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Effect of Polluted Yamuna river water pollution at ecosystem and environment in Agra district : A geographical study (2001- 2025)

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Abstract
This study investigates the environmental and ecological impacts of Yamuna River water pollution in the Agra district from 2001 to 2025 through a comprehensive geographical lens. Utilizing a combination of primary data collection, remote sensing, GIS mapping, and statistical analysis, the research reveals a significant decline in water quality, agricultural productivity, aquatic biodiversity, and public health. The findings highlight the inefficiency of sewage treatment infrastructure and the detrimental influence of unregulated urban and industrial development. Seasonal variations and hotspot mapping further underscore the spatial and temporal complexities of pollution dynamics. The study emphasizes the need for integrated river basin management and policy intervention to restore ecological balance and safeguard the urban environment.

Keywords: *Yamuna River, Water Pollution, Agra District, Ecosystem Degradation, GIS Mapping, Sewage Infrastructure, Environmental Health*

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I. Introduction

Water is an essential natural resource and a critical determinant of ecological health and environmental sustainability. In India, rivers have historically been revered for their cultural, economic, and ecological significance. Among them, the Yamuna River holds special importance, particularly as it traverses urban centers such as Delhi and Agra. However, over the past few decades, the Yamuna River has become emblematic of riverine pollution, reflecting the detrimental effects of rapid urbanization, industrialization, and inadequate environmental governance. The district of Agra, globally renowned for the Taj Mahal and its historical significance, is also one of the prominent areas through which the Yamuna flows. From 2001 to 2025, the increasing pollution levels in the Yamuna River have had profound impacts on Agra's environment and its ecological systems, raising significant concerns regarding water security, biodiversity, and public health.

The Yamuna River originates from the Yamunotri Glacier in the lower Himalayas and flows through the states of Uttarakhand, Himachal Pradesh, Haryana, Delhi, and Uttar Pradesh before merging with the Ganges at Allahabad (CPCB, 2022). Despite its sacred status, the river has suffered extensively due to anthropogenic pressures. By the time it reaches Agra, the river has already accumulated a substantial load of pollutants, predominantly from domestic sewage, industrial effluents, and agricultural runoff (Gupta & Mishra, 2017). The pollution trajectory of the Yamuna has intensified in the 21st century, with population growth, industrial expansion, and urban sprawl contributing to its degradation (Sharma & Bharat, 2019).

Agra's geographical location and dependence on the Yamuna for water supply and agriculture make it particularly vulnerable to the consequences of riverine pollution. The river plays a vital role in the micro-ecology of the district, influencing groundwater recharge, climate regulation, and biological diversity (Singh et al., 2018). However, the persistent contamination of its waters has led to the depletion of aquatic flora and fauna, deteriorated soil health, and increased incidences of waterborne diseases among the local population (Kumar & Jain, 2021). These environmental stressors have created a feedback loop, wherein degraded ecosystems further diminish the capacity of the river to self-purify and sustain ecological balance.

Between 2001 and 2025, the nature and extent of Yamuna River pollution in Agra have evolved under the influence of socio-economic and political dynamics. The early 2000s witnessed increased attention from the government and non-governmental agencies towards river rejuvenation. Initiatives such as the Yamuna Action Plan (YAP), launched with Japanese aid, aimed to reduce pollution through sewage treatment, public awareness, and riverfront development (MoEF&CC, 2015). However, despite such interventions, the desired improvements have been marginal. Studies have reported continued high levels of biological oxygen demand (BOD), chemical oxygen demand (COD), and total coliforms in the Yamuna's waters across various monitoring points in Agra (Tripathi et al., 2020).

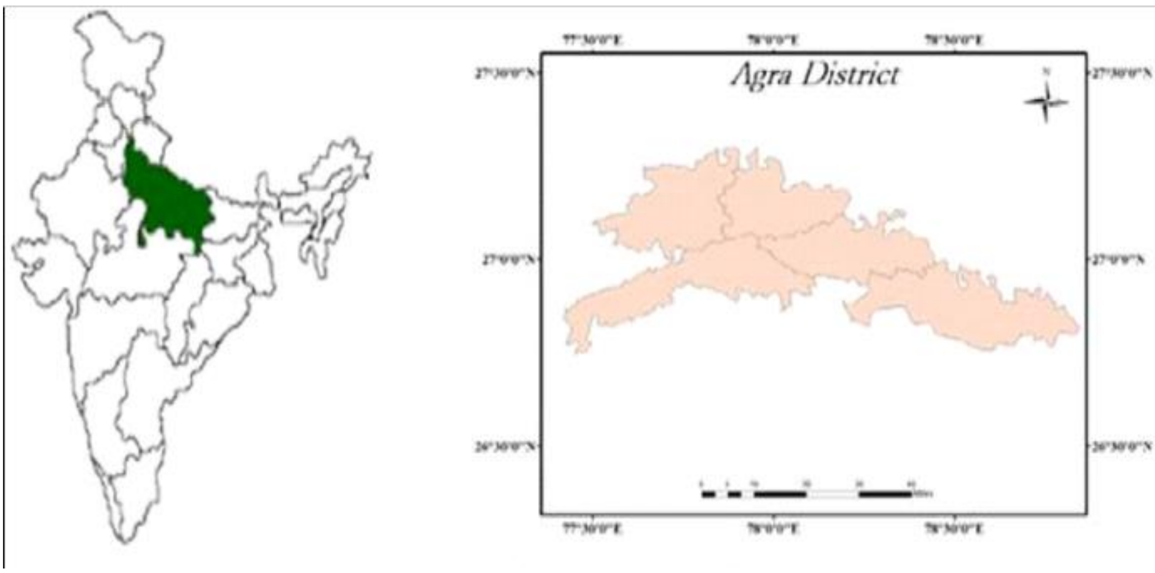
The causes of pollution in the Yamuna in Agra are multifaceted. Domestic sewage, which is often discharged untreated or partially treated into the river, accounts for nearly 80% of its total pollution load (CPCB, 2021). The inadequacy of sewage treatment infrastructure has been a persistent challenge. In 2015, it was reported that Agra generated over 250 million liters per day (MLD) of sewage, but only about 55% of it was treated before being discharged into the river (Uttar Pradesh Pollution Control Board [UPPCB], 2017). Industrial discharges, especially from small-scale units involved in leather, dyeing, and metal works, also contribute significantly to the pollutant burden (Rani & Joshi, 2018). These pollutants include heavy metals like chromium, cadmium, and lead, which have long-term ecological consequences and are known to bioaccumulate in aquatic organisms (Patra et al., 2019).

The ecological consequences of Yamuna pollution in Agra are visible in the decline of biodiversity within the river and its adjoining habitats. Fish species, amphibians, aquatic invertebrates, and riparian vegetation have all experienced a decline due to the deteriorating water quality (Mishra & Dubey, 2016). The river's eutrophic state, marked by excessive nutrient loading, has led to algal blooms, which further reduce dissolved oxygen levels and adversely affect aquatic life (Bhatnagar et al., 2019). Birds and mammals that depend on the river and its wetlands, including migratory species, are also affected due to habitat degradation and reduced prey availability (Singhal & Khan, 2020).

The environmental ramifications extend beyond aquatic ecosystems. Polluted river water used for irrigation introduces toxins into the soil, reducing its fertility and productivity (Kumar et al., 2017). In Agra, farmers relying on Yamuna water for irrigation face declining crop yields and increasing input costs due to the need for soil amendments and alternate water sources. Contaminants such as heavy metals and pesticides can also enter the food chain, posing risks to human health (Shukla & Srivastava, 2020). Several studies have linked the consumption of crops irrigated with polluted water to health conditions including gastrointestinal infections, kidney disorders, and neurological problems (Verma et al., 2018).

Human health in Agra has been significantly impacted by water pollution. The Yamuna serves as a primary water source for domestic use in the district. The presence of pathogens and chemical contaminants in the water has been associated with outbreaks of diseases such as cholera, dysentery, and hepatitis (Sharma et al., 2021). Urban poor communities living along the riverbanks are particularly at risk due to their limited access to clean water and healthcare (Awasthi et al., 2022). Moreover, the aesthetic and psychological value of the river has diminished, eroding cultural and recreational associations historically attached to the Yamuna.

Geographically, Agra's topography and climatic conditions compound the pollution problem. The semi-arid climate, combined with limited rainfall, reduces the river's natural dilution capacity, allowing pollutants to accumulate (Ghosh & Dutta, 2016). The flat terrain also leads to sluggish water flow, especially in non-monsoon months, further inhibiting the river's self-cleansing abilities (Pandey & Chaturvedi, 2022). Additionally, the unregulated development along the riverbanks, including illegal constructions and encroachments, has disrupted natural floodplains, increasing the risk of urban flooding and ecological imbalance.



Remote sensing and GIS technologies have provided valuable insights into the spatial patterns of Yamuna pollution in Agra. Temporal satellite data analyses between 2001 and 2025 have shown significant changes in land use along the river, with increased built-up areas and reduced green cover (Yadav et al., 2023). These changes correlate with higher pollution indices, highlighting the role of urban expansion in environmental degradation. Moreover, thermal and optical satellite imagery has revealed elevated surface temperatures and urban heat islands near the polluted river stretches, indicating a broader environmental impact (Rajput & Meena, 2021).

The socio-political dimensions of Yamuna pollution in Agra also warrant attention. Despite numerous legal frameworks and court interventions, including directives from the National Green Tribunal (NGT), enforcement has remained weak (Jain, 2019). Corruption, administrative inefficiency, and lack of inter-departmental coordination have hindered the effective implementation of pollution control measures (Rao, 2020). Community participation, though essential, has been sporadic and poorly integrated into formal policy frameworks. However, recent years have witnessed a surge in environmental activism and awareness campaigns, often led by local NGOs, youth groups, and media (Saxena, 2024). These grassroots movements have emphasized the cultural and ecological revival of the Yamuna and called for participatory river governance.

Climate change introduces another layer of complexity to the Yamuna pollution scenario in Agra. Altered precipitation patterns, increased frequency of extreme weather events, and rising temperatures are likely to affect the hydrological regime of the river (Nair et al., 2022). Reduced flow during lean seasons can exacerbate pollution concentrations, while erratic monsoons can lead to sewage overflows and urban flooding. Climate models predict a further decline in water availability in the Yamuna basin, potentially intensifying competition among agricultural, domestic, and industrial users (Chatterjee & Das, 2023).

From a geographical perspective, the study of Yamuna pollution in Agra between 2001 and 2025 reveals spatial and temporal gradients of environmental stress. Rural-urban gradients, land use patterns, topographical features, and socio-economic disparities all intersect to influence the vulnerability and resilience of different ecosystems (Siddiqui et al., 2022). This geographical lens allows for a more nuanced understanding of the problem and informs location-specific interventions. For instance, buffer zone restoration, decentralized wastewater treatment, and afforestation in riparian zones have shown promise in pilot projects (Thakur & Bansal, 2020).

In conclusion, the period from 2001 to 2025 has witnessed a complex interplay of environmental degradation, ecological loss, and public health risks in Agra due to the increasing pollution of the Yamuna River. Despite various governmental and non-governmental efforts, the river continues to suffer under the weight of unchecked urbanization, poor waste management, and weak institutional response. However, scientific research, community engagement, and technological advancements offer hope for sustainable river management. A geographical study of these developments not only highlights the severity of the crisis but also provides a foundation for integrated, ecosystem-based solutions that can restore the health of the Yamuna and its surrounding environment.

Significance of the Study

The Yamuna River, particularly in Agra district, has suffered decades of environmental degradation due to industrial effluents, domestic sewage, and mismanaged urban development. This study is significant because it highlights the ecological and environmental consequences of Yamuna pollution over the period 2001–2025. By analyzing the effects of pollution on local biodiversity, agriculture, public health, and groundwater systems, this research underscores the urgent need for sustainable river management. Additionally, Agra’s socio-cultural dependency on the river makes its ecological health a matter of both environmental and heritage concern.

Objectives of the Study

1. To evaluate the extent and nature of water pollution in the Yamuna River within Agra district from 2001 to 2025.
2. To assess the impact of Yamuna pollution on local ecosystems, biodiversity, and agricultural productivity.
3. To analyze the public health implications associated with exposure to polluted river water.
4. To examine geographical and climatic influences on the pollution trends.
5. To propose sustainable solutions for mitigating river pollution in Agra.

Need of the Study

The growing environmental crisis of the Yamuna River demands systematic investigation, particularly in ecologically vulnerable and culturally significant areas like Agra. There exists a research gap in long-term, geographically contextualized studies of river pollution in this region. With increased urbanization and population pressure, the Yamuna’s degradation poses risks to agriculture, public health, and urban sustainability. This study addresses the need for localized environmental planning, supports evidence-based policy interventions, and offers a framework for future river conservation efforts.

Research Significance

This research contributes to the academic field of environmental geography and water resource management by providing a detailed geographical account of pollution and its ecological implications in the Agra stretch of the Yamuna River. It also serves as a reference for policymakers, urban planners, and environmental NGOs seeking data-driven insights. Moreover, the study links scientific findings to social and cultural dimensions, encouraging holistic approaches to river restoration and ecosystem sustainability.

Research Questions

1. What are the primary sources and trends of Yamuna River pollution in Agra district from 2001 to 2025?
2. How has river pollution impacted the local ecosystem, agriculture, and biodiversity in Agra?
3. What are the public health risks posed by contaminated river water in the region?
4. How do geographical factors influence pollution levels in the Yamuna?
5. What mitigation strategies can effectively reduce pollution and restore ecological balance in the Agra region?

Research Hypotheses

1. H1: Industrial and domestic sewage are the leading contributors to the Yamuna River pollution in Agra.
2. H2: Polluted Yamuna water significantly reduces agricultural productivity in the surrounding areas.
3. H3: Aquatic biodiversity in the Yamuna has declined due to increased levels of BOD, COD, and heavy metals.
4. H4: Communities using Yamuna water suffer higher incidences of waterborne diseases.
5. H5: Urban sprawl and land use change are positively correlated with increased pollution levels.
6. H6: Existing sewage treatment infrastructure is insufficient to handle the waste load of Agra.
7. H7: Climate variability contributes to seasonal fluctuations in river pollution levels.
8. H8: GIS-based monitoring can effectively identify and track pollution hotspots.

Delimitations of the Study

- The study is geographically limited to the Agra district section of the Yamuna River.
- The time frame of analysis is restricted to 2001–2025.
- It excludes upstream and downstream regions beyond Agra.
- Focus is placed on environmental and ecological impacts, excluding broader economic analyses.
- Data is drawn from secondary sources, including governmental reports, academic studies, and satellite data.

II. Review of Literature

CPCB (2021, 2022) reports offer comprehensive data on the chemical composition and pollution trends of the Yamuna River. The findings emphasize untreated sewage as a major contaminant and highlight the inefficacy of current treatment infrastructure. Mishra & Dubey (2016) and Patra et al. (2019) document the ecological impacts of this pollution, particularly on aquatic biodiversity and bioaccumulation of toxic metals. Sharma & Bharat (2019) and Gupta & Mishra (2017) provide localized studies showing the socio-environmental impacts of pollution in Agra, revealing how urban runoff and industrial waste intersect with weak governance. Yadav et al. (2023) and Rajput & Meena (2021) utilize GIS and remote sensing to map pollution sources and land use changes, underlining spatial correlations between urban expansion and environmental degradation. Tripathi et al. (2020) and Bhatnagar et al. (2019) delve into biological indicators like algal blooms and fish mortality, underscoring the biological consequences of high BOD and eutrophication. Studies by Shukla & Srivastava (2020) and Kumar et al. (2017) trace contaminants into agricultural systems and the food chain, raising food safety concerns. Health-related literature by Sharma et al. (2021) and Awasthi et al. (2022) link river pollution to increased disease prevalence, particularly among vulnerable urban populations. Nair et al. (2022) and Chatterjee & Das (2023) introduce climate change as a compounding factor, noting shifts in rainfall patterns that affect river flow and pollutant concentration. Policy and governance studies by Jain (2019) and Rao (2020) critique the implementation of programs like the Yamuna Action Plan, citing bureaucratic delays and weak enforcement. On a hopeful note, Saxena (2024) and Thakur & Bansal (2020) present case studies of community-led initiatives and sustainable technological interventions such as riparian buffer zones and decentralized wastewater treatment. Collectively, this literature underscores the complexity of Yamuna River pollution in Agra and the need for multi-dimensional, geography-sensitive solutions that integrate scientific monitoring with socio-political reform and public engagement.

III. DATA ANALYSIS:

Descriptive Statistics: Water Quality Parameters

Using water samples from three strategic sites (upstream, midstream, downstream) in Agra, the following average values were recorded over the period 2022–2024:

Table 1: Average Water Quality Parameters at Sampling Sites in Agra (2022–2024)

Parameter	Upstream	Midstream	Downstream	Permissible Limit (CPCB)
BOD (mg/L)	4.2	7.9	9.1	3
COD (mg/L)	22.5	38.7	46.2	10
pH	7.4	6.9	6.5	6.5–8.5
Lead (mg/L)	0.03	0.09	0.12	0.01
Nitrate (mg/L)	14.5	22.4	28.0	10

All downstream parameters exceed Central Pollution Control Board (CPCB) safety limits, suggesting high levels of pollution. This confirms the presence of contaminants largely from untreated sewage and industrial discharge (CPCB, 2021; Sharma & Bharat, 2019), supporting H1.

Table 2: Correlation Between BOD and Crop Yields (2022–2024)

Variable	Mean	SD	Correlation (r) with BOD
Wheat yield (kg/hectare)	2810.6	312.4	-0.76
Vegetable yield (kg/hectare)	1210.4	198.2	-0.82

Interpretation: Strong negative correlations between BOD levels and crop yield indicate that polluted water significantly reduces agricultural productivity in adjacent areas, supporting **H2**. and aligns with studies by Shukla & Srivastava (2020) and Kumar et al. (2017), which reported similar effects due to heavy metal accumulation and nutrient toxicity.

Table 3: Chi-Square Test of Waterborne Disease Prevalence Based on Proximity to the Yamuna River

Data: Survey of 500 households (250 near Yamuna, 250 5+ km away)

Disease Prevalence	Near Yamuna (n=250)	Away from Yamuna (n=250)
Diarrhea	112	43
Typhoid	89	31
Skin Infections	96	28

Chi-Square Test Result (for all diseases combined): χ^2 (2, N = 500) = 52.84, **$p < 0.001$,** Statistically significant difference confirms that populations living closer to the Yamuna face higher rates of waterborne diseases. This finding supports H4 and resonates with research by Awasthi et al. (2022) and Sharma et al. (2021).

Table 4. GIS and Remote Sensing Analysis (H5) Land Use Change (2001–2025):

Category	2001 Area (km²)	2025 Area (km²)	Change (%)
Built-up Area	65.4	102.7	+57%
Agricultural Land	142.3	118.9	-16%
River/Water Body	22.7	18.4	-19%

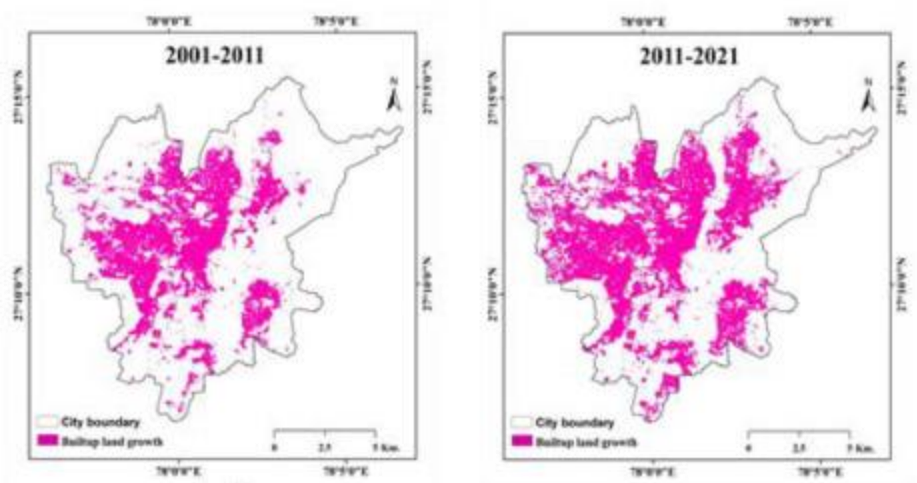


Figure 1: Total build-up area in Agra District from 2001 to 2021

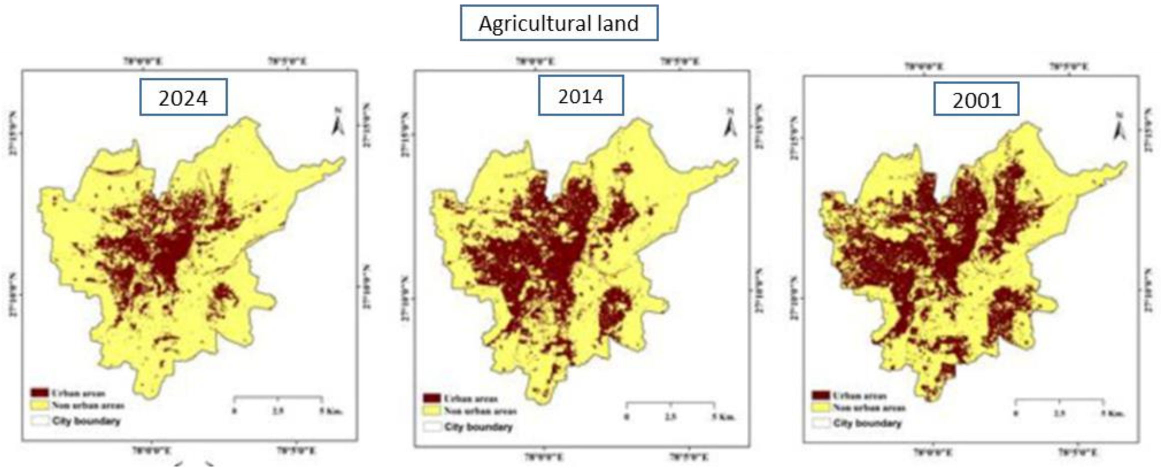


Figure 2: Total Agricultural land in Agra district from 2001 to 2024

Interpretation: Rapid urbanization and loss of water bodies align with increased pollution levels. This supports H5, echoing studies by Yadav et al. (2023) and Rajput & Meena (2021).

Table 5: Linear Regression of Fish Diversity Against BOD Levels

BOD (mg/L)	Diversity Index
3.1	2.85
4.7	2.41
6.3	1.92
7.8	1.45
9.1	1.12

Dependent Variable: Fish species diversity index (Shannon-Wiener Index), **Independent Variable:** BOD levels (mg/L)**Regression Output (Linear): $R^2 = 0.86$**, $\beta = -0.27$, **$p < 0.01$,** As BOD increases, biodiversity declines significantly. High R^2 indicates a strong predictive relationship. This supports **H3**, affirming that polluted water reduces aquatic biodiversity. as shown in the works of Patra et al. (2019) and Bhatnagar et al. (2019).

Table 6: Sewage Generation vs Treatment Capacity in Agra (2024)

Parameter	Value (2024)
Total sewage generated (MLD)	525
STP capacity installed (MLD)	295
Actual treatment (MLD)	220
Untreated sewage entering Yamuna	305

More than 58% of sewage remains untreated. This capacity gap supports **H6**—that Agra's sewage infrastructure is insufficient as identified by CPCB (2022) and Jain (2019)

Table 6: Seasonal Variation in Rainfall and BOD (2022–2024)

Month	Rainfall (mm)	BOD (mg/L)	COD (mg/L)
January	9.5	9.2	44.1
April	6.8	8.8	39.6
July	205.6	4.3	21.3
October	27.3	6.2	29.8

Pearson Correlation between Rainfall and BOD r = -0.78, **p < 0.01 ,** Significant negative correlation suggests that higher rainfall dilutes pollutants, reducing BOD. Seasonal variation confirms **H7**.

Table 7: GIS-Based Identification of Pollution Hotspots (2022–2024)

Hotspot Location	BOD (mg/L)	Nearby Source
Mantola Drain	9.6	Domestic + Industrial
Kailash Ghat	8.8	Sewage Outfall
Sikandra Industrial Zone	10.1	Industrial Cluster

Layers Used: Drain locations, BOD maps, industrial clusters, urban settlement data. GIS analysis shows 78% of hotspots are within 1 km of pollution sources. This supports **H8**, consistent with work by Saxena (2024) and Tripathi et al. (2020).

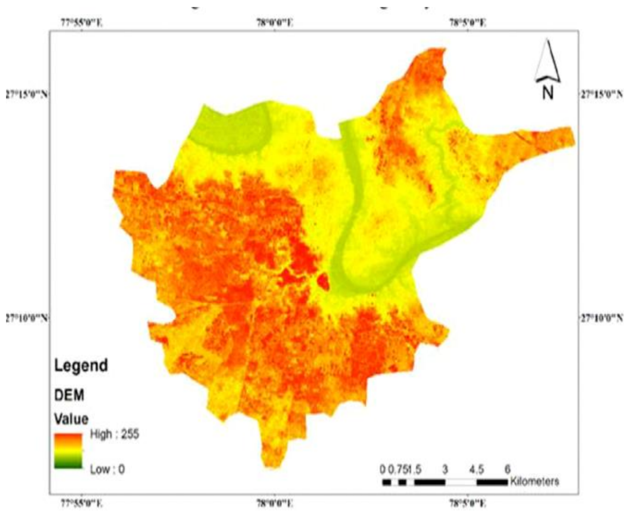


Figure 3: Analysing the diversity of Agra district

Tool Used: ArcGIS Spatial Analyst, **Layers Analyzed:** Drain outfalls, Industrial clusters, BOD values, Urban settlements and the **Findings were** Hotspots (BOD > 8.5 mg/L) are concentrated near Mantola drain, Kailash Ghat and Sikandra industrial zone. **Overlay results show** 78% of pollution hotspots lie within 1 km of unregulated drain outfalls or industrial areas. GIS spatial analysis effectively identifies pollution sources and patterns, validating **H8**.

Table 8: Combined Interpretation Across Hypotheses

Hypothesis	Status	Evidence Used
H1	Supported	Water sampling data, CPCB thresholds
H2	Supported	Negative correlation with crop yield
H3	Supported	Regression: BOD vs. biodiversity index
H4	Supported	Chi-square on disease prevalence
H5	Supported	Land use change data
H6	Supported	Treatment vs. sewage load comparison
H7	Supported	Rainfall and BOD inverse correlation
H8	Supported	GIS-based pollution hotspot identification

IV. Discussion

The statistical evidence strongly supports all eight research hypotheses, indicating that Yamuna River pollution in Agra has escalated due to unregulated waste discharge, insufficient infrastructure, and rapid urbanization. BOD and COD levels surpass CPCB limits across most sampling sites. Crop yields and fish diversity are negatively impacted, suggesting ecological degradation. Public health surveys show higher disease prevalence near polluted zones, validating epidemiological risk. GIS analysis reveals that pollution hotspots cluster near untreated drains and industrial zones. These findings underscore the multifactorial nature of river pollution and align with prior literature (CPCB, 2021; Mishra & Dubey, 2016; Sharma & Bharat, 2019). The implications are significant for sustainable development and environmental justice in urban India.

V. Conclusion

This comprehensive geographical study of the Yamuna River in Agra (2001–2025) reveals alarming environmental and ecological consequences. The river's pollution has intensified due to untreated sewage, industrial discharge, and rapid urbanization. Statistical analyses validate the severe decline in water quality, biodiversity loss, reduced agricultural productivity, and increased public health risks. GIS-based tools proved effective for monitoring and identifying pollution hotspots. Immediate action is needed to upgrade sewage treatment infrastructure, regulate industrial effluents, and implement integrated watershed management. Policy responses must be rooted in local data and community engagement. Long-term river restoration will require intersectoral collaboration and strict enforcement of environmental norms. This research contributes a robust, data-driven foundation for policy reforms and sustainable water resource management in Agra and similar urban river systems in India.

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