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Impact of Climate Change, Urbanisation and Land-Use Transformation on Environmental Sustainability and Biodiversity in Agra Region, Uttar Pradesh

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Abstract: ***Rapid urbanisation, changing land-use patterns and climatic variability have emerged as major challenges to environmental sustainability in developing urban regions. Agra, one of the historically significant cities of Uttar Pradesh, is experiencing considerable environmental pressure due to population growth, infrastructure development, industrial activities, agricultural transformation and increasing demand for natural resources. These processes are influencing the ecological characteristics of the region and creating challenges for biodiversity conservation and climate resilience.***

The present research paper examines the impact of climate change, urbanisation and land-use transformation on environmental sustainability in the Agra region of Uttar Pradesh. It investigates the changing relationship between built-up areas, agricultural landscapes, water bodies, vegetation cover and natural habitats. Particular emphasis is placed on urban heat island effects, groundwater depletion, air and water pollution, habitat fragmentation, wetland degradation and the ecological condition of the Yamuna River and Sur Sarovar Bird Sanctuary.

The study adopts a descriptive and analytical approach using secondary environmental information, published research, government reports and a proposed framework for spatial and ecological assessment. It identifies the major environmental pressures affecting the region and examines their implications for terrestrial and aquatic biodiversity. The paper further proposes strategies involving sustainable urban planning, climate-resilient infrastructure, green-cover restoration, wetland conservation, efficient water management and community participation.

The study argues that environmental sustainability in Agra requires an integrated planning approach in which urban development is balanced with ecological protection. Long-term environmental monitoring, geospatial analysis and biodiversity assessment can provide an important scientific foundation for regional climate adaptation and sustainable development.

Keywords: Climate Change, Urbanisation, Land-Use Change, Environmental Sustainability, Urban Heat Island, Biodiversity, Agra, Yamuna River, Wetland Conservation, Climate Resilience.

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1. Introduction

Environmental sustainability has become a major concern in contemporary development planning because economic growth, urban expansion and increasing consumption of natural resources are placing unprecedented pressure on ecological systems. The relationship between urban development and environmental quality is particularly important in rapidly developing cities where population growth and infrastructure expansion are accompanied by changes in land utilisation, vegetation distribution, water availability and local climatic conditions.

Urbanisation is an important driver of environmental transformation. The conversion of agricultural land, wetlands and natural vegetation into residential, commercial and industrial areas alters the ecological structure of landscapes. Such transformations may increase surface temperatures, reduce groundwater recharge, modify natural drainage patterns and fragment habitats.

Climate change further intensifies these environmental pressures. Increasing temperatures, irregular rainfall, prolonged dry periods and extreme weather events can influence agricultural production, water-resource availability and biodiversity distribution. The interaction between urbanisation and climate change can therefore create multiple environmental vulnerabilities.

Agra provides an important geographical setting for investigating these processes. Situated in the western part of Uttar Pradesh, the region combines an expanding urban environment with agricultural landscapes, the Yamuna River, wetlands and scattered natural vegetation.

The historical and ecological significance of Agra is also associated with its proximity to important natural habitats, particularly Sur Sarovar Bird Sanctuary (Keetham Lake). These habitats provide ecological services, including water storage, biodiversity conservation, carbon regulation and support for wildlife.

However, the expansion of built-up areas, increasing vehicular traffic, industrial development, groundwater extraction, wastewater discharge and solid waste generation create substantial environmental management challenges.

The present research examines how these interconnected processes influence environmental sustainability and biodiversity in the Agra region and identifies appropriate strategies for reducing ecological vulnerability.

2. Conceptual Understanding of Urbanisation and Environmental Sustainability

2.1 Urbanisation and Ecological Transformation

Urbanisation refers to the increasing concentration of population and economic activities in urban areas, accompanied by the expansion of built-up infrastructure.

Its ecological implications include:

1. Conversion of natural vegetation into built-up surfaces.
2. Reduction in agricultural and open spaces.
3. Fragmentation of wildlife habitats.
4. Increased demand for freshwater.
5. Modification of natural drainage systems.
6. Increased generation of solid waste and wastewater.
7. Changes in local temperature and atmospheric conditions.

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Urbanisation is not necessarily environmentally destructive. Properly planned urban development can improve resource efficiency, environmental infrastructure and access to public green spaces. However, unregulated expansion can accelerate ecological degradation.

2.2 Environmental Sustainability

Environmental sustainability involves the responsible utilisation and conservation of natural resources to maintain ecological balance and support the needs of present and future generations.

Its major dimensions include:

- Conservation of biological diversity.
- Protection of water resources.
- Maintenance of soil fertility.
- Reduction of air and water pollution.
- Sustainable utilisation of land.
- Climate change mitigation and adaptation.
- Restoration of degraded ecosystems.

2.3 Climate Resilience

Climate resilience refers to the ability of ecological and human systems to withstand, adapt to and recover from climatic disturbances.

In the Agra region, climate resilience requires effective management of heat stress, water scarcity, rainfall variability, urban flooding and ecological degradation.

3. Profile of the Study Area: Agra Region

Agra is situated in western Uttar Pradesh within the Indo-Gangetic plains. The geographical setting includes an extensive alluvial landscape, agricultural areas, urban settlements and riverine environments.

3.1 Geographical Characteristics

The major geographical characteristics include:

- Predominantly flat alluvial terrain.
- Agricultural land surrounding urban settlements.
- Yamuna River and associated drainage systems.
- Wetlands, ponds and artificial water bodies.
- Urban and peri-urban vegetation.
- Expanding residential and commercial settlements.

3.2 Climatic Conditions

Agra experiences a subtropical climate with hot summers, monsoon rainfall and relatively cool winters.

The climatic conditions are characterised by considerable seasonal fluctuations in temperature and rainfall.

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The major environmental concerns include:

1. High summer temperatures.
2. Heatwave episodes.
3. Seasonal water scarcity.
4. Variable monsoon rainfall.
5. Increasing pressure on groundwater resources.
6. Dust and air pollution.

3.3 Land-Use Characteristics

The land-use pattern of the Agra region can broadly be classified into:

Land-use category	Major characteristics	Environmental importance
Built-up land	Residential, commercial and industrial areas	Urban infrastructure
Agricultural land	Cultivated fields and horticulture	Food production
Water bodies	Rivers, lakes, ponds and reservoirs	Aquatic biodiversity
Vegetation cover	Parks, plantations and natural vegetation	Carbon storage
Open and barren land	Uncultivated and exposed surfaces	Soil and landscape processes
Wetlands	Marshes and seasonally inundated areas	Wildlife habitats and water regulation

The actual distribution and percentage of each category should be established through satellite imagery and GIS-based land-use analysis.

4. Review of Related Literature

4.1 Research on Urbanisation and Land-Use Change

Lambin et al. (2001) examined the underlying causes of land-use and land-cover change and demonstrated that human activities, economic processes and institutional factors collectively influence landscape transformation.

Seto et al. (2012) examined global urban land expansion and its implications for biodiversity and carbon pools. Their findings highlighted the importance of incorporating ecological considerations into urban development planning.

Grimm et al. (2008) discussed the ecological consequences of urbanisation and emphasised the need to understand urban ecosystems as complex socio-ecological systems.

4.2 Research on Urban Heat Islands

Oke (1982) examined the relationship between urban geometry, surface characteristics and urban climate. The research established an important scientific foundation for understanding urban heat island formation.

Voogt and Oke (2003) investigated the thermal characteristics of urban environments using remote sensing. Their work demonstrated the importance of satellite-based temperature observations for studying urban thermal conditions.

4.3 Research on Climate Change

The Intergovernmental Panel on Climate Change (IPCC, 2022) highlighted the increasing risks associated with climate change, particularly for water resources, agriculture, biodiversity and urban populations.

The assessment emphasised that adaptation measures are essential for reducing climate vulnerability and strengthening ecosystem resilience.

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4.4 Research on Biodiversity and Ecosystem Services

The Millennium Ecosystem Assessment (2005) explained the importance of ecosystem services for human well-being and sustainable development.

The assessment identified provisioning, regulating, cultural and supporting services as major categories of ecosystem benefits.

4.5 Research on Wetland Conservation in Agra

Research on Soor Sarovar Bird Sanctuary provides important evidence of the ecological significance of wetlands in the Agra region.

Tiwari and Chauhan (2006) documented 73 phytoplankton species in Keetham Lake, while Wagh (2016) reported 76 invasive alien plant species in Soor Sarovar Bird Sanctuary.

These studies demonstrate the importance of wetland ecosystems and the need for continuous biodiversity monitoring.

4.6 Research Gap

Although considerable research has been conducted on urbanisation, climate change and biodiversity at global and national levels, the integrated relationship between these factors requires further investigation at the regional level.

The major research gaps include:

1. Limited integration of urban expansion and ecological degradation assessments for Agra.
2. Insufficient long-term examination of land-use changes and biodiversity patterns.
3. Limited district-specific studies of urban heat island intensity.
4. Need for integrated assessment of climate change and groundwater vulnerability.
5. Limited comparative analysis of urban and peri-urban ecological conditions.
6. Need for a spatial framework connecting urban development with wetland and habitat conservation.

The present research seeks to address these gaps through an integrated environmental sustainability framework.

5. Objectives of the Study

The principal objective is to examine the effects of climate change, urbanisation and land-use transformation on environmental sustainability and biodiversity in the Agra region.

The specific objectives are:

1. To examine the patterns of urbanisation and land-use transformation in Agra.
2. To analyse the relationship between urban expansion and environmental degradation.
3. To assess the influence of built-up areas on local temperature conditions.
4. To examine the impact of land-use changes on vegetation cover and biodiversity.
5. To investigate the environmental consequences of groundwater depletion and water pollution.
6. To study the vulnerability of wetlands and riverine ecosystems to urban development.
7. To examine the relationship between climatic variability and regional ecological conditions.
8. To identify major environmental challenges associated with urban expansion.

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9. To evaluate existing environmental conservation and climate adaptation measures.
10. To suggest strategies for sustainable urban and ecological development.

6. Research Hypotheses

The following hypotheses are proposed for empirical investigation:

- H01: Urbanisation has no significant relationship with changes in land-use and land-cover patterns in the Agra region.
- H02: The expansion of built-up areas has no significant influence on land surface temperature.
- H03: Land-use transformation has no significant relationship with regional biodiversity.
- H04: Climate variability has no significant influence on the environmental sustainability of the Agra region.
- H05: Urban expansion has no significant association with the degradation of water resources and natural habitats.
- H06: Green-cover development has no significant relationship with the improvement of urban environmental conditions.

7. Research Methodology

7.1 Research Design

The study adopts a descriptive, analytical and geospatial research design. It combines environmental literature, secondary statistical information, satellite-based observations and a proposed primary field investigation.

The methodology is designed to understand the spatial and temporal relationship between urban expansion, climate variability, land-use changes and ecological sustainability.

7.2 Study Area and Spatial Coverage

The research covers Agra district, with particular attention to the following ecological and urban environments:

Study zone	Main research focus
Central urban Agra	Urban heat and built-up expansion
Sikandra	Industrial and residential development
Tajganj and surrounding areas	Tourism-related urban pressure
Yamuna river corridor	Riverine ecology and pollution
Keetham and Sur Sarovar	Wetland biodiversity
Shamsabad and Fatehabad areas	Peri-urban land-use changes
Agricultural surroundings	Agricultural land conversion and climate vulnerability

These are proposed study zones; final sampling boundaries should be established using administrative maps and GIS analysis.

7.3 Sources of Data

A. Primary Data

Primary data may be collected through:

- Field surveys of selected urban and rural locations.
- GPS-based mapping of land-use features.
- Household questionnaires.

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- Interviews with farmers and local residents.
- Vegetation and biodiversity surveys.
- Water-quality sampling.
- Observations of urban environmental conditions.

B. Secondary Data

The major sources include:

1. India Meteorological Department.
2. National Remote Sensing Centre.
3. Indian Space Research Organisation.
4. Landsat satellite datasets.
5. Sentinel-2 satellite imagery.
6. Central Pollution Control Board.
7. Uttar Pradesh Pollution Control Board.
8. Ministry of Environment, Forest and Climate Change.
9. Uttar Pradesh State Action Plan on Climate Change.
10. Published scientific research and environmental reports.

7.4 Remote Sensing and GIS Techniques

Remote sensing and Geographic Information Systems (GIS) are important tools for analysing spatial environmental changes.

The proposed study may use satellite imagery from different periods to identify changes in land-use and land-cover categories.

The suggested observation years are 1991, 2001, 2011, 2021 and 2026, subject to satellite data availability, comparable seasonal conditions and image quality.

The principal land-use classes include:

- Built-up land.
- Agricultural land.
- Vegetation and forest cover.
- Water bodies.
- Barren and open land.
- Wetlands.

7.5 Assessment of Land-Use and Land-Cover Changes

The percentage change in a land-use category can be calculated as:

\[\%\ Change=\frac{A_2-A_1}{A_1}\times100 \]

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Where:

- \(A_1\) = Area of a particular land-use category in the initial year.
- \(A_2\) = Area of the same category in the final year.

The analysis can help determine whether built-up land, vegetation, agricultural land and water bodies have increased or decreased over the selected observation period.

7.6 Assessment of Land Surface Temperature

Land Surface Temperature (LST) is an important indicator of the thermal characteristics of urban and rural environments.

It can be estimated from thermal satellite observations after appropriate radiometric, atmospheric and emissivity corrections.

The relationship between vegetation cover and land surface temperature can be examined using the Normalised Difference Vegetation Index (NDVI):

\[NDVI=\frac{NIR-Red}{NIR+Red} \]

Where:

- NIR = Near-infrared reflectance.
- Red = Red-band reflectance.

Higher vegetation density generally contributes to lower surface temperatures, although the relationship varies with soil moisture, season, vegetation type and surface characteristics.

7.7 Statistical Techniques

The following statistical techniques are proposed:

Statistical technique	Purpose
Percentage analysis	Assessment of land-use distribution
Mean and standard deviation	Descriptive environmental analysis
Linear regression	Temperature and rainfall trends
Pearson correlation	Relationships between environmental variables
Multiple regression	Assessment of multiple environmental influences
Chi-square test	Categorical survey analysis
ANOVA	Comparison of environmental observations
GIS change detection	Spatial land-use transformation
NDVI analysis	Vegetation assessment
LST analysis	Thermal condition assessment

8. Land-Use and Land-Cover Transformation in Agra

Land-use transformation is one of the important indicators of environmental change. Increasing demand for residential, commercial and industrial infrastructure can alter the spatial distribution of natural and agricultural landscapes.

8.1 Expansion of Built-Up Areas

The expansion of built-up areas is associated with population growth, infrastructure development, road connectivity and economic activities.

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A 2023 study by Gavsker and colleagues, published in Sustainable Cities and Society, examined urban growth and surface thermal characteristics in Agra using geospatial analysis for 1991–2021. It reported an increase in mean land surface temperature of 8.76°C over the study period, equivalent to approximately 0.292°C per year. This is a study-specific satellite-derived result and should not be interpreted as an increase in standard meteorological air temperature.

ScienceDirect

8.2 Transformation of Agricultural Land

Agricultural land in peri-urban areas may be converted into residential colonies, commercial establishments, roads and industrial infrastructure.

Such conversion can have several ecological consequences:

1. Reduction in agricultural land availability.
2. Loss of natural vegetation.
3. Changes in soil characteristics.
4. Reduction in agricultural biodiversity.
5. Increased surface runoff.
6. Modification of local ecological processes.

A 2025 study of Agra's peri-urban interface, covering 1981–2021, reported that built-up area increased from 20.87 to 100.62 square kilometres, while agricultural land declined from 208.13 to 154.35 square kilometres. The study also reported declines in forest cover and water bodies. These figures relate to the study's defined peri-urban boundary, not the entire Agra district.

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8.3 Changes in Vegetation Cover

Vegetation cover plays an important role in regulating local environmental conditions.

The removal of vegetation may increase solar heat absorption, reduce carbon storage, disturb soil moisture and affect biodiversity.

The conservation of urban parks, roadside plantations, riverbank vegetation and peri-urban green spaces is therefore essential.

8.4 Changes in Water Bodies

Urban development may affect ponds, wetlands and natural drainage systems through encroachment, pollution and changes in water inflow.

The conservation of water bodies is particularly important in semi-arid environments because they support biodiversity, groundwater interactions and local climatic regulation.

9. Urban Heat Island Effect in Agra

The urban heat island (UHI) effect refers to the phenomenon in which urban areas experience higher temperatures than surrounding rural areas, primarily due to differences in land cover, surface materials, urban geometry and human activities.

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9.1 Major Causes of Urban Heat Islands

The principal causes include:

- Expansion of concrete and asphalt surfaces.
- Reduction in vegetation cover.
- Increased building density.
- Heat released from vehicles and machinery.
- Changes in surface reflectivity.
- Limited natural ventilation.
- Reduced soil moisture.

9.2 Evidence from Agra

Research by Gavsker et al. (2023) identified a substantial increase in urban land surface temperature in Agra during 1991–2021. The study associated the changing thermal characteristics with urban expansion and changes in biophysical land-surface conditions.

ScienceDirect

More recently, Dubey et al. (2026) examined urban and rural temperature patterns in Agra using ERA5 two-metre temperature data for 1961–2020. Their research reported that urban locations experienced higher temperatures than rural areas, particularly during winter and pre-monsoon seasons. It also found that the urban-rural temperature difference had decreased in recent decades as rural temperatures increased.

Sage Journals

These studies demonstrate that the relationship between urbanisation and local temperature is complex and requires analysis of both urban and surrounding rural environments.

9.3 Environmental Consequences

The urban heat island effect may contribute to:

1. Increased heat exposure among urban residents.
2. Greater energy demand for cooling.
3. Higher water requirements.
4. Thermal stress on urban vegetation.
5. Changes in urban habitat conditions.
6. Increased vulnerability of elderly and other heat-sensitive populations.

9.4 Measures for Mitigation

The following measures are recommended:

- Development of urban green belts.
- Protection of existing trees.

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- Plantation of suitable native species.
- Green roofs and walls where appropriate.
- Use of reflective and thermally efficient building materials.
- Protection of urban water bodies.
- Climate-sensitive urban planning.

10. Climate Change and Regional Environmental Vulnerability

Climate vulnerability refers to the extent to which natural and human systems are susceptible to adverse climatic effects.

The Agra region requires particular attention because of its seasonal temperature extremes, dependence on water resources and sensitivity to rainfall variability.

10.1 Temperature Variability

Temperature variations influence evaporation, soil moisture, crop growth and ecological processes.

The Uttar Pradesh State Action Plan on Climate Change provides an important framework for understanding the climatic risks affecting different sectors of the state.

According to the Ministry of Environment, Forest and Climate Change climate action dashboard, Uttar Pradesh experienced increasing annual maximum and minimum temperature trends during 1980–2019. The state-level assessment also identified declining rainfall trends and increasing dry days. These state-level observations should be supplemented with Agra-specific meteorological records.

MoEFCC

10.2 Rainfall Variability

Rainfall is an important factor influencing agricultural productivity, groundwater recharge and wetland hydrology.

Gardner (2025) investigated precipitation patterns in Agra district using a century-long historical series covering 1922–2022. The study projected an average annual precipitation of approximately 590 mm for 2022–2031, compared with a historical mean of approximately 644 mm. This represents a model-based forecast rather than an observed rainfall total.

Geografiya i prirodnye resursy

10.3 Water Resource Vulnerability

Water-resource vulnerability may arise from:

- Excessive groundwater extraction.
- Seasonal rainfall variability.
- Increasing domestic consumption.
- Industrial demand.
- Agricultural irrigation requirements.
- Contamination of surface and groundwater.

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10.4 Agricultural Vulnerability

Climate variability can affect crop production through changes in temperature, rainfall and soil moisture.

Agricultural vulnerability may be reduced through improved irrigation management, drought-resistant crop varieties, crop diversification and conservation agriculture.

10.5 Urban Climate Vulnerability

Urban areas may experience increased vulnerability due to dense construction, inadequate drainage, limited vegetation and high concentrations of people and economic activities.

Climate-resilient infrastructure and heat-action planning are therefore important for the future development of Agra.

11. Impact of Urbanisation on Biodiversity

Urbanisation affects biodiversity through direct habitat loss, habitat fragmentation, pollution and changes in ecological connectivity.

11.1 Habitat Fragmentation

Habitat fragmentation occurs when continuous natural habitats are divided into smaller and isolated patches.

In Agra, the expansion of residential and commercial infrastructure may affect the continuity of vegetation and natural habitats.

The consequences include:

- Reduction in suitable wildlife habitats.
- Isolation of species populations.
- Disturbance of animal movement.
- Reduction in breeding opportunities.
- Increased human-wildlife interaction.

11.2 Impact on Bird Diversity

Bird populations are influenced by habitat availability, vegetation structure, food resources, water quality and climatic conditions.

Wetlands and riverine ecosystems provide important feeding and resting habitats for migratory and resident birds.

Sur Sarovar Bird Sanctuary is particularly important in this regard. Its conservation requires protection against pollution, excessive human disturbance, invasive vegetation and habitat modification.

11.3 Impact on Aquatic Biodiversity

Aquatic biodiversity is influenced by water temperature, dissolved oxygen, nutrient availability and pollution levels.

Changes in water quality may affect fish, plankton, aquatic vegetation and other freshwater organisms.

The Yamuna River and associated wetlands therefore require continuous ecological monitoring.

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11.4 Impact on Agricultural Biodiversity

Changes in agricultural land-use patterns may affect traditional crop varieties, soil organisms, pollinators and beneficial insects.

Sustainable agricultural practices can help maintain ecological diversity while supporting agricultural productivity.

12. Major Environmental Challenges in Agra

Table 1: Major environmental challenges and their ecological implications

Environmental problem	Major driving factor	Potential ecological impact
Air pollution	Vehicles, industries and dust	Vegetation and human health impacts
Water pollution	Sewage and industrial discharge	Aquatic biodiversity degradation
Groundwater depletion	Excessive extraction	Water-resource stress
Urban heat island	Built-up expansion	Increased thermal stress
Habitat fragmentation	Infrastructure development	Loss of ecological connectivity
Wetland degradation	Encroachment and pollution	Loss of aquatic habitats
Soil degradation	Unsustainable land management	Reduced soil quality
Climate variability	Changing temperature and rainfall	Ecosystem vulnerability
Solid waste	Inadequate disposal	Soil and water contamination
Vegetation loss	Urban expansion	Reduced ecological services

13. Quantitative Evidence from Published Research

The following table presents selected published findings that provide empirical context for this research.

Table 2: Selected published findings relating to environmental change in Agra

Research indicator	Published finding	Study period
Increase in mean land surface temperature	8.76°C	1991–2021
Annual LST increase rate	0.292°C/year	1991–2021
Peri-urban built-up area, initial	20.87 sq. km	1981
Peri-urban built-up area, final	100.62 sq. km	2021
Increase in peri-urban built-up area	382.13%	1981–2021
Peri-urban agricultural land, initial	208.13 sq. km	1981
Peri-urban agricultural land, final	154.35 sq. km	2021
Forecast average annual precipitation	Approximately 590 mm	2022–2031

Sources: Gavsker et al. (2023); peri-urban LULC research (2025); Gardner (2025).

ScienceDirect+2

Interpretation

The available evidence suggests that urban growth and land-use transformation have been associated with significant changes in the thermal and spatial characteristics of Agra.

The expansion of built-up land and reduction in agricultural and natural land cover are particularly important concerns for environmental sustainability.

However, the figures in Table 2 represent results from different studies, geographical boundaries and methodologies. They should not be combined as if they were observations from one uniform dataset.

14. Proposed Environmental Vulnerability Assessment

An environmental vulnerability assessment can help identify locations that are particularly susceptible to ecological degradation and climate-related risks.

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The following framework is proposed.

Table 3: Environmental vulnerability indicators for Agra

Environmental dimension	Indicators	Assessment method
Climatic vulnerability	Temperature and rainfall variability	Meteorological analysis
Land vulnerability	Built-up expansion and vegetation loss	GIS analysis
Water vulnerability	Groundwater levels and water quality	Field and secondary data
Biodiversity vulnerability	Species richness and habitat fragmentation	Ecological surveys
Agricultural vulnerability	Crop productivity and irrigation dependency	Agricultural statistics
Urban vulnerability	Heat exposure and drainage conditions	Spatial and field analysis
Wetland vulnerability	Water spread and habitat quality	Remote sensing and field surveys

14.1 Environmental Vulnerability Index

A composite environmental vulnerability index may be developed to compare different locations.

A generalised model is:

\[EVI=\frac{\sum_{i=1}^{n}w_iX_i}{\sum_{i=1}^{n}w_i} \]

Where:

- EVI = Environmental Vulnerability Index.
- \(X_i\) = Normalised environmental indicator.
- \(w_i\) = Assigned weight of the indicator.
- \(n\) = Total number of indicators.

Higher index values can represent greater environmental vulnerability, provided that the indicators are consistently normalised and oriented.

The weights should be established through a transparent method such as expert consultation, principal component analysis or an appropriately justified analytical hierarchy process.

No numerical EVI values are assigned in this paper because the required location-specific dataset has not yet been collected.

15. Sustainable Urban Development Strategies

15.1 Compact Urban Development

Compact urban planning can help reduce unnecessary conversion of agricultural and natural landscapes.

It may be achieved through:

- Planned urban expansion.
- Improved utilisation of existing infrastructure.
- Protection of environmentally sensitive zones.
- Sustainable public transport.
- Appropriate zoning regulations.

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15.2 Green Infrastructure Development

Green infrastructure can improve urban environmental conditions by providing ecological connectivity and regulating local temperatures.

Recommended interventions include:

1. Urban forestry.
2. Green belts.
3. Roadside plantations.
4. Institutional green spaces.
5. Green roofs.
6. Restoration of urban parks.
7. Protection of natural vegetation.

15.3 Sustainable Water Management

Water management is essential for ecological sustainability in Agra.

Important measures include rainwater harvesting, wastewater recycling, efficient irrigation and groundwater monitoring.

15.4 River and Wetland Restoration

The Yamuna River and Sur Sarovar require long-term ecological protection.

Conservation programmes should prioritise wastewater treatment, prevention of encroachment, habitat restoration and regular biodiversity assessment.

15.5 Climate-Resilient Infrastructure

Climate-sensitive infrastructure should incorporate:

- Sustainable drainage systems.
- Heat-resistant building design.
- Energy-efficient buildings.
- Urban water conservation.
- Disaster-resilient planning.
- Adequate urban vegetation.

16. Role of Government Institutions and Environmental Policies

Environmental sustainability requires coordinated institutional action.

The following institutions have important roles in regional environmental management.

Institution	Major responsibility
Ministry of Environment, Forest and Climate Change	Environmental policy and climate action
Uttar Pradesh Forest Department	Forest and wildlife conservation
Uttar Pradesh Pollution Control Board	Pollution monitoring and regulation

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Central Pollution Control Board	National pollution-control framework
Agra Municipal Corporation	Municipal waste and urban environmental management
National Mission for Clean Ganga	River conservation and wastewater management
India Meteorological Department	Weather and climate observations
National Remote Sensing Centre	Satellite-based environmental information
Academic institutions	Research, monitoring and environmental education

16.1 National and State Policy Framework

The study can be aligned with the following policy frameworks:

- National Action Plan on Climate Change.
- Uttar Pradesh State Action Plan on Climate Change 2.0.
- National Water Policy.
- National Biodiversity Action Plan.
- Wetlands (Conservation and Management) Rules, 2017.
- Environment (Protection) Act, 1986.
- Water (Prevention and Control of Pollution) Act, 1974.
- Air (Prevention and Control of Pollution) Act, 1981.

These frameworks provide the policy foundation for addressing environmental pollution, climate adaptation, biodiversity protection and sustainable resource utilisation.

17. Major Findings

The review of published research and environmental information leads to the following findings:

1. Urbanisation is an important driver of land-use transformation in Agra.
2. Built-up expansion has been associated with changes in the thermal characteristics of the urban landscape.
3. Published geospatial research indicates substantial growth of built-up land in Agra during the last several decades.
4. Agricultural land and natural vegetation in peri-urban areas face increasing conversion pressures.
5. Urban heat island effects require attention in the context of regional climate vulnerability.
6. Changes in temperature and rainfall can influence water availability and ecological functioning.
7. The Yamuna River and Sur Sarovar are important ecological assets requiring continuous conservation.
8. Habitat fragmentation and wetland degradation can adversely affect biodiversity.
9. Climate-resilient infrastructure and green urban planning can help reduce environmental vulnerability.
10. Long-term environmental monitoring is necessary for evidence-based regional planning.

18. Recommendations

The following recommendations are proposed:

1. Strengthening land-use planning: Environmentally sensitive areas, wetlands and important agricultural landscapes should be protected through scientific spatial planning.

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2. Increasing urban green cover: Municipal authorities should promote native vegetation and develop interconnected green spaces.
3. Controlling urban heat: Reflective construction materials, urban forestry and climate-sensitive building design should be encouraged.
4. Improving water management: Rainwater harvesting, wastewater recycling and groundwater monitoring should be strengthened.
5. Protecting biodiversity: Systematic surveys of birds, vegetation, mammals and aquatic organisms should be undertaken.
6. Conserving wetlands: Sur Sarovar and other regional water bodies should receive regular ecological assessments.
7. Promoting sustainable agriculture: Climate-resilient farming, soil conservation and efficient irrigation should be encouraged.
8. Strengthening pollution control: Industrial effluents, sewage discharge and solid waste disposal should be monitored effectively.
9. Developing climate information systems: Agra-specific climatic datasets should be maintained for long-term research and planning.
10. Encouraging public participation: Local communities, schools, universities and NGOs should participate in environmental conservation.

19. Future Scope of Research

The present paper provides a foundation for several future investigations.

- Multi-temporal GIS analysis of Agra's urban expansion.
- Assessment of urban heat island intensity using Landsat and ERA5 datasets.
- Prediction of land-use changes through Cellular Automata and Markov models.
- Climate vulnerability mapping of urban and rural Agra.
- Analysis of the impact of urban expansion on wetland biodiversity.
- Assessment of groundwater quality and availability.
- Relationship between vegetation cover and surface temperature.
- Evaluation of environmental awareness among urban and rural residents.
- Development of an integrated urban ecological sustainability index.
- Comparative study of ecological conditions in urban, peri-urban and rural environments.

20. Conclusion

Urbanisation, climate change and land-use transformation represent interconnected challenges for environmental sustainability in the Agra region of Uttar Pradesh. The expansion of built-up areas, conversion of agricultural land, reduction in natural vegetation and increasing pressure on water resources have important implications for the ecological stability of the region.

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The published research reviewed in this paper provides evidence of changes in Agra's land-use patterns and surface thermal characteristics. The reported increase in land surface temperature and substantial expansion of built-up areas in peri-urban locations demonstrate the importance of incorporating ecological considerations into urban development planning.

Climate variability further increases environmental vulnerability by influencing rainfall, temperature, groundwater recharge, agricultural production and wetland hydrology. These processes may collectively affect biodiversity and the ecological services provided by the Yamuna River, Sur Sarovar and surrounding natural habitats.

The study emphasises that sustainable urban development must move beyond infrastructure expansion and incorporate environmental protection as an essential planning objective. Conservation of green spaces, restoration of degraded habitats, protection of wetlands, sustainable water management and climate-resilient infrastructure should form the foundation of regional environmental policy.

An integrated approach combining remote sensing, GIS, ecological fieldwork, statistical analysis and community participation can help establish a stronger scientific basis for sustainable development in Agra.

The long-term environmental future of Agra depends on the ability of its institutions and communities to balance urban growth with biodiversity conservation, climate adaptation and responsible natural-resource management.

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