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Function to Flux: Assessing Ecosystem Services and Change Drivers at Najafgarh Wetland

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Abstract **Original Research Article**

The Najafgarh Wetland, a vast transboundary waterbody located along the Delhi–Haryana border, represents one of the most dynamic urban wetlands in northern India, currently undergoing rapid ecological and socio-spatial transformation. This study assesses its evolving ecosystem services and identifies the natural and anthropogenic drivers influencing its transition from a functional wetland to one under flux. Using the Function–Flux–Driver (FFD) framework, the wetland is interpreted as a socio-ecological system undergoing adaptive reorganization under sustained anthropogenic and institutional pressures. The research is based on a mixed-methods approach combining field-based observations, structured household surveys of 748 respondents, and institutional interviews. Findings show that while Najafgarh continues to perform key hydrological functions such as flood regulation, groundwater recharge, and microclimate moderation, its ecological balance is severely compromised. The wetland's hydrology has shifted from rainfall-driven to being sustained by 350–864 MLD of urban wastewater, resulting in eutrophication, weed proliferation, and oxygen depletion. Despite these trends, 99.5% of respondents perceived biodiversity to have increased, reflecting a major perception gap between ecological reality and visual appearance. Fragmented governance between Delhi and Haryana has emerged as the principal driver of this decline, producing an "institutional vacuum" that has stalled notification, weakened enforcement, and allowed unchecked pollution and encroachment. The study concludes that the degradation of Najafgarh is less an ecological inevitability than a governance failure. It proposes an adaptive co-management approach integrating legal clarity, pollution control, participatory governance, and livelihood inclusion. This framework offers a pathway for transforming Najafgarh from a flux-driven, degraded ecosystem into a resilient urban wetland capable of sustaining both ecological functions and community well-being.

Keywords: Najafgarh Wetland; Ecosystem Services; Urban Wetland Dynamics; Change Drivers; Sustainable Wetland Management.

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1. INTRODUCTION

Urban wetlands are dynamic socio-ecological systems that perform very crucial ecological, hydrological, and socio-cultural functions essential for sustaining life in rapidly urbanizing regions. They regulate local microclimates and recharge groundwater, store carbon, and filter out pollutants while providing recreational, spiritual, and aesthetic benefits contributing to community well-being (Millenium Ecosystem Assessment [MEA], 2005; Mitsch & Gosselink, 2015). In this sense, wetlands act like natural infrastructure, buffering cities from hydrological extremes and ecological degradation (Alikhani *et al.,* 2021). Yet, with the intensification of urban growth, the sustainability of these multifunctional landscapes is increasingly challenged.

Urbanization represents one of the most powerful agents of wetland transformation. The transformation of floodplains and lowlands into built-up areas disrupts natural hydrological regimes, fragments habitats and reduces infiltration capacity (Seto *et al.,* 2012; Grimm *et al.,* 2008). Other structural changes include embankments, drainage channels, and flood-control structures that simplify the flow dynamics and reduce habitat diversity, weakening ecosystem resilience (Zedler & Kercher, 2005). The results of these changes are sometimes paradoxical i.e. flooding in local areas during heavy rainfall alongside long-lasting post-

monsoon aridification, which jeopardizes the persistence of both ecological and socio-economic systems dependent on wetlands.

Pollution further catalyzes these changes. Wetlands across many urban basins serve as unintended basins for untreated sewage, nutrient-rich stormwater, and industrial wastes that cause eutrophication, hypoxia, and loss of biodiversity (Paul & Meyer, 2001; Joshi *et al.,* 2021). These inputs degrade water quality, reduce habitat viability, and erode the wetlands' ability to provide regulating services such as purification and nutrient cycling. Meanwhile, climate variability enhances these vulnerabilities through erratic rainfall, evapotranspiration, and temperature extremes that further destabilize seasonal hydrology and accentuate ecosystem stress (Grimm *et al.,* 2008; Mitsch & Gosselink, 2015).

Governance deficiencies often determine the trajectory of urban wetland degradation. Overlapping jurisdictions, inconsistent land-use planning, and weak institutional enforcement result in fragmented management and ineffective restoration (Ramsar Convention Secretariat, 2010; Hobbs *et al.,* 2014). Integrated governance and participatory decision-making are therefore indispensable for any meaningful conservation strategy. Recent approaches emphasize the role of adaptive governance through technology-driven monitoring (such as satellite imagery, IoT sensors), transparency, and community engagement to improve resilience and accountability (Hawkins, 2023; Colding & Barthel, 2019).

Against this backdrop, the Najafgarh Wetland, located at the Delhi–Haryana border, provides a unique opportunity to examine how urban wetlands function as coupled socio-ecological systems experiencing both environmental and institutional flux. Historically a vast seasonal lake connected to the Sahibi River, Najafgarh has evolved into a complex mosaic of marshes, open-water bodies, agricultural patches, and urban fringes (INTACH, 2003; Kumar & Rana, 2021). Its ecological persistence, despite intense human pressure, makes it an ideal site to study the interaction between functions (ecosystem services) and fluxes (drivers of change).

This study takes an integrated Socio-Ecological Systems (SES) perspective, conceptualizing wetlands as dynamic systems dependent upon feedback among ecological processes, human action, and governance structures (Folke *et al.,* 2010). In this context, the study proposes a Function–Flux–Driver (FFD) model, which interprets Najafgarh's transformation as a process of adaptive reorganization under complex stressors such as hydrological, climatic, anthropogenic, and institutional (Mukherjee *et al.,* 2021). The FFD framework allows understanding of how ecological functions emerge, persist, or degrade under interacting forces, and offers a holistic approach for both analysis and policy design.

The research is guided by the central aim of assessing evolving ecosystem services and identifying the main drivers that influence Najafgarh Wetland's functional dynamics. It seeks to fill key knowledge gaps in understanding urban wetland resilience, where rapid land-use change, weak governance, and livelihood dependence intersect. Specifically, it investigates how Najafgarh's hydrological, ecological, and socio-cultural functions have responded to anthropogenic fluxes, and how institutional fragmentation has mediated or magnified these transformations. The study further attempts to conceptualize Najafgarh's transition from a functioning ecosystem to a flux-driven socio-ecological complex and to propose adaptive management strategies to reverse degradation.

Thus, the objectives of this study are threefold. First, to examine the extent and nature of ecosystem services provided by Najafgarh Wetland, including hydrological regulation, biodiversity support, and cultural value through spatial and field-based assessment; Second, to identify and analyze the natural and anthropogenic drivers such as rainfall variability, pollution, land-use conversion, and governance fragmentation, that shape ecological and social outcomes; and third, to create a conceptual and practical management framework grounded in the principles of adaptive governance, resilience thinking, and nature-based solutions (Daily *et al.,* 2009; UNEP, 2024).

By incorporating ecological assessment, community perception, and governance analysis, this paper adds to the growing literature on sustainable urban wetlands and offers an empirical model for understanding how peri-urban ecosystems in India can be managed within a framework of resilience and adaptive policy.

2. STUDY AREA

The Najafgarh Wetland lies along the southwestern boundary of Delhi and the adjacent Gurugram district of Haryana, stretching between 28°30′–28°38′ N and 76°56′–77°05′ E as depicted in Figure 1. It occupies a natural topographic depression that historically formed Najafgarh Jheel, once hydrologically linked to the Sahibi River flowing from the Aravalli hills into the Yamuna (INTACH, 2003; Kumar & Rana, 2021). Over the past century, it has developed into a complex wetland system sustained by seasonal rainfall and inflows via the Najafgarh Drain, which carries both stormwater and untreated wastewater from the Delhi-Gurugram urban corridor.

Hydrologically, the wetland's area varies seasonally, from less than 10 sq. km. in the dry season to over 30 sq. km. during the monsoon depending on

rainfall intensity and the functioning of upstream drainage structures (Bhardwaj *et al.,* 2025). Its dynamic hydroperiod supports critical ecological processes such as flood attenuation, groundwater recharge, and sediment retention (Mitsch & Gosselink, 2015). However, these services are constrained by nutrient enrichment, sedimentation, and impaired hydrological connectivity caused by infrastructural encroachments.

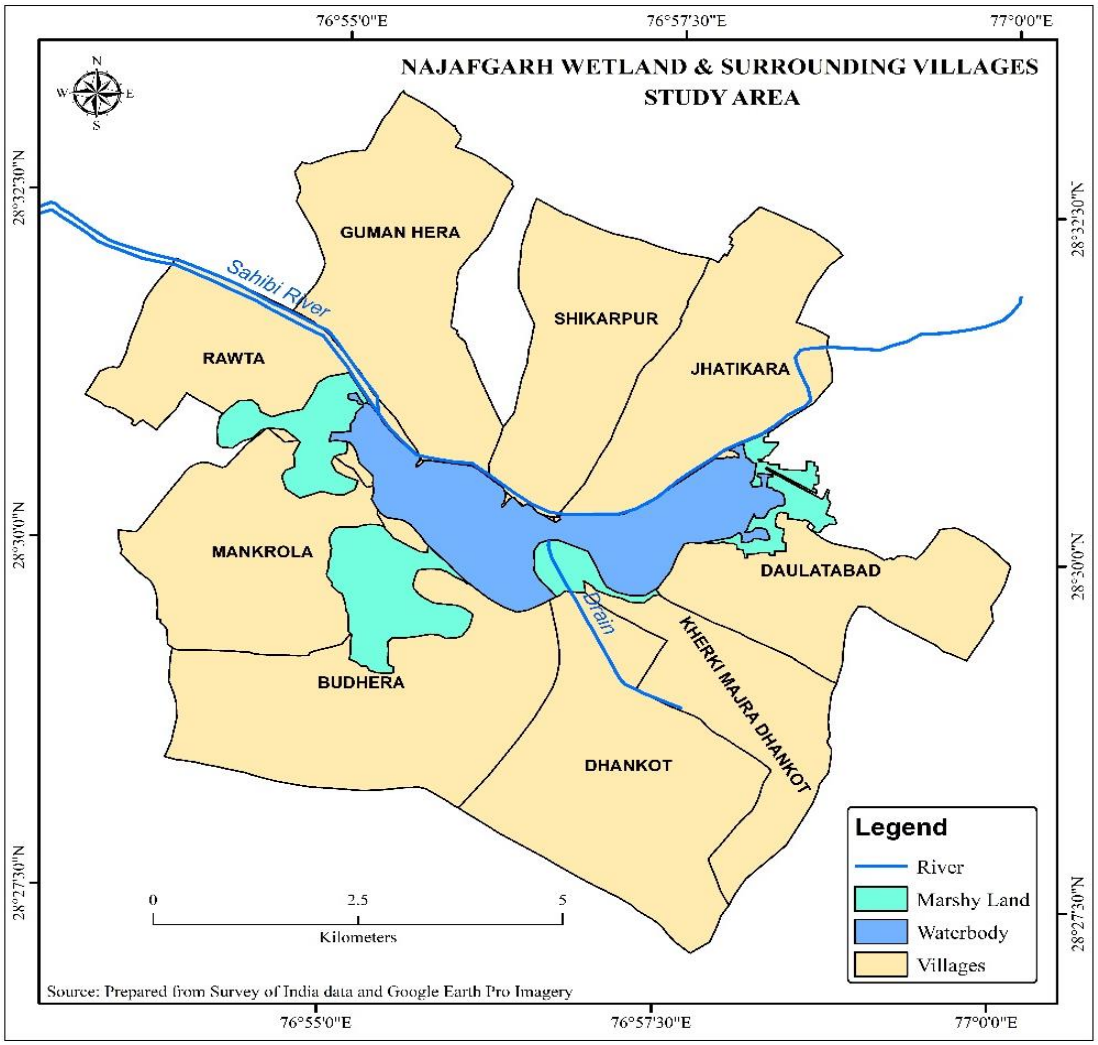


Figure 1: Map of Study Area

Ecologically, Najafgarh supports about 281 avifaunal species, including globally threatened taxa such as the Sarus Crane (*Antigone antigone*) and the Black-necked Stork (*Ephippiorhynchus asiaticus*) (Kumar & Rana, 2021). Common macrophytes like *Typha angustata*, *Phragmites karka*, and *Ipomoea aquatica* improve nutrient uptake but also indicate eutrophication linked to excessive pollutant inflows. The wetland's role as a key stopover along the Central Asian Flyway highlights its regional biodiversity importance (MoEFCC, 2017).

Socio-economically, Najafgarh falls in a peri-urban transition zone where agricultural dependence coexists with rapid real-estate expansion and infrastructural projects (Bhanot & Chatterjee, 2023). Seasonal flooding supports agriculture but also inundates croplands, creating livelihood stresses. Meanwhile, urban encroachment fragments the wetland and weakens ecological resilience. Administratively, governance is split between Delhi and Haryana, resulting in institutional ambiguity about its legal status and management responsibility, a challenge that mirrors the ecological flux shaping the wetland's future.

3. MATERIALS AND METHODS

The study adopted an integrated socio-ecological systems (SES) perspective operationalised through the Function–Flux–Driver (FFD) framework. Within this framework, wetlands are understood as dynamic socio-ecological entities whose ecological functions are shaped by continuous interactions among natural processes, anthropogenic pressures, and governance mechanisms (Folke *et al.,* 2010; Mukherjee *et al.,* 2021). The Najafgarh Wetland, therefore, is examined as a living system where ecosystem functions

such as flood regulation, groundwater recharge, biodiversity support, and cultural value are influenced by fluxes generated through human activity and climatic variability.

These were guided in the methodological design by three interlinked objectives:

- assessment and characterization of ecological and socioeconomic functions of the Najafgarh Wetland;
- to define the natural and human-induced drivers of those functions; and
- to put ecological, social, and institutional perspectives together into a coherent explanatory framework.

Accordingly, the study adopted a mixed-method, multi-scale design that incorporated field-based ecological observation, structured household surveys, institutional interviews, and documentary review.

3.1 Conceptual and Analytical Framework

The framework acts as conceptual and operational scaffolding for the present study. Here, the Function refers to the wetland's ecological and socio-economic services; Flux denotes the hydrological, climatic, and/or anthropogenic processes of change that alter those services; while Driver stands for the land-use policy, governance, and demographic or market dynamics. Thus, the framework enables the integration of quantitative evidence from community surveys with qualitative insights from institutional narratives, creating a systemic understanding of Najafgarh's transformation from a functioning ecosystem into a flux-dominated socio-ecological system (Folke *et al.,* 2010; Shan *et al.,* 2021).

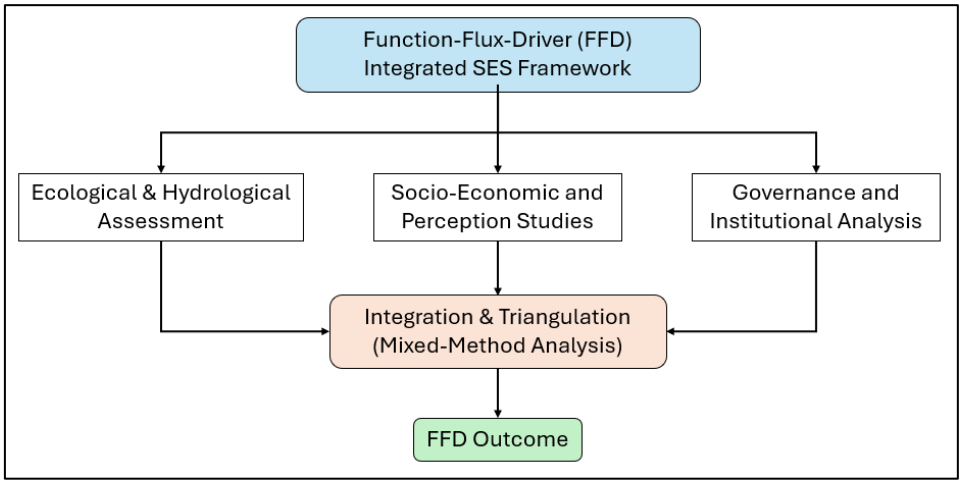


Figure 2: Methodological Framework adopted for this study

3.2 Data Sources and Study Design

The research relied on three principal data streams: primary field data, institutional and documentary material, and supporting secondary literature.

(a) Primary Field Data

Primary data was collected through extensive field surveys and observation across villages adjoining or within the wetland influence zone, such as Jhatikara, Guman Hera, Daulatabad, Kherki Majra, Dhankot, Budhera, and Mankrola. In all, 748 respondents participated in a structured household survey conducted using stratified random sampling. The strata were formed along livelihood categories such as farmers, daily-wage labourers, business owners, service workers, and non-working adults, to ensure representation of socio-economic diversity in the area.

The questionnaire comprised 21 items organised around five thematic sections:

i. socio-demographic profile,
ii. dependence on wetland resources,
iii. perception of ecological change,
iv. awareness of institutional interventions, and
v. priorities for management and restoration.

Each interview was conducted manually as well as responses were recorded manually before being analyzed. In addition to the household survey, key-informant interviews were conducted with officers from the Haryana State Wetland Authority, Delhi Wetland Authority, Delhi Jal Board, Gurugram Metropolitan Development Authority, and local non-governmental organisations involved in environmental action. These provided context on governance mechanisms, jurisdictional issues, and past restoration attempts.

Field observation was a continuous part of data collection. Multiple site visits during the monsoon and dry seasons allowed qualitative documentation of hydrological behaviour, water quality indicators (colour, odour, visible pollution), vegetation types, and faunal presence. Field Photographs supplemented these records,

capturing conditions of inflows, outflows, and surrounding land use.

(b) Institutional and Documentary Data

Documentary evidence was gathered from technical reports, environmental clearances, and judicial documents such as National Green Tribunal (NGT) proceedings related to Najafgarh Jheel. Policy documents, including the *Wetlands (Conservation and Management) Rules, 2017*, *Master Plan Delhi 2041*, and *State Action Plans on Climate Change*, were reviewed to identify legal and institutional drivers influencing wetland governance. Historical sources such as INTACH (2003) provided insight into the wetland's hydrological and ecological evolution.

(c) Secondary Literature

Peer-reviewed studies and government reports on Indian urban wetlands were reviewed to place the Najafgarh case within broader regional trends of ecological degradation and governance fragmentation (Mitsch & Gosselink, 2015; Shan *et al.,* 2021; Wetlands International South Asia, 2020).

3.3 Data Processing and Analysis

Quantitative Analysis

Survey data were coded and analyzed using IBM SPSS v26. Descriptive statistics summarised demographic patterns and perception frequencies. To test associations between socio-economic variables and ecological perceptions, Chi-Square tests of independence were conducted at a 5% significance level. Effect sizes were calculated using Cramer's V to evaluate the strength of relationships (Field, 2024). For instance, occupation and residence-duration variables were analyzed to determine whether dependence on wetland resources influenced awareness of ecological threats.

Qualitative and Thematic Analysis

Open-ended survey responses, field notes, and interview transcripts were thematically coded using an inductive approach. Categories such as flood regulation, pollution perception, institutional coordination, and cultural attachment emerged through repeated readings. Triangulation across respondents, officials, and documentary sources verified recurring themes.

Integration and Interpretation

Results from quantitative and qualitative analyses were merged through a convergent mixed-methods strategy (Creswell & Plano Clark, 2018). Quantitative trends such as respondents' perceptions of increased flooding or biodiversity loss were contextualized with qualitative insights from interviews and field observations. This integration helped link ecological patterns with governance processes in line with the FFD conceptual model.

3.4 Reliability, Validity, and Ethics

Multiple measures ensured methodological reliability and ethical integrity. The survey was pilot-tested to refine question clarity and sequence. Participation was voluntary, verbal consent was obtained before each interview, and confidentiality was maintained.

To enhance validity, triangulation was applied across three levels:

a. Data triangulation: verifying community responses against official records
b. Methodological triangulation: combining quantitative and qualitative techniques
c. Temporal triangulation: conducting observations across different time periods to capture variation

Institutional interviews were conducted in compliance with standard ethical research protocols in India (ICSSR, 2020).

3.5 Summary of Analytical Logic

The analytical framework directly engages the dual focus of this study viz. understanding the functions of the Najafgarh Wetland and identifying the drivers that induce flux in those functions. Ecological and hydrological observations reveal how the wetland sustains regulatory and supportive functions. Socio-economic surveys uncover how local communities perceive and depend on these ecosystem services, while governance and documentary analysis expose institutional factors that mediate or amplify ecological change.

By integrating these dimensions under a unified conceptual lens, the methodology synthesizes diverse empirical inputs into a cohesive understanding of how urban wetlands like Najafgarh persist, adapt, and decline under simultaneous ecological and socio-political pressures.

4. RESULTS

The results are organized into two thematic clusters that reflect the study's dual focus:

(1) Ecosystem functions of the Najafgarh Wetland as an urban wetland, and
(2) Drivers of change, both natural and anthropogenic, that shape and transform these functions.

Together, they reveal a complex interplay of ecological persistence, socio-economic dependence, and governance fragility within a rapidly urbanizing landscape.

4.1 Ecosystem Functions of Najafgarh Wetland

Hydrological and Ecological Functions

The Najafgarh Wetland performs vital hydrological roles such as flood peak attenuation, excess rainfall storage, and groundwater recharge, consistent with global understandings of urban wetland functions (Mitsch & Gosselink, 2015; Ramsar Convention Secretariat, 2010). Field observations and local testimonies show that what was once a narrow river corridor has expanded into a 30 sq. km. wetland, functioning as a natural detention basin during monsoons. This water body moderates stormwater from Gurugram and prevents flooding downstream in southwest Delhi, a service noted in earlier assessments (INTACH, 2003).

Survey data further support this. Over 70% of respondents identified flood regulation and water storage as the wetland's most valuable roles. However, these benefits are not evenly distributed. Villagers in Budhera and Kherki Majra reported chronic waterlogging and crop damage, while downstream residents observed reduced flood severity. This contrast illustrates a recurring pattern in peri-urban wetlands—regional hydrological benefits offset by local livelihood disruptions (Grimm *et al.,* 2008).

Water quality degradation threatens this balance. About 83% of households rated the water quality as "very poor," attributing this to sewage inflows, solid waste, and foul odours. Field notes confirmed grey, turbid water, foaming, and excessive vegetation—clear signs of eutrophication (MoEFCC, 2017; Joshi *et al.,* 2021). While flood moderation and recharge functions persist, the wetland's natural purification capacity has been heavily compromised.

Perceived Ecological Threats and Biodiversity Patterns

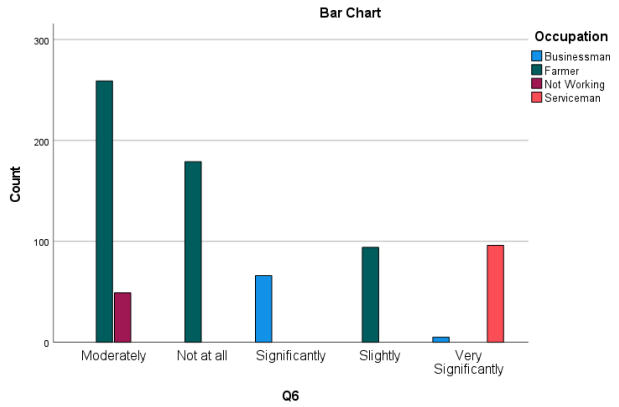
Statistical analysis of community responses (n = 748) reveals significant associations between respondents' occupation, place of residence, and perception of ecological threats.

Community responses reveal that livelihood type and residential proximity strongly influence how people perceive ecological threats to the Najafgarh Wetland. As shown in Table 1, 41.2 % of respondents rated threats as *moderate*, while 23.9 % perceived *no threat at all*. Smaller shares considered them *very significant* (13.5 %), *slight* (12.6 %), or *significant* (8.8 %), indicating recognition of stress but no consensus on crisis severity.

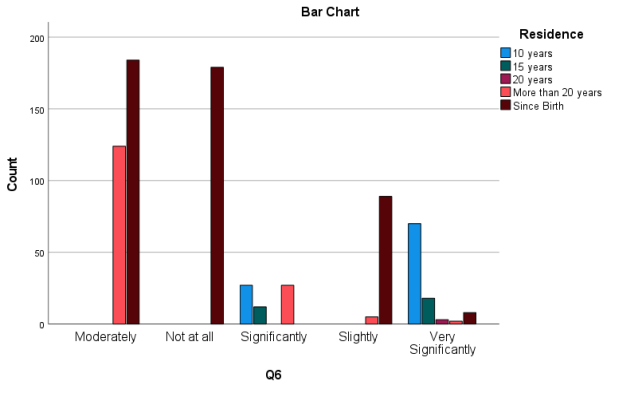
Table 4.1. Perception of Major Threats to the Ecological Balance of Najafgarh Wetland

Response Category	Frequency (n)	Percent (%)
Moderately	308	41.2
Not at all	179	23.9
Very significantly	101	13.5
Slightly	94	12.6
Significantly	66	8.8
Total	**748**	**100**

Statistical tests confirm these patterns as seen in Figure 3. For Occupation, the Chi-square value (χ^2 = 1048.521, $p < 0.001$) shows a strong association between livelihood and threat perception, while Residence (χ^2 = 778.463, $p < 0.001$) demonstrates the role of spatial exposure.



	Value	df	p value
Pearson Chi-Square	1048.521	12	0.000



	Value	df	p value
Pearson Chi-Square	778.463	16	0.000

Figure 3: Responses to the major threats to the ecological balance of Najafgarh Wetland based on Respondents' Occupation and Residency

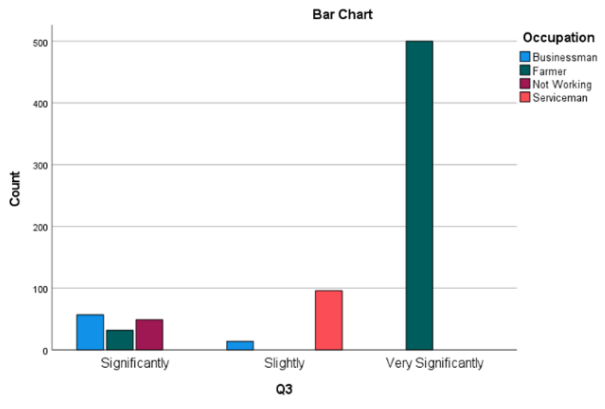
Farmers, whose land lies adjacent to the wetland, often do not perceive ecological degradation as a "threat," focusing instead on loss of cultivable land due to expansion or formal protection. Non-farming residents, however, expressed more concern about pollution and declining biodiversity. Overall, perceptions are shaped by both economic dependence and proximity, revealing that awareness of ecological change is socially differentiated rather than uniform across communities (Dilay *et al.,* 2020). These results highlight how Najafgarh's environmental understanding is intertwined with livelihood realities and governance uncertainty.

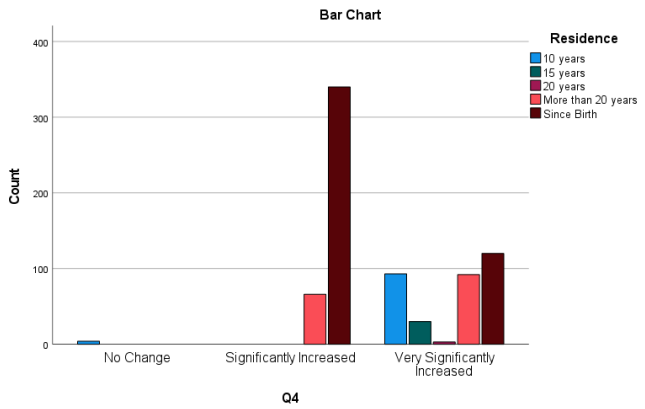
Biodiversity assessment revealed that the Najafgarh Wetland supports at least 281 bird species, including Greater Flamingo (*Phoenicopterus roseus*), Sarus Crane (*Antigone antigone*), and Black-necked Stork (*Ephippiorhynchus asiaticus*), consistent with prior ornithological surveys (Kumar & Rana, 2021). However, field inspection noted the dominance of Typha angustata, Phragmites karka, and Ipomoea aquatica, indicative of nutrient enrichment. Fish mortality events observed in 2022 support evidence of oxygen depletion and eutrophication (Wetlands International South Asia, 2020).

Table 4.2. Responses to Perception of Biodiversity Change in Najafgarh Wetland Over Time

Response Category	Frequency (n)	Percent (%)
Significantly Increased	406	54.3
Very Significantly Increased	338	45.2
No Change	4	0.5
Very Significantly Decreased	0	0
Significantly Decreased	0	0
Total	**748**	**100**

Community perceptions of biodiversity change reveal significant variation across both occupational and residential categories. As shown in Table 2, an overwhelming 99.5 % of respondents perceived biodiversity to have increased, with 54.3 % reporting it as *significantly increased* and 45.2 % as *very significantly increased*, while only 0.5 % observed no change. Statistical analysis confirms these perceptions differ by social and spatial factors as seen in Figure 4. For Occupation, $\chi^2 = 459.304$ ($p < 0.001$), and for Residence, $\chi^2 = 298.883$ ($p < 0.001$), indicating strong associations between livelihood type, proximity, and biodiversity interpretation.





	Value	df	p value
Pearson Chi-Square	978.566	6	0.000

	Value	df	p value
Pearson Chi-Square	298.883	8	0.000

Figure 4: Responses to the changing of the biodiversity of Najafgarh Wetland over time based on Respondents' Occupation and Residency

Farmers and long-settled residents often attribute perceived increases to favourable rainfall and expanding water spread, interpreting visible vegetation and bird abundance as ecological recovery. However, this optimism largely reflects misinterpretation—locals equate invasive growth and opportunistic species with improvement, even as habitat complexity and native vegetation decline. Scientifically, these trends signal ecological degradation rather than restoration, supporting the Function–Flux–Driver framework's insight that urban wetlands may appear visually resilient while functionally weakened (Folke *et al.,* 2010; Shan *et al.,* 2021).

Socio-Economic and Livelihood Functions

Najafgarh Wetland represents a transitional livelihood zone. Around 40% of respondents are engaged in agriculture, yet dependence on wetland-based income has diminished as peri-urban development expands. Occupational diversification is visible, with rising shares of wage labour and service employment in Gurugram's expanding economic zone.

Respondents reported agricultural yield declines, soil salinity, and persistent waterlogging as major constraints, directly linking these to hydrological changes and sewage-fed irrigation. Fishing activities have nearly disappeared due to reduced aquatic diversity and water pollution. Despite these setbacks, 58% of respondents still derive direct or indirect benefits from the wetland, either through borewell recharge, microclimatic regulation, or flood protection that enhances property stability.

Economic diversity shapes conservation perspectives. Newer residents and real-estate stakeholders emphasize aesthetic and recreational uses, while older farming families prioritize compensation and crop viability. This divergence mirrors national findings that sustainable wetland management must balance ecological goals with livelihood justice.

Socio-Cultural and Recreational Functions

Culturally, Najafgarh remains a landscape of memory and identity. Elders recall fairs, collective fishing, and grazing rituals around the historic Najafgarh Jheel. Though these practices have vanished, birdwatching and nature photography now draw visitors from Delhi and Gurugram.

However, organized community participation remains minimal. While 68% expressed pride in the wetland, fewer than 20% had engaged in conservation or public dialogue. This reflects institutional disconnect rather than social apathy where communities value the wetland but lack legal recognition or avenues for involvement (Bassi *et al.,* 2014; Ramsar Secretariat, 2010).

4.2 Drivers of Change: Natural and Anthropogenic

Natural Drivers

Najafgarh's geomorphology positions it within a natural hydrological depression at 209–211 m above mean sea level, with a 100-year flood contour of 212.5 m (Singh *et al.,* 2021). This physiographic setting accumulates runoff from the Aravalli foothills and Gurugram plains. Rainfall records (IMD, 2010–2020) show episodic high-intensity storms (>100 mm/day) every three years, producing runoff volumes up to 72 million cubic metres (MCM) over the basin (Bisht *et al.,* 2024). These events sustain wetland extent but also deposit sediment and alter vegetation patterns, confirming that natural hydrology remains a foundational but variable driver of the system's dynamics.

Anthropogenic Drivers

Rapid peri-urban expansion is the most visible human driver. Residential and institutional developments have replaced croplands and marshes, reduced infiltration and altering inflow regimes (Singh *et al.,* 2023; Mahapatra *et al.,* 2024). The wetland now functions as a receiving basin for urban wastewater. Official records estimate inflows of about 350 MLD of treated/grey water, while total sewage generation in Gurugram is projected at 533–864 MLD (Duhan, 2022). These continuous discharges sustain high water levels but also drive nutrient loading, macrophyte proliferation, and hypoxic conditions leading to fish kills (Joshi *et al.,* 2021).

Fragmented governance further compounds these pressures. The Najafgarh Wetland lies across two jurisdictions, Delhi and Haryana, creating administrative ambiguity and policy inertia. Despite recognition by multiple agencies, the wetland remains unnotified under India's Wetland Rules (MoEFCC, 2017). Interviews revealed conflicting mandates, delayed compensation for affected farmers, and limited enforcement of pollution control—collectively producing what stakeholders termed an "institutional vacuum."

4.3 Integrative Interpretation: Linking Functions, Fluxes, and Drivers

The Najafgarh Wetland exemplifies the Function–Flux–Driver dynamic central to this study. Its functions of flood moderation, groundwater recharge, and biodiversity support remain intact but increasingly fragile. Fluxes, both natural (rainfall pulses, sedimentation) and anthropogenic (urban runoff, sewage inflow, land conversion) continuously reshape its ecological and social equilibrium. Drivers of fragmented governance and socio-economic transition determine whether these fluxes result in resilience or degradation.

Empirical findings confirm this duality:

- Hydrological storage and biodiversity persist, but under severe pollution stress.
- Livelihood benefits continue, but dependence is declining.
- Cultural attachment remains strong, but institutional engagement is minimal.

The overall pattern aligns with global urban wetland trends where ecological services persist through adaptation until governance failures push systems toward irreversible degradation (Folke *et al.,* 2010; Daily *et al.,* 2009).

Najafgarh thus stands at a critical ecological threshold: capable of recovery through coordinated

governance and pollution control, yet equally vulnerable to collapse if unmanaged fluxes persist.

5. DISCUSSION

The findings position the Najafgarh Wetland as a transitional socio-ecological system, where ecosystem functions persist amid accelerating anthropogenic flux. The wetland continues to regulate floods, recharge groundwater, and support biodiversity, but these functions have been structurally altered and maintained increasingly through sewage-fed hydrology and constrained ecological processes. This condition typifies what Folke et al. (2010) describe as *resilience through transformation*, where systems adapt functionally even as their ecological integrity declines.

The study's Function–Flux–Driver (FFD) framework reveals three key transitions:

I. First, the hydrological regime has shifted from rainfall-driven to wastewater-sustained. Inflows of 350–864 MLD of treated and untreated sewage (Duhan, 2022) now sustain base water levels, converting Najafgarh into a permanent yet polluted wetland. This aligns with patterns seen in other Indian urban wetlands where wastewater sustains wetland hydrology but induces eutrophication (Shan *et al.,* 2021).

II. Second, ecological function has become visually deceptive, respondents' overwhelmingly positive perceptions of biodiversity (99.5% reporting increase) contrast with field indicators of vegetation loss and invasive dominance. This gap between perceived and actual resilience exposes a critical management challenge: public acceptance of degradation masked as recovery (Wetlands International South Asia, 2020).

III. Third, socio-economic dependence is diversifying but fragmenting stewardship. While 58% of households derive some benefit from the wetland, direct livelihood dependence is declining, particularly among farmers facing inundation losses. As in other peri-urban wetlands, this detachment erodes local custodianship (Rao *et al.,* 2024).

Governance emerges as the decisive driver linking ecological and social flux. The wetland's transboundary position between Delhi and Haryana creates regulatory ambiguity, an "institutional vacuum" that permits encroachment, pollution, and stalled notification under India's *Wetlands (Conservation and Management) Rules, 2017* (MoEFCC, 2017). Similar institutional fragmentation has been identified as a primary cause of functional erosion in Indian wetlands (Bassi *et al.,* 2014). This finding supports the view that wetland decline is less a biophysical inevitability than a governance failure (Daily *et al.,* 2009).

To sustain Najafgarh's multifunctionality, the study suggests for adaptive co-management integrating science, community, and policy. Legal notification and creation of a joint transboundary authority are prerequisites for coordinated restoration. Pollution-source control must precede hydrological or habitat interventions, ensuring water quality before expanding extent. Equally, livelihood justice through compensation, alternative employment, or community-managed eco-tourism must underpin any conservation plan to secure local legitimacy (Dilay *et al.,* 2020).

Ultimately, function alone cannot ensure resilience. Without governance coherence and public participation, flux dominates. Turning Najafgarh from a passive flood sink into an active ecological asset demands inclusive, adaptive governance that embraces variability as a process to manage, not a threat to suppress.

6. Conclusion and Recommendation

The Najafgarh Wetland exemplifies the transformation of a peri-urban ecosystem from a functioning natural landscape into a flux-driven socio-ecological system. The study reveals that while the wetland continues to deliver essential ecosystem services such as flood regulation, groundwater recharge, biodiversity support, and cultural value, its ecological foundations are being reconfigured by sustained anthropogenic and governance pressures. This duality defines the central challenge for urban wetlands in India: maintaining functionality within systems increasingly shaped by human-induced flux.

Empirical findings demonstrate that Najafgarh's hydrological persistence is now largely sustained by urban wastewater inflows (350–864 MLD) (Duhan, 2022), leading to a condition of *engineered resilience* where ecological continuity is maintained through artificial inputs. While flood control and water storage services remain evident, water quality deterioration, invasive species proliferation, and vegetation loss signal a decline in ecosystem integrity (Joshi *et al.,* 2021; Wetlands International South Asia, 2020). These transformations are accompanied by socio-economic shifts, direct dependence on wetland resources is declining, yet indirect benefits such as microclimate regulation and groundwater recharge remain vital to peri-urban livelihoods.

The study identifies institutional fragmentation as the most critical driver undermining restoration efforts. The transboundary governance structure of Delhi and Haryana has created overlapping jurisdictions, delayed statutory notification, and inconsistent implementation of the *Wetlands (Conservation and Management) Rules, 2017* (MoEFCC, 2017). This governance gap, compounded by urban expansion and

pollution inflows, has transformed the wetland into what Bassi et al. (2014) term an "administrative void." Unless governance coherence is achieved, physical restoration measures will yield only short-lived outcomes.

To reverse this trajectory, the study recommends an adaptive co-management framework that integrates science, governance, and community participation. Legal notification and the establishment of a transboundary wetland authority are prerequisites for unified action. Pollution-source control particularly sewage treatment upgrades and catchment-based runoff management must precede large-scale habitat restoration. Ecological rehabilitation should prioritize water-quality improvement, native vegetation reestablishment, and sediment management over mere expansion of wetland area.

Equally, community inclusion and livelihood justice are essential. Farmers' concerns regarding submergence and land loss must be addressed through transparent compensation, alternative livelihood schemes, and shared economic incentives such as eco-tourism or community-managed fisheries (Dilay *et al.,* 2020). Without local legitimacy, technical interventions risk opposition and failure.

Ultimately, Najafgarh's sustainability depends on reframing flux as opportunity using adaptive governance and continuous monitoring to transform variability into resilience. The Function–Flux–Driver approach adopted here underscores that effective wetland management requires not static preservation, but dynamic, evidence-based adaptation. By integrating ecological science with participatory governance, Najafgarh can shift from a flux-dominated, degraded system toward a resilient urban wetland that continues to provide essential ecosystem services for both people and biodiversity.

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