminución de las poblaciones de aves en santuarios como Karaivetti, atribuida a los escombros de la construcción, el aumento de los asentamientos humanos y las perturbaciones del tráfico vehicular y las actividades pesqueras. El estudio empleó el análisis de la cobertura del suelo y el uso del suelo (LULC) e imágenes satelitales para monitorear los cambios en los humedales de 2013 a 2023. Los hallazgos de la presente investigación indicaron reducciones sustanciales en la cobertura vegetal y la calidad del agua debido a los vertidos industriales, las aguas residuales y la escorrentía agrícola. Estas alteraciones han afectado negativamente a los hábitats, lo que ha dado como resultado una disminución de las visitas de aves migratorias y de la biodiversidad en general. Los humedales brindan servicios ecológicos invaluable y sustentan una rica biodiversidad. La degradación de estos ecosistemas debido a actividades antropogénicas amenaza a las especies que dependen de ellos. Se requieren acciones inmediatas para lograr estrategias de gestión y conservación efectivas para proteger y restaurar los hábitats de humedales. La presente investigación recomienda minimizar las actividades pesqueras durante las temporadas migratorias, establecer zonas silenciosas para reducir las perturbaciones y aplicar medidas estrictas contra el vertido ilegal de escombros de construcción. De ahora en adelante, la implementación de estas medidas ayuda a mitigar los impactos adversos sobre los humedales y promueve la sostenibilidad de estos ecosistemas esenciales.

Palabras clave: Humedales, LULC, Karaivetti, Cobertura vegetal, Aves migratorias, Antropogénico, Ecosistema

Código JEL: R0 General, Q0 General

1. INTRODUCTION

Freshwater wetlands cover more than 8% of the Earth's land surface (Dayathilake et al., 2021) and are recognized as keystone ecosystems due to their disproportionate impact on landscape processes relative to their area (PA, 2009). These wetlands offer a wide array of ecosystem services, including flood control, water purification, carbon sequestration (Lu & Xiao, 2024), and support for a diverse range of plants and animals (Balwan & Kour, 2021). Their ecological functions are crucial for regulating the ecological balance and maintaining biodiversity, as they provide essential habitat, food, shelter, and water for numerous species (Jisha & Puthur, 2021; Rijal et al., 2021). High

biodiversity within freshwater wetlands enhances the stability of these functions, supporting nutrient cycling and resilience against external disturbances (Nayak & Bhushan, 2022).

Despite their immense value, wetlands are experiencing significant decline (Dayathilake et al., 2021). Globally, as much as 87% of wetlands have been lost over the past 300 years, with much of this loss occurring since 1900, primarily due to changes in climate and land use, including urbanization and infrastructural development (Davidson, 2014). In the United States, wetland area depreciation is largely attributed to these factors (Davidson, 2014). The ecological consequences of these changes can be measured using specialized tools, which help generate long-term, large-scale, and comprehensive assessments of wetland health and function (Demarquet et al., 2023; Salimi et al., 2021).

Bird migration is closely tied to the seasonal availability of food resources in wetlands, with birds making round trips between nesting and resting areas (Barik et al., 2022; Bathrick et al., 2024; Smetzer et al., 2021). Migratory birds positively influence ecosystem health (Faaborg et al., 2010; Schmaljohann et al., 2022), but their populations are rapidly declining due to habitat loss, reduction in food sources, and loss of nesting sites often linked to urban expansion and modern architecture (Seress & Liker, 2015; Yong et al., 2021). Changes in land use and land cover driven by infrastructural development reduce available habitats, impacting bird nesting and feeding grounds (Bhatta, 2023; James Reynolds et al., 2019; Xu et al., 2018). This habitat loss leads to fewer bird visitations and population declines, forcing birds to adapt to new migratory locations, which introduces additional threats (Dawson-Scully, 2024; Radić & Gavrilovic, 2021).

The Karaivetti Bird Sanctuary exemplifies these challenges. Known for its rich diversity of ducks, waders, swimmers, divers, migrants, and endangered species, the sanctuary has recently seen a decline in migratory bird numbers due to land area changes caused by Public Works Department operations (Baranidharan et al., 2024; Satheesh et al., 2024). These modifications disrupt the delicate ecosystem balance, resulting in habitat degradation that adversely affects avian populations (Gokula, 2013).

The Karaivetti Bird Sanctuary is a 4.537 sq. km protected area. It is located at Karaivetti village in the Ariyalur District of Tamil Nadu, South India (Pradeepkumar et al., 2015). It was established on April 5, 1999. Additionally, it is one of Tamil Nadu's biggest freshwater lakes, located in the south (Salahudeen et al., 2013). It is known to be the habitat for at least 188 species of birds. International recognition comes from Karaivetti Wildlife Sanctuary. Karaivetti, which benefits from water derived from the Kaveri River and rainwater through the Pullambadi-Kattalai canal, lies approximately 50 km northeast of Tiruchchirappalli town. Also, it is the district's largest water body and receives half a million bird visitors annually. The government of Tamil Nadu declared it as a bird sanctuary in 1999 because it holds importance as a habitat for a large variety of birds. The lake has the capacity to hold water up to an average depth of three meters when it is full. A total of 188 species of birds has been found to inhabit the sanctuary, of which 82 are water birds. For water birds on migration, the sanctuary is one of the most important freshwater feeding sites.

The study aims to investigate the causes of this decline with the following objectives:

- To measure land use and land cover (LULC) changes in the Karaivetti wetland region between 2013 and 2023 based on satellite images and remote sensing methods.
- To determine trends in migratory and resident bird populations in the Karaivetti Bird Sanctuary between the same years based on census data.
- To examine the interconnection between LULC change, vegetation cover (NDVI), and avian population dynamics.
- To assess the influence of factors associated with urbanisation (e.g., pollution, development, human disturbance) on the quality of wetland habitat and avian diversity.
- To offer pragmatic conservation measures oriented towards compensating for the negative impacts of urbanisation and enhancing the sustainability of wetland ecosystems and associated avian fauna.

On the basis of the above discussion, the present research has formulated the following research questions:

1. What is the demographic status of the migrating bird populace in Karaivetti Bird Sanctuary?
2. What patterns have arisen in the populations of migratory birds over the past decade in the bird sanctuary?
3. What are the broader implications of the transformation of land use and cover on the avian populace in Tamil Nadu?
4. How does the variation in vegetation influence the habitat preference of migratory birds?

The research hypotheses are as follows:

Rapid urbanisation and associated land use changes in and around the Karaivetti Bird Sanctuary have led to significant degradation of wetland habitats, resulting in a measurable decline in avian diversity and migratory bird populations over the past decade.

The significance of the research lies in the crucial examination of the impact of land use changes and urbanization on wetlands. It focuses on the avian populace in India. The factors contributing to the decline of bird populations are essential for the conservation of biodiversity and monitoring of ecological health (Fraixedas et al., 2020). Thereafter, the study intends to suggest the targeted conservation measures that counteract the negative effects on the habitats that are beneficial to both the local people and wildlife dependent on the wetland resources. In examining the particular reasons for the reduction of the avian population, the study research intends to provide actionable information that can inform effective management practices. The current study seeks to heighten awareness towards the importance of wetlands among local communities, policymakers, and conservationists. It encourages the decision-making process that reconciles urban landscape development with ecological integrity.

Therefore, this study seeks to comprehend why bird populations are decreasing and to develop protective measures to lessen the effects of environmental and infrastructure changes.

The rest of the paper is organized as follows: The second section describes the research design with detailed descriptions of methods for LULC classification, NDVI analysis, and bird census data collection. The third section communicates the findings related to land use changes, vegetation cover changes, and the avian population trends for the study period. The fourth section interprets these results with reference to the literature, revealing the intricate interactions between urbanization, wetland degradation, and biodiversity loss. Section 5 talks about the study limitations and the potential practical and theoretical implications of the findings. The article ends with a declaration section and thorough references that back up the research framework and the authors' interpretations.

2. MATERIALS AND METHODS

2.1 Research design

The LULC pattern and land use and cover pattern for the periods 2013, 2016, 2018, 2020, and 2023 were evaluated using satellite data from Landsat 8-9 Operational Land Imager (OLI) and Thermal Infrared (TIRS). Then the datasets of Landsat MSS, TM, and OLI (USGS Earth Explorer) were used to examine the LULC (Islam et al., 2021). Satellite images showing vegetation coverage in the designated wetlands across various years were gathered from Google Earth Pro. The study area is the Karaivetti Bird Sanctuary (10°59'N, 79°14'E), located in Karaivetti village, Ariyalur District, Tamil Nadu, India, covering 4.537 km². All satellite images were selected for the post-monsoon season (December–February) to minimize seasonal variation.

2.2 Land use and land cover classification (LULC)

The land use pattern was categorized into dense vegetation, wetlands, buildings, less vegetation, and dry land (Table 1) (Sarkar & Maji, 2022). The supervised Maximum-likelihood classifier

technique was utilized for the identification of LULC changes throughout the study period. ERDAS Imagine software was utilized for image processing of Landsat TM images. Multi-temporal Landsat satellite data were utilized for LULC changes assessment. The NDVI is a dominant remote sensing method used to illustrate the vegetation features in a region (Jin et al., 2024; Rouse Jr et al., 1973; Tucker et al., 1985). The ratio of the difference between spectral bands responsive to the spectral features gives a single value that is the index (1). By adding the initial value of NDVI, a multiplication by 10,000, and their rounding, numbers were converted into an integer scale of 0–20,000 for deleting the wrong numbers and thus transforming them into unsigned integers up to the hundredths place accurately. These transformed units of NDVI are applied during the computation as well as in the output of the original model of regression.

The transformed NDVI units will be represented as NDVIT.

$$NDVI = (Band4 - Band5)/(Band4 + Band5) \quad \text{Eq. (S1)}$$

The precision of the classified images was estimated with ground truth data. Measures were user's accuracy (Eq. S2), producer's accuracy (Eq. S3), overall accuracy (Eq. S4), and kappa coefficient (Eq. S5). The adjustments in the image analysis according to the precision were conducted as outlined in the schematic representation (Figure 1).

For each year, a minimum of 50 training polygons per class were selected using field GPS points and high-resolution Google Earth imagery. Validation was performed with at least 200 random points (40 per class) per classified map, cross-checked with field data and high-resolution imagery.

$$Users\ Accuracy = \frac{(Number\ of\ correctly\ classified\ pixels\ in\ each\ category)}{Total\ number\ of\ classified\ pixels\ in\ that\ category} * 100$$

Eq. (S2)

In the user accuracy, the total number of classified pixels is the summation of the rows.

$$Producer\ Accuracy = \frac{(Number\ of\ correctly\ classified\ pixels\ in\ each\ category)}{Total\ number\ of\ reference\ pixels\ in\ that\ category} * 100$$

Eq. (S3)

In producer accuracy, the total number of reference pixels refers to the summation of columns.

$$Overall\ Accuracy = \frac{(Total\ number\ of\ correctly\ classified\ pixels)}{Total\ number\ of\ reference\ pixels} * 100$$

Eq. (S4)

In overall accuracy, the diagonal values are added for the total number of correctly classified pixels.

$$Kappa\ coefficient\ (T) = \frac{((TS \times TCS) - \sum[(Column\ total \times Row\ total)])}{(TS^2 - \sum[(Column\ total \times Row\ total)])} \times 100$$

Eq. (S5)

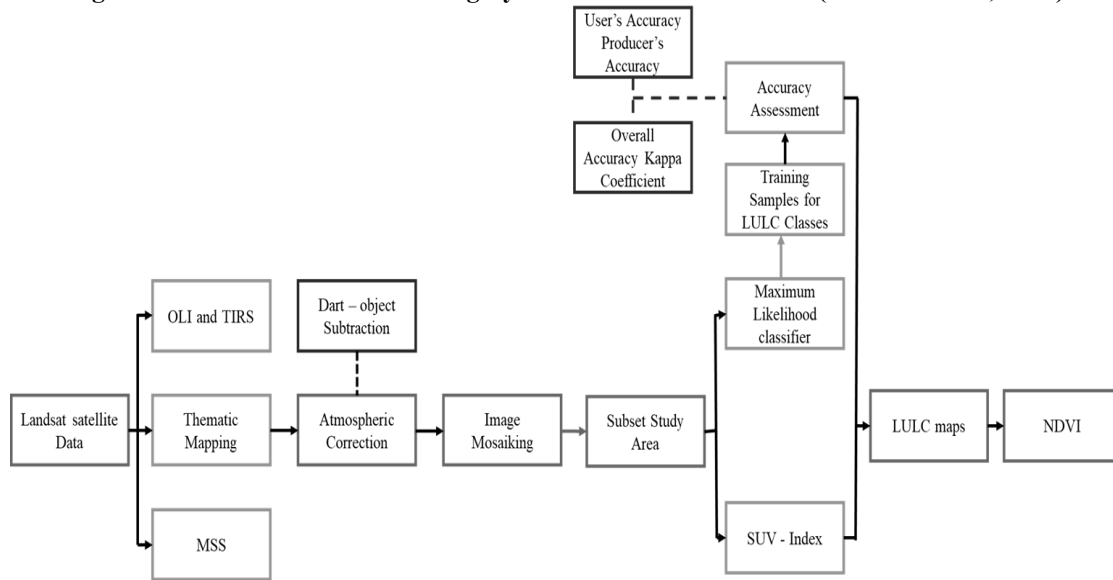
Table 1. Classification Scheme (Camilleri et al., 2017; Deb & Nathr, 2012).

ID	Land use/land cover	Description
1	Dense vegetation	The areas with natural vegetation cover in the form of herbs, shrubs, grassland, trees, and other plants.
2	Wetlands	It comprises all forms of surface water present in drains, canals, ponds, lakes, and wetlands.
3	Less	It consists of cultivated and non-cultivated areas.
4	Dry land	It contains the land left with no vegetation and harsh terrain with poor moisture.
5	Buildings	Areas of constructed land.

2.3 Bird census

Bird surveys were undertaken during the Northeast monsoon (October-December) and winter months (January-February) of 2023. Counts were done during morning hours (6:00 to 10:00 AM GMT+5:30) so that there was no two-fold counting. Point counts were done by counting all birds observed by sight and hearing from a fixed point for a particular duration. Bird tally at 6 observation points with binoculars and cameras. Species identification and foraging habitat were noted on the Asian Water Bird Census (AWC) form. Aquatic birds were counted during morning and evening sessions at 6 locations, each for 15 minutes. Forest Survey of wetland migratory birds’ data was used for interpretation and cross-verification.

Figure 1 Flow chart of satellite imagery to obtain the NDVI index (Essaadia et al., 2022)



Each of the 6 observation points was georeferenced using GPS (coordinates provided in Supplementary Table 1). A minimum of three trained observers participated in each survey session. Sample sizes per survey ranged from 1,615 to 10,943 individual birds, depending on the year. Historical census data from 2013, 2016, 2018, and 2020 were also included for trend analysis.

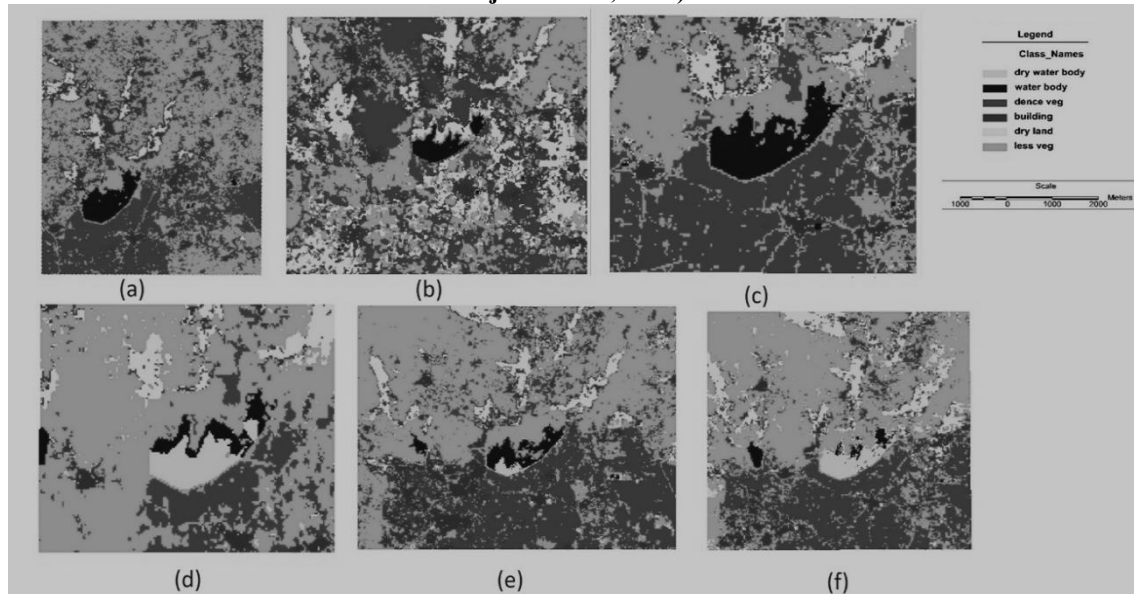
3. RESULTS

The LULC change has been observed in wetlands from 2013 to 2023. Each wetland region has been categorized into five LULC classes: building, wetland, dense vegetation, less vegetation, and dry land.

3.1 Classification accuracy assessment

Accuracy analysis is very important in image classification for the verification of LULC. Many pixels are still wrongly classified in MLS because the data is not evenly distributed. Accuracy assessment was carried out by summarizing and quantifying the data through the use of an error matrix. The accuracy results were obtained, including producer accuracy, user accuracy, overall accuracy, and the kappa coefficient index. It is being tested m overall accuracy to come up with the accurate result for the classification accuracy. Therefore, the overall for accuracy was determined for satellite images of Karaivetti Lake in 2013, 2016, 2018, 2020, 2021, and 2023 and is reported as 85%, 85%, 90%, 95.83%, 91.6%, and 87.5%, respectively, with kappa statistics of 75%, 86.36%, 87.5%, 95%, 89.91%, and 85%, respectively.

Figure 2 Vegetation, water body, density, dry lands and building at Karaivetti bird sanctuary and nearby area in 2013 (a), 2016 (b), 2018 (c), 2020 (d), 2021 (e) and 2023 (f) (Sivasubramaniyan & RajaPerumal, 2024)

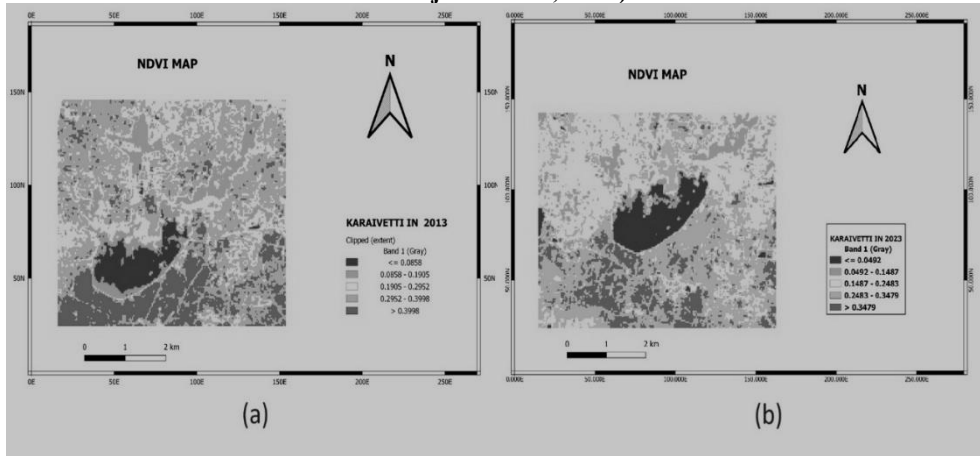


The overall evaluation outcomes of each classified image from 2013 to 2023 for the vegetation, water body, density, dry lands, and building at Karaivetti Bird Sanctuary are shown in Figure 2. The LULC maps clearly demonstrate a marked reduction in wetland and dense vegetation areas between 2013 and 2023. Built-up areas and dry land have expanded, particularly along the sanctuary's boundary and near access roads. For instance, the northwestern and southeastern edges show the most pronounced urban encroachment. This spatial pattern highlights the direct impact of urban expansion on natural habitats and supports the quantitative findings of wetland and vegetation loss. The visual progression across the years provides compelling evidence of habitat fragmentation and landscape transformation.

3.2 Normalised differential vegetation index

The result of the NDVI assessment communicated that the wetlands were exposed to significant alterations in the vegetation indices that affect their ecosystem and habitat. NDVI values of research areas indicate unstable water availability. In addition, the presence of water raises them, but their superiority starts to decline because of the industrial effluents, release of sewage water, and construction waste. It severely affects the vegetation cover. The NDVI maps (Figure 3) and time-series plots reveal a consistent decline in overall vegetation health from 2013 to 2023. Average NDVI values dropped from approximately 0.65 in 2013 to 0.38 in 2023, indicating a substantial reduction in healthy green vegetation. Areas with NDVI below 0.2, representing degraded or barren zones, have increased, especially in the southern and central wetland regions. This trend is closely associated with increased anthropogenic disturbance, such as construction, effluent discharge, and agricultural runoff. The correlation between NDVI decline and LULC change underscores the loss of productive habitat for avian fauna.

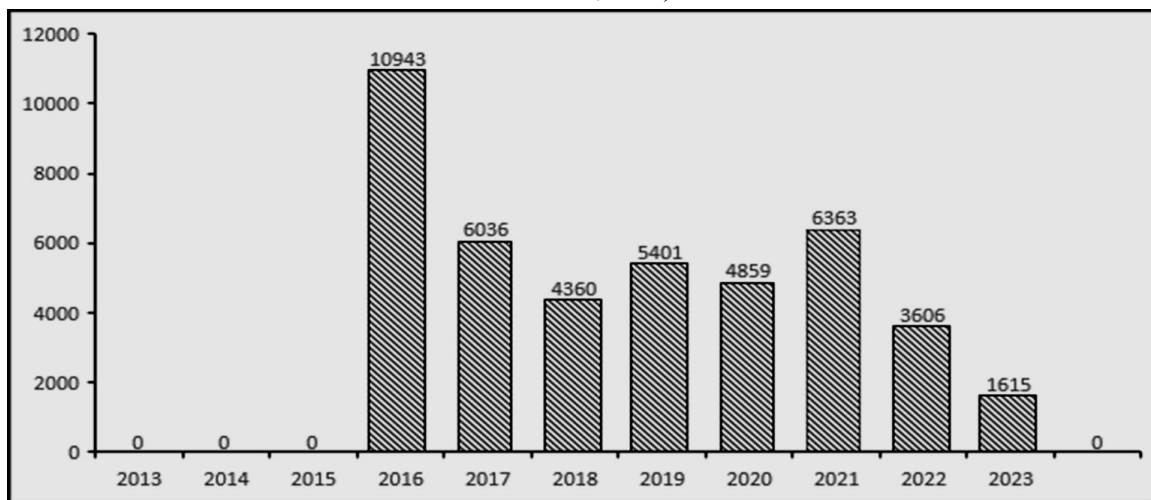
Figure 3 NDVI Map of Karaivetti Bird Sanctuary in 2013 (a) and 2023 (b) (Sivasubramaniyan & RajaPerumal, 2024)



3.3 Avian fauna population

The number of migrating birds in the Karaivetti bird sanctuary has reduced in comparison to prior years, and some of the species are not being visited. In 2016, there were 10,943 birds recorded, and in 2023, the number was just 1,615. The glossy ibis' black-winged stilt population is drastically declining. Greenshank, Bar-headed Goose, Spoonbill, and a few other birds have not been observed. The total number of migratory birds visiting the bird sanctuary is shown in Figure 4.

Figure 4 Total number of Migratory Birds observed in the year of 2013-2023 (Gokula, 2013; Shree & Malathi, 2024)



The research location has been recorded as having intensive use of farmlands and the excessive discharge of industrial and sewer waste. Land use and land cover were manifested through processed satellite images of the research site. These classificatory pictures refine the awareness regarding the LULC pattern for the study location. The study shows that the unregulated and ongoing process of land use pattern expansion occurs here. The data obtained revealed that there was a rapid contamination of the wetlands as well as excessive use of synthetic chemicals in agricultural processes that might hurt the environment and affect public health.

Availability of water and the natural vegetation cover on the ground influence the expansion of new areas of agriculture and the rate at which birds visit. However, the decline in water availability and unplanned agricultural practices can affect the aesthetic value of the natural environment and contribute to desertification and soil degradation, thereby reducing biodiversity and bird migration.

There are rising and falling trends in the overall variation in each variable's occurrence in wetland areas. The classified images of the whole study area indicate a significant change that implies a concealed decrease over the last ten years for all the investigated classes: wetland, dense vegetation, sparse vegetation, buildings, and dry land. The spatial overlap between areas of greatest LULC change and key bird habitats highlights the direct ecological consequences of land transformation. The data strongly suggest that anthropogenic activities are the primary driver of these negative trends.

Similarly, the connection between vegetation and temperature was examined through NDVI data from 2013 to 2023. The resulting LULC maps showed a reduction in vegetation during the examined timeframe. This notable reduction in plant life is linked to the over-release of industrial, municipal, and agricultural substances, which also impacts the accessibility of plant habitats near the wetland. The periods before and after the monsoon are typically when there is an increased availability of water. The region under investigation is, in several respects, facing similar environmental issues that have ravaged the wetland's natural allure.

The research argues that the inflow of wastewater from domestic, commercial, and saline seepage into the wetlands was the primary reason for the decreased water quality. The study implies that the key causes of the drop in water quality were attributed to the release of effluents from industrial, domestic, agricultural, and saline discharges into the wetlands. The findings gathered indicated that this vital resource has disappeared due to poor management and human activities that have significantly affected the natural biodiversity habitat, leading to a reduction in migratory bird visits. The PWD development on the plant cover and arid lands around the water body has resulted in a reduction in natural vegetation cover within the lake boundaries. This leads to the modification of natural wetlands, resulting in vegetation losing the necessary habitat and environment for bird populations.

4. DISCUSSION

Wetlands are essential in ensuring ecological stability and hosting diversity in wildlife, as emphasized by (Dayathilake et al., 2021) and (Lu & Xiao, 2024). The current research illustrates the immense reduction in wetland cover and bird population at Karaivetti Bird Sanctuary during the last decade, a pattern that is congruent with global and regional studies of wetland depletion (Davidson, 2014). The declining wetland and dense vegetation cover, coupled with expanding built-up and dry land, mirrors the trends of land use change documented for other fast-growing urbanizing areas in South Asia (Islam et al., 2021). Spatial analysis registers the worst encroachment along the periphery of the sanctuary, especially in the northwestern and southeastern areas. This is in agreement with Bhatta (2023), who opined that peripheral urban expansion is one of the main causes of habitat fragmentation of Indian wetlands. The reduction of average NDVI values between 2013 and 2023, as was found in this research, is reflective of decreased vegetation quality and concurs with (Barik, Saha, & Mazumdar, 2022), who attributed NDVI reduction to pollution, development, and agricultural runoff in Indian wetlands.

A steep decline in Karaivetti migratory birds from 10,943 in 2016 to 1,615 in 2023 is a reflection of the worldwide trend in declining wetland-dependent bird species (Fraixedas et al., 2020). The incorporation of LULC and NDVI trends into the study and avian census data furnish unequivocal proof of land use change influencing bird populations. Habitat specialist and migratory birds, like the glossy ibis and bar-headed goose, have shown the most severe declines, while generalist species remain present. This makes sense with the findings of Dawson-Scully (2024) and (Seress & Liker, 2015), who highlighted the susceptibility of habitat specialists to habitat destruction driven by urbanization.

Whereas (Barik, Saha, & Mazumdar, 2022) discovered that habitat heterogeneity is able to cushion some of the effects of land use change, the Karaivetti data indicate that the magnitude and extent of urban encroachment have surpassed the ability of habitat heterogeneity to sustain avian diversity. The concurrent loss of vegetation cover and water quality decline due to industrial and agricultural effluents has lowered the availability and quality of feeding and nesting sites, in agreement with Gokula (2013) and (Satheesh, Baranidharan, Krishnamoorthi, Vijayabhama, & Mugilan, 2024).

Moreover, certain local stressors like illicit dumping of construction waste, intensified fishing activity during the migration periods, and vehicular disturbance have been found to play a prominent role in habitat degradation. These observations concur with (Gokula, 2013), who pinned down uncontrolled human activities as driving wetland degradation in South India.

The findings indicate that site-specific management interventions may be efficient. Policies like banning fishing during migration seasons, providing silent zones, and having anti-dumping laws are feasible and can be easily implemented. Such a method aligns with the pragmatic conservation suggestions discussed by (Sarkar & Maji, 2022). By integrating multi-temporal remote sensing (NDVI and LULC) and field-based bird census data, this research enhances the causal association between land use alteration and biodiversity decline. This interdisciplinary approach improves over past descriptive research by adding quantitative, spatially-explicit proof of ecosystem degradation (Demarquet et al., 2023; Salimi et al., 2021).

5. CONCLUSION

The primary purpose of this research was to find out how urbanization influenced land use changes and bird fauna within the Karaivetti Bird Sanctuary. A 10-year study involving satellite-based LULC, NDVI data, and bird population censuses helped us to comprehend the environmental degradation and its direct impact on biodiversity. Our research hypothesis is supported by the findings as it is shown that rapid urbanization together with associated anthropogenic activities has resulted in wetland habitat degradation to an extent that can be measured and a decline in avian diversity has occurred. The major changes illustrate that the wetland area and dense vegetation cover have been significantly reduced, the built-up and dry land have been simultaneously increased, and the decline of vegetation health, as shown by NDVI values, has been very obvious. The changes in the environment have led directly to a substantial decrease in the migratory bird population by 85% between 2016 and 2023, and several species have stopped visiting the sanctuary entirely. Among the factors causing these effects are industrial effluents, sewage discharge, agricultural runoff, illegal dumping of construction debris, and increased human disturbance from traffic and fishing activities. This decline in the bird population has far-reaching effects that not only threaten the sanctuaries but also put the regional ecological stability and biodiversity at risk. To counterbalance these detrimental effects and maintain the vitality of this tightly-knit ecosystem, we suggest the introduction of focused conservation measures such as the reduction of fishing activities during the migratory seasons, the creation of silent zones for disturbance abatement, and the enforcement of strict measures against illegal dumping. This research is an essential, data-driven example of the necessity of careful wetland management in areas undergoing rapid urbanization. It clearly points out that there is an urgent need to strike a balance between urban development and ecological preservation if we want to conserve these priceless ecosystems for the future.

5.1 Practical implications

There is an immediate requirement for specific conservation tactics, such as creating quiet areas during migration periods and enforcing stricter rules against unlawful dumping. These actions can significantly reduce the negative effects on wetland environments and aid in the recovery of biodiversity. Decision-makers have the ability to utilize the data from this research to create long-term land-use policies that integrate wetland preservation, such that these vital environments are protected against urban growth. Engaging with local communities is also essential; by instilling a sense of ownership and responsibility towards wetland conservation, stakeholders can enhance the success of such efforts. Additionally, public awareness-raising campaigns can educate communities regarding the importance of wetlands and the consequences of their degradation and encourage sustainable ways that benefit the environment and regional economies.

5.2 Theoretical implications

The current research serves to create a link between ecosystem service degradation and the loss of biodiversity, highlighting the need for healthy wetlands in ensuring ecological balance and facilitating different species. This study further adds to current knowledge regarding urbanisation influence on natural ecosystems through the provision of empirical data that can be used to inform future studies into similar trends within other regions. The findings recommend a multidisciplinary strategy in the study of wetland health by bringing together ecological, sociological, and economic perspectives to develop more comprehensive models. Lastly, the research underscores the necessity for long-term studies in order to understand better the current changes in wetland ecosystems over a period of time, stressing the significance of considering the long-term impacts of conservation activities and urbanization on wetland health and diversity.

5.3 Limitations

The present research study only covers a short time frame from 2013 to 2023, which may not capture long-term ecological patterns. Additionally, the focus is mainly on specific wetland areas like Karaivetti, which could restrict the applicability of the results to other regions facing different environmental challenges. In addition, though the study focuses on migratory bird populations, it fails to provide a complete analysis of other species residing in these wetlands and may miss general biodiversity shifts. Assessing human activities influencing wetlands is complex because there are local practice variations and socioeconomic determinants not extensively investigated. Although the analysis is restricted, the study provides useful data regarding wetland degradation and its influence on biodiversity.

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