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Special Issue: Urban Growth and Infrastructure

Institute of Town Planners, India
New Delhi

Institute of Town Planners, India

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JOURNAL OF ITPI

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Journal of ITPI

Editorial

Rapid urbanization has been a global phenomenon, with more than half of the global population living in the urban settlements. As per the estimates of United Nations, nearly 70 percent of the world population is expected to live in the towns and cities by 2025. Consequent to the rapid urbanization, the cities are facing the challenges of rapid urban sprawl, housing shortage, infrastructural deficiencies, environmental degradation, etc. The municipal bodies are starved of finances for development, maintenance, and management of basic amenities. Climate change has worsened the conditions under the present ways and patterns of development. International and national agencies are on the task to suggest mitigation strategies for better quality of life in the future cities.

Prof. Veena Garella has made comprehensive efforts to gather information on the impacts of climate change on the urban growth and infrastructural aspects of human habitat. She has taken different aspects, as viewed/ expressed by experts and institutions, to deliver what is required to be done to make the quality of life in the future cities conducive.

In the paper titled 'Peri-Urbanisation in National Capital Region of Delhi - A Spatial Temporal Analysis', Sunil and Dr. Sanjukkta Bhaduri have viewed that there is no consensus on the methodology to delineate the peri-urban area. They have attempted to review the delineation process of the rural urban fringe and have also attempted to delineate the same in the National Capital Region of Delhi. Factors like distance from metropolitan centres, transport infrastructure and commercial & industrial centres, as points of attractions/opportunities, have been analyzed to assess their relative importance in the delineation of the peri-urbanization in the NCR of Delhi. The research reveals that every fifth settlement in the NCR is peri-urban. Distance from the commercial and industrial centres and transport infrastructure were found to be important causative factors towards peri-urbanization.

Ruma Pal, Dr. Arup Guha Niyogi, and Dr. Jayita Guha Niyogi in their paper titled 'Spatio-temporal Dynamics of LULC in Baruipur Municipality around South Kolkata' have identified that urban sprawl of Kolkata is mostly directed southward i.e. towards the Baruipur municipality. The objective of their research is to monitor the efforts to replace the pockets of water bodies, greeneries, orchards and crop fields with built up facilities resulting in fragmented land use that would need longer haul to connect them to end-users. They have recommended facility planning approach to enhance local accessibility and reduce travel instead of a unified hierarchical neighbourhood.

In the third paper titled 'An Assessment of Relationship Between Industrialization and Urbanization in Bhiwadi Region of Rajasthan: A Spatio-Temporal Analysis' Vinod Kumar, Vikas Rawat, Veena Sanadhya, and M.S. Negi have tried to examine the relationship between industrialization and the urbanization process in Bhiwadi industrial area. Indicators such as capacity of workers, trends in urban population, industrial status, and the extent of built-up or infrastructure areas were studied. Normalized difference built-up index (NDBI) was used to identify the changes in the land use and land cover for two decades i.e. 2000 to 2020.

The fourth paper by Hasna P. on the topic 'Eco Tourism Concept: A Case for Ottappalam - Shoranur Region' is an attempt to appreciate the eco-tourism initiatives for the Ottappalam-Shoranur region towards sustainable environmental, social, and economic development along with livelihood empowerment. The research reflects that the region under study has many unutilized tourism potentials such as scenic beauty in the backdrop of the Nila River and tangible and intangible heritage, but lack of infrastructure facilities and publicity, improper management of tourist destinations, no tourism development plan have left the region unattended. The research opined that sustainable tourism planning should be done for the region.

Himani Gautam, Varsha Khetrapal Kumar in their paper titled 'Integrating Green Infrastructure for Resilient Cities: A Review Paper' have opined that green infrastructure (GI), a network of natural and semi-natural features integrated into urban areas, is pivotal in building resilient cities. Their research aims to investigate the role of GI in building resilient cities, exploring the multifaceted contributions of nature-based solutions in enhancing urban resilience to environmental, social, and economic challenges. It explores GI's role in urban resilience, tackling rapid urbanization and climate change impacts through case studies. Further, it explores GI principles and components like parks, green roofs, and permeable pavements, emphasizing their benefits. The research concludes that a holistic approach to building urban resilience based on GI is important to address a fuller range of ecosystem disturbances and disasters to create outcomes that develop urban sprawl's environmental and ecological benefits.

In the paper titled 'Assessment and Optimization of Solid Waste Disposal Practices in Srinagar, Garhwal: The Sustainable Approach for Himalayan Region' Anjali Naik, Jyoti Yadav, M. S. Negi, K. S. Bisht have delved into the solid waste disposal practices within the Himalayan region of Srinagar, Garhwal, with a focus on evaluating waste generation rates and types as a primary objective. The research also aims to assess the effectiveness of waste management strategies and formulate sustainable approaches for infrastructure development in hilly terrains. Their analysis reveals that municipal solid waste management in Srinagar is ineffective, marked by poor segregation and handling practices, including the disposal of collected waste in open landfills without employing scientific methods. The research recommends setting specific objectives and deadlines, defining roles and responsibilities for local government entities, nonprofit organizations, and the Srinagar Municipal Authority, allocating sufficient funding, and ensuring proper transportation and disposal of municipal solid waste.

The seventh paper on 'Integrating Waste Management into Urban Planning: Production of Bioethanol through Acid Hydrolysis and Fermentation Using Municipal Organic Waste of Indore City' by Dr. R. N. Singh and Neha Gour has pointed that urban planning is essential for tackling the pressing issue of fossil fuel depletion and fostering sustainable energy solutions. It presents that bioethanol production from municipal organic waste (MOW) is a viable alternative, particularly in cities like Indore, where significant quantities of organic waste are generated. They have suggested that integrating bioethanol production from MOW into urban planning strategies offers multiple benefits, including improved waste management, reduced greenhouse gas emissions, enhanced energy security, and economic development, hence advancing towards a cleaner and greener energy future.

The paper titled 'Developing Blue-Green Infrastructure in Megacities of India: Case of Delhi & Mumbai' by Somya Gupta, Garima Sarwan and Ishani Garg addresses the Blue-Green Infrastructure (BGI) concerns in four major cities i.e. Mumbai, Copenhagen, Delhi, and New York City to evaluate their efforts in promoting sustainable urban development. The research attempts to identify common themes in BGI development across the cities, such as community engagement, multi-stakeholder collaboration, and institutional support. However, it also highlights the unique challenges faced by each city in implementing BGI. The study contributes to the emerging literature on urban resilience and sustainable development, providing insights into the design, implementation, and management of BGI in diverse urban contexts.

The last paper of the volume title 'Uncovering the Impacts of Land Use Change: A Case Study of Open/ Green Areas Converted to Commercial Areas in Bathinda City, Punjab' have expressed that expansion of various activities has put increased pressure on cities to build more spaces. They assessed the spatio-temporal variations in land use and their impact along one of the major commercial streets of Bathinda, Punjab, between 2002 and 2022. Their research reveals that the commercial areas along the mall road have increased at the expense of shrinking green and open areas. These alterations in land use have increased impervious surface coverage, resulting in water logging issues, putting more pressure on the existing road capacity, and causing a loss of sense.

Ashwani Luthra, Ph.D.
Editor & Secretary (Publication)

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Journal of ITPI

Transitioning Urban Growth and Infrastructure into Beating Climate Change: Facts and Enabling

Aggregations and Views of Prof. Veena Garella[1]

1. INTRODUCTION

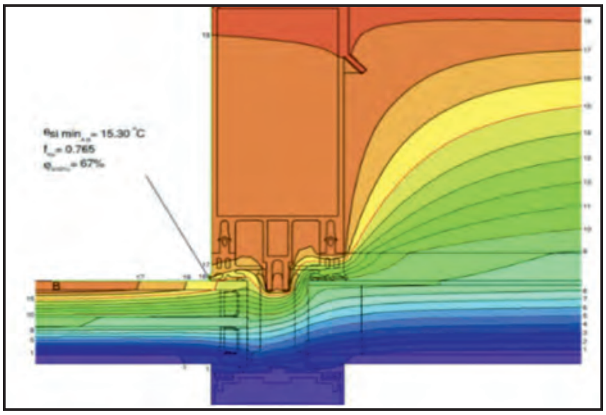
Temperature in cities is getting amplified due to a number of factors which are currently being well shared on several media (as against rural areas) and these happen to be due to fossil fuels used in transportation, building construction materials and energy used in creating indoor comforts. There are several more such factors getting added in the production processes for consumer need satisfaction. But it is well known that wisdom to reduce this anomaly has gone for a toss. The more the heat, the more the devices to circumvent it. All adding up to more atmospheric heat.

2. CONCERNS, IDEAS AND EFFORTS FOR MITIGATING HARMFUL EFFECTS OF CLIMATE CHANGE

- It has been suggested by the president, Paul Marriott, SAP Asia-Pacific and Japan, that India can be leading on climate change and driving sustainability and ESG initiatives for the entire South Asian region. The Asian market is believed to be leading, generating more than 50 percent of global emissions resulting from an innovation based fast growing economy. This creates the right ground work being the leader for climate change, and encouraging Indian firms to invest in sustainability and ESG activities, for reaching its $30 trillion GDP goal by 2047, which Paul Marriott, a technocrat, feels that AI technology is capable of giving businesses a boost to achieve the targets envisaged, which is 10 times from today, and cloud software firms have begun investing significantly in India. Most firms (86 percent) see a positive correlation in sustainability and profitability. Thereby, inciting investments in sustainability and its integration with the carbon and financial data which can help inform decision making.
- An alarming factor is the heat waves on land. Generally, poorly planned cities with heat trapping infrastructure, dwindling natural green and blue areas are responsible for turning up temperature in Indian Cities.
- The current state of urban green spaces and water bodies need to be analyzed for standards and guidelines, identifying critical gaps in quantity, quality and accessibility of the blue green infrastructure in the city region. This is possible through geo-spatial analysis tools, and by examining data over at least 25 years to find out changing patterns which have evolved so that the planning proposals initiated and the initiatives for guiding future improvements in the area are done.
- Some studies have noticed a link of urban centres turning to heat islands with serious impacts on human health and suggest urgent mitigation actions.
- Thermal design of buildings has been an area of concern and there are some who favour a legal framework for it (figure 1). Since there is an inter-connectedness of applied principles of engineering in material selection for facades, the thermal analysis software helps make an effective system beneficial to the design process and the energy efficiency of the system.

[1] *Ex. Professor, School of Planning and Architecture, Delhi*

Figure 1: The Importance of Thermal Analysis in Building Facade Design



Author: CladUp Design Ltd.

- On World Design Day (held April 27, 2024), many have shown concern for beating heat island effects in urban centres. Sanjay Bhardwaj, a writer and partner at team 3 has introduced the concept of 'Kindness Centric Design' which aims at cooling cities and prioritizing human comfort – human wellbeing. In his estimate, green infrastructure is perceived as a powerful tool in combating urban heat islands, creating cooler micro-climates, and fostering community life. Planting trees along streets; integrating green-blue corridors appear to be a tangible step forward for this goal.

  Further, he suggests some initiatives such as,

  - Following the example of Singapore 'Gardens by the Bay' integrating vast green spaces and sustainable technology for cooling the surrounding area – this features super trees, towering vertical gardens that provide shade, harness solar energy, collect rainwater – all of which combats heat, promotes biodiversity and creates a powerful social node.
  - Recharging groundwater and enabling the creation of water bodies which act as natural heat sinks whilst it also replenishes groundwater. Earlier civilization created architectural wonders of baolies, stepwells for some relief and recharging the groundwater providing natural cooling during summers and showcasing the heritage consciousness for sustainable approaches.
  - Traditional thinking revived can help foster social purposes and community feelings whilst providing relief from heat, e.g. having drinking water kiosks in shaded environments on cycle and walkable routes imparting restfulness to a traveller.
  - Neighbourhoods can create cooling zones through rainwater harvesting, rejuvenating any existing water body, creating artificial ponds and lakes, etc.
  - Urban centric master plan preparations have to ensure that the built-up zones and open space ratios have studied the water's percolation potential for maximizing and conserving local water efforts. Water features and vegetation incorporated into modern infrastructure help as heat sinks.
  - In Delhi, the lake at Rajokri was revived through scientific wet land system, giving the city three benefits – ground water recharge, water quality improvement and buffer against flooding. The project also included landscaping for public gatherings, creating green play areas, and constructing rain gardens to prevent flooding and enhance water availability for local needs.
  - Public transportation networks introduced into cities help reduce personal private vehicles on roads, ease congestion, lower vehicle heat transmission, improved Air Quality Index plus reduced temperature; in addition to combating heat, shared transportation nurtures community feel amongst residents.
  - Introducing 'Drinking Water Stations' in a city help support the kindness centric design created in shaded environments to reduce heat stress and allowing an integration into community open space can help form a cohesive society.

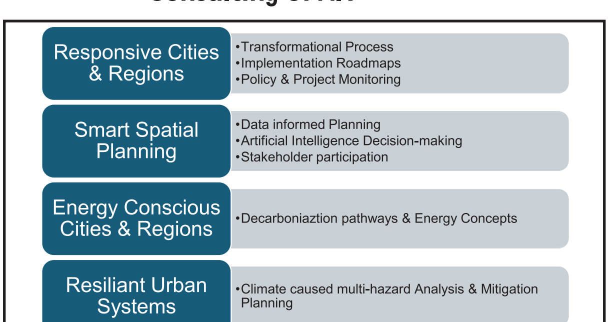
- Buildings designed for sun-breakers, projected eaves (chhajjas) and screens of varying geometric designs help reduce heat gain in buildings. French architect Le Corbusier understood this to introduce such elements in Chandigarh's housing areas in the 1950s.
- In addition, sun tracking panels, automated shading devices also help respond to environmental challenges. Here, the louvres, shades, panels, etc. are just angles based on intensity of heat due to sunlight. Other features such as awnings / fins / canopies also help cast shadows to surfaces helping to avoid external heat of AC units.
- Green roofs are coming into function for insulation, lowering indoor temperature, reducing storm water runoff, thus adding water features to create a sense of relief.

2.1 City Centric Examples from Other Countries

2.1.1 The Austrian Institute of Technology (AIT) is the country's largest research and technology organization dealing with challenges of the future. Figure 2 reveals its research and consultancy areas.

- The organization specializes in addressing transformative challenges related to climate change and energy transition.

Figure 2: Four Pronged Research and Consulting of AIT



- It tracks the success of the policy / strategies / actions - projects through smart monitoring based on tailored key performance indicators (KPIs).
- It customizes app for air quality management / citizen participation.
- Its expertise is into transforming urban centres into energy conscious cities.
- It assesses possible Decarbonization Pathways / Low Carbon Action Plans / Energy Transition Plans.
- Design energy concepts and cost efficient energy retrofitting for entire districts and/or buildings.
- It initiated the TRANSFORM project in a consortium of six leading European cities for low carbon city development, and defining the most effective implementation strategies for cities transmitting to low carbon status.
- AIT provided a strategy against climate change impact, particularly with respect to flood protection through unpaving of surfaces, soil drainage, flood retention basin construction and urban heat exposure mitigation through urban green area cover, networking green areas, balancing green deficit areas.
- Promoting green roofs and facades.

2.1.2 A research document on 'Cities of the future', prepared by future->iQ partners, authored by Lehna Malmkvist, Freija van Duijne, David Beurle.

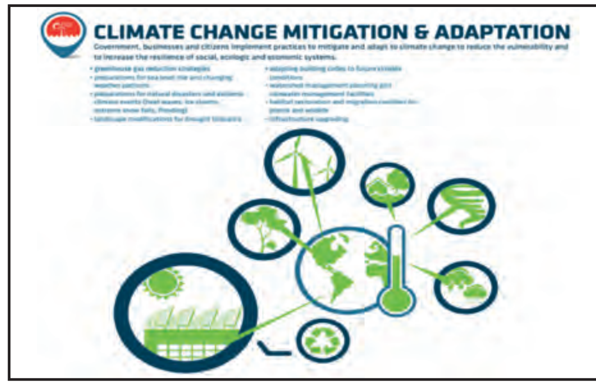
Placed below are some of the strategies perceived to tackle climate change issues in future cities.

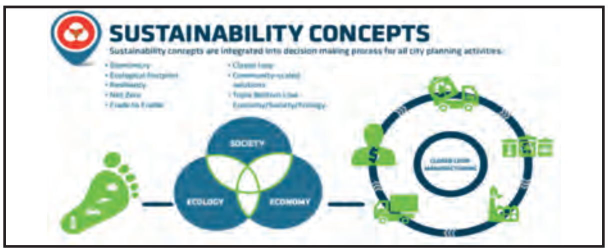
ECOLOGY & SUSTAINABILITY

In the future, cities will mimic the natural processes and functions of ecosystems Including water, nutrient, energy and waste cycles. Habitats of other species are integrated into the land use planning.

We are only recently starting to understand the extent to which ecosystems are e:xtraordinarity valuable to society by providing essential goods and services. Including clean water, fresh air, pollinating Insects and protection from natural disasters.

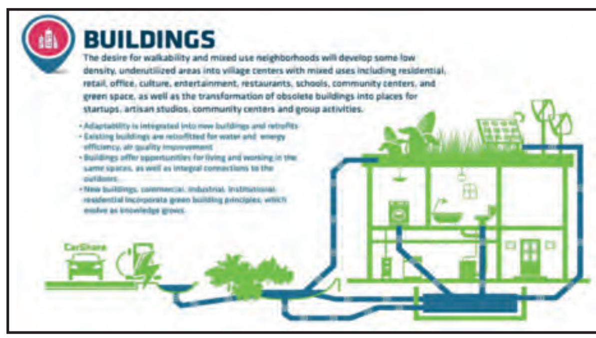

ECOLOGY AND GREEN SPACES
The city is integrated within the ecosystem, green spaces provide provide opportunities for water management, habitat for birds and wildlife, and connections to nature for the community.
• New green spaces and connections are part of re-development
• Green roofs, living walls, and bioremediation facilities provide rainwater management, as well as food and habitat for birds and insects
• The urban forest is regenerating through plating trees and other vegetation in green spaces and roadways
• Water, birds, wildlife and insects and connected through green spaces
• Ecological restoration is part of green space management, including water bodies, and rare and endangered species and communities
URBAN FOREST
HEDGEROWS AROUND AGRICULTURE
PROTECT & RESTORE WATERBODIES
RAINWATER CAPTURE
SOLAR PANELS
LIVING WALLS
WIND TURBINE
GREEN ROOF

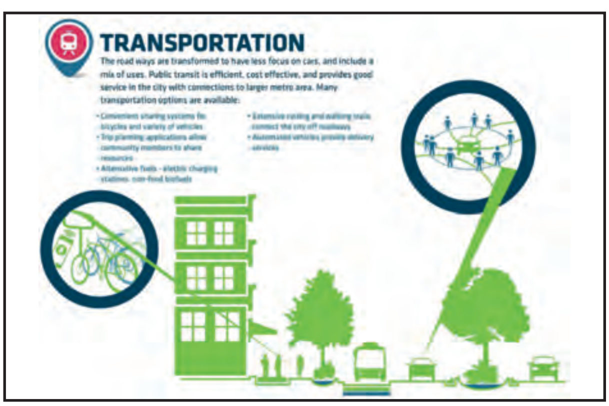

CLIMATE CHANGE MITIGATION & ADAPTATION

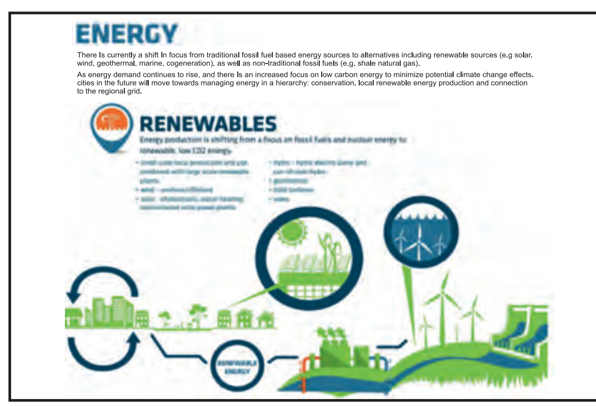

SUSTAINABILITY CONCEPTS
SOCIETY
ECOLOGY
ECONOMY

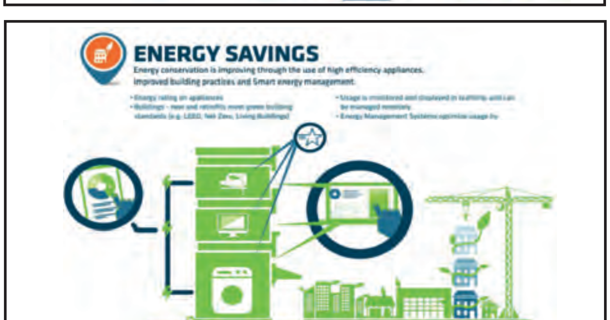

WATER

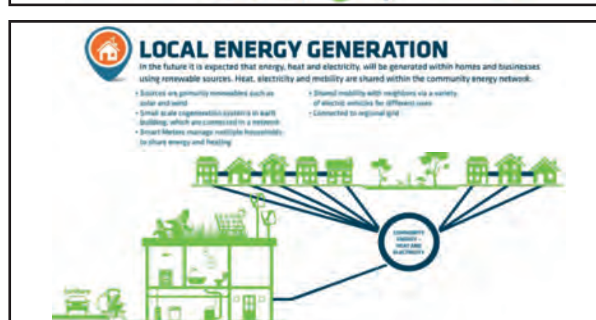

WASTE
COMPOST


BUILDINGS
The desire for walkability and mixed use neighborhoods will develop some low density, underutilized areas into village centers with mixed uses including residential, retail, office, culture, entertainment, restaurants, schools, community centers, and green space, as well as the transformation of obsolete buildings into places for startups, artisan studios, community centers and group activities.


TRANSPORTATION


ENERGY
There Is currently a shift In focus from traditional fossil fuel based energy sources to alternatives including renewable sources (e.g solar. wind, geothermal. marine. cogeneration). as well as non-traditional fossil fuels (e.g. shale natural gas).
As energy demand continues to rise, and there Is an increased focus on low carbon energy to minimize potential climate change effects. cities in the future will move towards managing energy in a hierarchy: conservation. local renewable energy production and connection to the regional grid.
RENEWABLES


ENERGY SAVINGS


LOCAL ENERGY GENERATION

2.1.3 A status report (prepared by Kasper Benjamin, Consultant activist - Head of innovation) and currently in circulation of the system's collapse looks at three notable factors to watch closely. A) Earth system trends B) Socio-economic trends C) Health system trends. It lists following 18 factors to be watched closely.

Earth System Trends

- Greenhouse gas emissions have never been higher.
- 70 percent of the world's animals have died and they are dying 1,000 times faster than ever before.
- 75 percent of the world's surface and 66 percent of the marine environment have been destroyed and altered.
- 80 percent of all rainwater now contains microplastics and toxic chemicals.
- 4-5 tipping points are dangerously close to being transgressed, making irreversible climate change a reality.
- 86 percent of all insects on the planet have died.

Socio-economic Trends

- 1 percent of the population owns 50 percent of the world's wealth.
- According to the World Inequality Report, more people live in absolute poverty today than in 1820.
- Unequal exchange and inequality have never been higher.
- Civil unrest around the world has doubled in the last decade.
- We have never been more polarized.
- UN calls this age 'A New Era of Conflict and Violence'.

Health System Trends

- We have never been more lonely.
- Life expectancy has gone up, but we live less quality years because we are sicker than ever.
- Lifestyle diseases are affecting an increasing 75 percent of the population.
- Greenhouse gas emissions have never been higher.
- Human fertility has declined 50 percent since the 1950s.
- Even though we live closer, more connected than ever, we have never been more depressed, lonely, anxious, and stressed.

2.1.4 The State of Global Climate Report 2023 by the World Meteorological Organization reveals that most climate change indicators reached record levels in 2023. It confirmed 2023 to be the hottest year since we started recording global temperatures. Records were also broken for ocean heat, sea level rise, Antarctic Sea ice loss and glacier retreat. UNDP experts Caitlin Wiesen (resident representative of UNDP India) and Ashish Chaturvedi (head Action for Climate and Environment, UNDP India), whilst presenting their views on planet Earth being under stress and impacting people's right to live a healthy life … have questioned humanity's dependence on nature, yet harming nature and harming humanity … There is an urgent need to restore harmony with nature.

- India's fast growing economy has made strides to de-couple emissions from economic growth achieving two National Determined Contribution (NDC) targets with reduced emission intensity of its GDP by nearly 35 percent from 2005 level, and achieving 40 percent electric power installed capacity from non-fossil fuel sources, ahead of the target year 2030.

- Vulnerability to climate change is still very high, as more than 80 percent of the population lives in areas that are at risk of climate induced disasters; these factors manifest into crises affecting livelihoods, food security, and enlarging the existing socio-economic inequalities. Experts wish to put climate change in the purview of constitutional fundamental rights, thereby 'Legal Accountability of Climate Action'.
- Climate actions for national level and state level action plans should have capacities to drive the allocation of funds, functions, functionaries.
- The UNDP has considered the climate change framework law (prepared by London School of Economics) for sixty countries giving them strategic direction for national policies that go beyond targets under global environment convention.
- In brief, the framework law helps strengthen climate governance by building effective institutional frameworks and processes in an ambitious way, plus making it stringent with attached accountability, exchange of knowledge and ideas, creating a forum for sharing best practices can bring about coherence between states and union territories.
- Further, it suggests extensive knowledge sharing within stringent accountability stating that 18 of the Indian States and UTs have moderate to high vulnerability to climate change, and recommends sharing of best practices for implementing policies and action plans. It also suggests initiating a 'ONE HEALTH' scheme and bring together Ministries, Departments of Health, Environment, Science, Technology for disease control, research, pandemic preparation, ….as well as integrate the private sector for a 'Right-Based Approach to Climate Action' in their core operations.
- Locating SDGs has been initiated with States & UTs having learnt to create road maps and monitoring systems where participation has been enabled and encouraged from business houses, NGOs, citizens indicating a collaborative approach to achieve SDGs.
- Environment Laws can be leveraged to empower citizens groups for a Right-based Dialogue on environment, biodiversity, climate change. This helps build consensus and reduce tension.

2.1.5 Wild Life Conservation

Further, when planning for Wild Life Conservation, (in one case, where a solar energy park was developed.. it was noticed that it could endanger a bird species- Indian Bustard… it was viewed that a citizens right to be protected from climate change can’t be overruled…. it is necessary to expand renewable energy capacity

2.1.6 Indian Culture

Indian culture and traditions have respect for Mother Earth as a living thing. It is not a resource and is commemorated as Mother Earth Day since 2009, on April 22, so whilst hearing a case of changing classification of forest land, the Madras High Court (in 2023) granted it the status of a legal person with rights, duties, liabilities to preserve and conserve it.

2.1.7 Socio-economic Inequality

Climate change can exacerbate Inequality and may even create new forms of injustice

- Competing for resources has negative impacts on the poor, vulnerable, marginalised; perhaps make it starker
- Climate change is not natural, nor resulting from Darwin's Theory of Natural Selection... it being a result of human activity such as
  - o Using Fossil Fuels, Deforestation, exhausts of Carbon Dioxide trapping heat- warming-climate change-global warming
  - o Methane and Nitrogen Oxide from the dropping of from the what animals eat
  - o Gases from driving, use of iPhones, laptops, aerosol sprays ..... heat is thus created and carbon footprint from both natural and human activities.

Inequalities are further exacerbated with the economic ones dividing the world into rich and poor. Already economically-socially-geographically vulnerable face higher impacts of climate change sending them down further.

The current carbon control has been deemed unfair to some countries And climate justice can cover the divide of gender/ tribe/ culture/ community/race... all of which requires inclusive approach.

2.1.8 Report of the Indian Metrology Department

Findings of the Indian Metrological Department (IMD) state that there is a fall in the solar radiation in India and that radiation which is converted to electricity by solar panels has shown alarming decreasing trend in several locations in India, causes being aerosol load,fossil fuel burning, dust, fine particles of carbon emissions, clouding that causes it. Hence, there is a need for more efficient solar panels.

Aerosols absorb sunlight to deflect it from ground to form dense clouds that again block sunlight affecting the sunlight falling on panels. Radiation of 45 in house stations where solar radiation could be measured, but computation was done for 13 to compute changes in Solar Photovoltaic (SPV) potential which had records from 1985-2019.

Cities where decline was observed include Ahmedabad, Chennai, Goa, Delhi, Pune, Shillong, Jodhpur, Kolkata, Mumbai, Nagpur, Trivandrum, Visakhapatnam.

- Solar parks in Gujarat & Rajasthan have shown decrease in SPV potential.
- Installed solar power capacity is 81 GW (1GW=1000megawatt)... say 17 percent of total installed electricity.
  - o Plans are afoot to source 500 GW from non fossil fuel sources by 2030.
  - o 280 GW from solar power by adding 40 GW annually until 2030.
  - o 25-40 GW annually planned.

2.1.9 Report of 'State of Climate in Asia" by World Metrological Organisation-2023 states impact on India as under

- Asia has warmed faster than global average since 1960.
- 2023 was the warmest on record.
- Alarming gap between climate projections and Asian countries ability to adapt to, mitigate CC impacts.

- o than 3000 people killed by heat.
- o 9000 affected by extreme climate events.
- 80 percent were due to storms & floods
  - o heat related mortality under reported.
  - o In India severe heat waves killed 110 people in 23 April and June.
  - o Heatwaves prolonged in S & SE Asia in April, May, affecting Bangladesh and eastern India.

2.1.10 Economy and Green Growth

Reserve Bank of India in its recent Monetary Policy Report (April 2024) has shown concern on extreme weather events/ climate shocks, all of which reflect food inflation in the financial stability of country's economy.

Central Banks Monetary Policy allows maximum economic output whilst checking on inflation.

New Keynesian Model makes distinction between 'no climate change' and 'Physical Climate Risk Damage Function' for estimating the latter's 'macro-economic impacts of climate change'.

It states, if climate mitigation policies are absent, outputs may lower by 9 percent by 2050. This could result in higher interest rates for curbing inflation by central banks, which could lead to greater output loss. Hence, RBI is incrementally transitioning into the 'Green Economy', thus requiring 17 trillion dollars to achieve Net Zero Ambitions by 2070.

In Europe, a Green Taxonomy shall help aid Eurozone's economic value chain.

India has issued Sovereign Bonds to the tune of Rs. 16,000 crores to expand resource pool as well as allow foreign institutional investors to participate in future 'Green Growth Securities'.

2.1.11 Forests and Green Credits

- Ministry of Environment (October 2023), announced the 'Green Credit Program', a market driven mechanism where individuals and companies can claim Incentives, called 'Green Credits' for contributing to 'Environmental and Ecological Restoration'.
- Some are questioning the incentives and the manner of granting them, even if by Command and Control and suggesting this be done for both 'Water Conservation and Afforestation'.
- It should also help restore degraded forests, care for existing areas of bushes, penalise uprooting of trees, and state about the 200 types of forests existing in India…. avoid monoculture, and take extensive care of local biodiversity soil health local community engagement growth of natural forests in the coming 10-15 years.
- Devising a logical and credible system for 'Green Credits' is considered a must so it isn't misused.
- It also suggests that when reviving an ecosystem, there must be accountability for how much of carbon is captured by how many units of ecosystems
- Also, to ensure that having green credits does not imply any forest clearance for setting up any industry or commercial units.

2.1.12 Warming of Indian Ocean

Indian Ocean is observed to have warmed up by 1.2* Celsius between

1950-2020, and is expected to heat up further by 1.7* Celsius to become 3.8* Celsius.

- This can give rise to 'Marine Heatwaves' and its counterparts in the sea.
- It is expected that formation of cyclones will increase 10 times from the current average of 20 days per year to 220-250 days per year.
- Global warming will impact Indian Ocean into a 'near permanent heat wave state', and accelerate coral bleaching, sea grass destruction, loss of kelp forests, loss of fisheries.... as per the findings of Indian Institute of Tropical Metrology (IITM) Pune.
- Heating in the ocean has gone deeper, increasing the overall 'Heat Content' of the ocean. At a depth of 2000 metres it is currently increasing at 4.5 zeta joules per decade and is predicted to increase at a rate of 16- 22 zeta joules per decade in future (Joule is a unit of energy; 1 zeta joule=1 billion trillion joules).
- This equates to adding the heat content equivalent of 1 Hiroshima atom bomb detonation every second/ all day / every day for a decade (Scientists at IITM).
- Sea level rise due to heating (thermal expansion of water) will lead to increased volume of water which will lead to more than half of the sea level rise in the Indian Ocean.

2.1.13 Climate Change Preparations by Industrial Houses

Corporate achieving Net Zero status by 2030.

Grundfos Pumps India aims to achieve Net Zero status by 2030.

Grundfos Pumps is a water solution company getting ready to making its India plant achieve Water and Energy targets by 2030, as stated by its India country President Usha Subramanian, at its plant at Thoraipakkam which was a platinum certified 'Green Building' (the first one), by Leadership in Energy and Environment Design (LEED);

Further, it is likely to achieve 'Water Positive' by 2025, with the company already piloting 'Circular Water Pumps', in the Ahmedabad plant, which is working on Solar energy.

The Company is on way to reduce greenhouse gas emissions by 90 percent, in line with science based target initiative, which is the 'Company Campaign Truck', launched in September 2023, and has covered 12,500 kilometres visiting more than 90 cities

Company aims to become an Export Hub for castings and machined components.

Advanced Tech Producing Zero Bacterial Water

The Indian Institute of Science (IIS) scientists have enabled Bangalore Water Supply and Sewerage Board (BWSSB) to implement, with advanced technology, the production of zero bacterial water for its water treatment, to the tune of 1200 MLD of treated water from its plant every day, cure supplying for non domestic purposes. The waste water generated everyday in the city is 1800 MLD.

The technology was developed by scientists in just 2 weeks and water quality now is consistent with the Karnataka State Pollution Control Board criteria. Water is fit for domestic purposes other than drinking and the capacity now is for producing 1 crore litre bacteria free water everyday.

Generating Energy through Innovation

- GE has explored innovation, technology, and manufacturing initiatives in India.
- Wind energy is planned to play a pivotal role in future for strengthening India's power sector infrastructure and providing universal energy access to the nation, through technological revolution.
- GE has already introduced state-of-art wind energy technology solution for local conditions in the country through wind turbine design technology, wind farm layouts to optimise power generation, and innovations in manufacturing. GE's latest offering is 1.7-103 turbine model designed specially for low wind environments in the country. This was engineered at GE's John F. Welch Technology Centre in Bangalore, uses GE's evolutionary technology platform and is based on the success of the 22,000 GE wind turbines installed globally. It uses an enhanced control system, which operates on a physics-based turbine model, to improve energy capture at low-wind speeds. Due to GE's proprietary 50.2-meter blades, the 1.7-103 is highly efficient, offering a 56 percent increase in wind swept area compared to the 1.6-82.5, a previous model.

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Peri-Urbanisation in National Capital Region of Delhi - A Spatial Temporal Analysis

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Abstract

Peri-urban areas have been defined diversely and so have their delineation. The analysis of the existing literature suggests that there is no consensus on the methodology used for the delineation. This paper attempts to review the previous literature on the delineation of rural urban fringe and also attempts to delineate the same in the National Capital Region of Delhi. Using GIS and buffer analysis techniques it also assesses the role of factors like distance from metropolitan centres, transport infrastructure and commercial & industrial centres as points of attraction/opportunities in these settlements' growth. The present study finds significant peri-urbanisation in the study area between 2001-21 as every fifth settlement was found to be peri-urban. Distance from the commercial and industrial centres was found to be an important causative factor. Besides, among all the transport infrastructure national highway was found to be the most significant.

1. INTRODUCTION

Peri-urban regions exhibit a fusion of attributes from both urban and rural environments (Ravetz et al. 2013) and are subject to rapid transformation, making them a subject of interest for researchers, geographers, policymakers, and urban planners (Gottero et al. 2023) who have conceptualized it in many ways. Peri-urban areas which are otherwise called rural urban fringe (Ramachandran, 1989), Desakota (McGee, 1991) etc. in different parts of the world have been defined by Dupont (2005) as 'mixed spaces', which are at a midpoint between urban centres and rural landscapes. They are typically located around cities and towns, (Periurban, 2006) where urban and rural land uses intersect. They represent the interface between densely populated urban centres and the open, sparsely populated countryside. The precise definition can vary by location, but their distinct features include a combination of residential, industrial, and agricultural pursuits, as well as the coexistence of urban amenities and rural landscapes (Ravetz et al. 2013). These regions are dynamic transition zones experiencing swift and significant changes in their physical structures, population, and social demographics (Dupont, 2005).

1.1 Delineation of Peri-urban Areas

There is no single, universally accepted method for their delineation, and the specific approach used can vary based on local context and objectives (Mortoja et al. 2020). Peri-urban areas are dynamic, and their boundaries may change over time due to urban expansion, infrastructure development, and changes in land use (Ravetz et al. 2013). Therefore, a flexible and adaptive approach to delineation is often necessary.

They are dynamic, and their characteristics may change over time due to urbanization and development (Periurban, 2006). It is important to note that the choice of indicators and their definition can vary depending upon the specific goals of research or policy initiatives (table 1). Researchers and policymakers often use a combination of these indicators to capture the unique features of peri-urban regions such as demographic change,

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Table 1: Showing the Indicators for Peri-Urban Delineation Used by Different Authors

Parameter	Indicator	References
Demographic	Number of Household	• Dutta et al. (2022) • Vishal Chettry (2022) • Arif & Gupta (2018) • Mishra (2017) • Surendra Kumar Yadav (2015) • Dinesh Singh & Prof. (Dr.) Anjana Vyas (2014), • Thirumurthy (2005) • MMP Sinha (1980)
	Size of the Household	
	Population Density	
	Decadal Growth Rate	
	Literacy Rate	
	Sex Ratio	
Socio-Economic	Percentage of Working Population	
	Percentage of Main Worker	
	Percentage of Marginal Worker	
	Percentage of Cultivators	
	Percentage of Agricultural Labour	
	Percentage of other Workers	
	Number of BPL Families	
	Average Land Value in Thousand/sq.m.	
Physical	Distance from City Centre in Km	
	Percentage of Agricultural Land	

Source: Compiled by Author using the given references

socio-economic development, and land use transformation in their respective contexts (de Ferreiro et al., 2016; Budiyantini & Pratiwi, 2016). These indicators, when used together, offer a comprehensive view of the peri-urban transition.

The indicators like the percentage of agriculture use and percentage of non-agriculture use indicate the same information and therefore, any one of them will suffice for the identification of these areas. The percentage of main and marginal workers as an indicator may not exclusively signify a peri-urban area as these workers might also be prevalent in certain rural regions. On the other hand, the classification of "other workers" might be broad and could include diverse occupations, making it less specific to peri-urban identification. Indicators such as the percentage of cultivators, the percentage of agricultural labour were evaluated by Thirumurthy (2005) for the same in the Chennai Metropolitan Area but were not found to be significant. Therefore, the percentage of non-agricultural workers which includes all types of workers other than agriculture sector, thus, could be an adequate indicator for peri-urban identification.

Indicators like the number of households and the size of household do not depict significant additional information from population growth rate and population density and thus, they can be eliminated. In some cases, sex ratio as an indicator may not have validity at all (Ramachandran, 1989) and thus, it cannot be a good indicator for peri-urban identification as it can be found higher in both the urban and rural settlements. The Below Poverty Line (BPL) population cannot be considered as a significant indicator as both the urban and rural areas might have higher BPL population. Therefore, five indicators like population density, decadal growth rate of population, literacy rate, percentage of non-agriculture workers and percentage of non-agriculture land use are sufficient for the identification of peri-urban areas.

1.2 Peri-Urbanisation & its Delineation in NCR

Peri-urbanization in the NCR of Delhi is an evolving and dynamic process influenced by various factors, including demographic trends, urban policies, and economic activities. The continued study and monitoring of peri-urban areas are essential for sustainable urban development and regional planning in this populous and growing metropolitan region. Before 1950, even the largest metropolitan cities in India didn't have a recognizable rural-urban fringe due to the slow pace of urban growth during that time (Ramachandran R., 1989). In the Delhi Metropolitan Area, the fringe begins well beyond city limits (Ramachandran R., 1989, pg. 304). Peri-urban regions are located outside of municipal borders and occasionally even outside of the legal jurisdiction of cities (Shaw, 2005) and the fringe zone around Delhi stretches from a minimum of 8 to a maximum of 16 km, according to the use of indirect approaches based on secondary data for delineation (R. Ramachandran, 1989). The density of population, the decadal growth rate of population and proportion of workers in non-agricultural activities were utilised for the rural-urban fringe zone identification in the Delhi region (R. Ramachandran, 1988.

The distance from the city centre is a critical causative factor for peri-urban development. As urban areas expand, the proximity to the city centre plays a pivotal role in shaping the peri-urban dynamics (Banu & Fazal, 2013; Kundu et al., 2002). They are typically located at a certain distance from the city centre, which makes them accessible to urban services and employment opportunities. The expansion of urban infrastructure, such as roads and public transportation, enhances connectivity and accessibility, attracting population and economic activities to these areas. (Kundu, A., et al., 2002). Peri-urban development can be primarily attributed to industrial growth around these areas. (Zambon et al. 2019; Arulbalaji et al. 2020). These areas are often attractive locations for industrial and commercial activities due to available cheaper land and higher accessibility thus generating suitable conditions for the growth of peri-urban development (PERIURBAN, 2006).

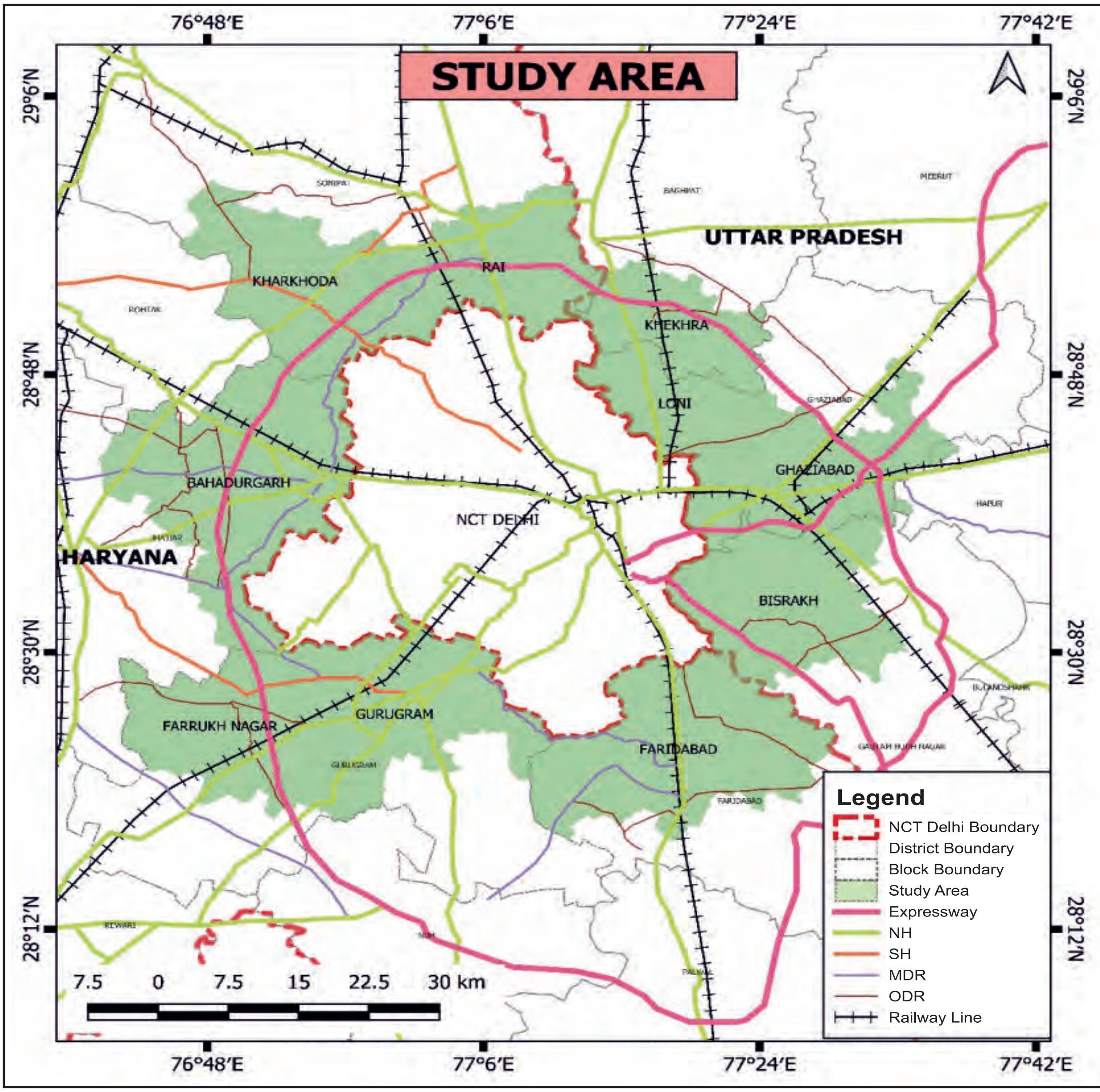
Therefore, the present study aims to study the peri-urbanisation process in the National Capital Region of Delhi during the last two decades and further make an effort to explore its relationship with the driving factors like the distance from the city centre, transport infrastructure (e.g. types of roads, rail) and also the distance from commercial & industrial activities. The core questions explored in the present study are as follows:

- What is the extent of peri-urban areas in NCR Delhi?
- What is the role of distance from the city centre in determining these dynamic areas?
- What is the role of transport infrastructure & areas of attraction/opportunities (e.g. commercial and industrial centres) in peri-urbanisation in NCR Delhi?

1.3 Location & Profile of the Study Area

The study area lies in the National Capital Region of Delhi in India which was created in 1985 and it presently includes NCT-Delhi, and many districts from three adjoining states/ currently including fourteen districts from Haryana, eight districts from Uttar Pradesh, two districts from Rajasthan (figure 1). According to Census of India, the population of this region was 5.81 crores in 2011 (Draft NCR Plan 2041). In the present study area, 494 villages from 10 different blocks adjoining the National Capital Territory of Delhi (NCTD) from seven districts of Haryana & Uttar Pradesh states of India were taken. The study area is spread over 324865 hectares and it had a total population of 6973289 persons in 2011 (District Census Handbook, 2011).

Figure 1: Location of the Study Area



Source: *Created by author using data from a. Geoportal for National Capital Region (NCR) Planning Board, b. Functional Plan on Transport for National Capital Region-2032, c. NCR Plan 2021 and d. draft NCR Plan 2041*

1.3.1 Blocks taken from Haryana

Two blocks i.e. Sonipat and Kharkhoda are taken up for the present study from Sonipat district. The Sonipat block has 55 villages, while the Kharkhoda block has 42 villages in total. In Jhajjar district, the Bahadurgarh block contains 60 villages. In Gurugram, district there are two blocks: Gurugram with 32 villages and Farrukhnagar with 49 villages. In Faridabad district, the Faridabad block has 62 villages.

1.3.2 Blocks taken from Uttar Pradesh

The Kherka block, from Baghpat district, consists of 52 villages. There are two blocks from Ghaziabad district: Loni with 46 villages and Razapur with 41 villages. The Bisrakh block from Gautam Budh Nagar has 55 villages.

2. DATABASE AND METHODOLOGY

Population data, density data, literacy rate data, non-agricultural workers data and decadal growth rate data have been taken from Census of India 2001 & 2011 whereas the 2021 data was estimated using the trend method in Excel software. Administrative boundaries such as state, district, block and transport infrastructure i.e. all types of roads & rail infrastructure data were taken from Geoportal for NCR Planning Board, Functional Plan on Transport for National Capital Region-2032, NCR Plan 2021 and Draft NCR Plan 2041. Nonagricultural land use data was calculated using built-up data from multiple sources. For 1999, built-up data was taken from the Land Use/ Land Cover map available on the NCR Planning Board Geoportal website. For 2011-12, it was obtained from the BHUVAN website whereas for 2020, data was extracted from Sentinel Imagery Data 2020, ESRI. The built-up data from different sources was digitized and calculated using the QGIS software.

Peri-urban regions could be located outside of municipal borders and occasionally even outside of the legal jurisdiction of cities (Shaw, 2005) and determination of the boundaries of the fringe zone should ideally be based on a study of the settlements located within a 10 to 20 kilometers radius of a city (R. Ramachandran, 1989, pg. no. 299). Therefore, all the villages lying in the adjacent blocks of NCTD were studied for peri-urban identification.

Areas having an absence of distinct urban land use do not lie in the peri-urban category (Ramachandra R. 1989, pg. no. 298). Density of population, decadal growth rate of population and proportion of workers in non-agricultural activities were used in the Delhi and Bangalore studies (R. Ramachandran, 1988, pg. no. 300).

Therefore, five indicators i.e. population density, decadal growth rate, literacy rate, percentage of non-agricultural workers and percentage of non-agricultural land use have been used for peri-urban identification in the study area (table 2a, 2b, 2c). Composite

Table 2a: Composite Score of the Settlements Using the Five Indicators (2001)

Name of the Settlement	Pop. Density 2001 PPH	Normalized Value of Population Density 2001 (a)	Growth Rate 1991-01 (percent)	Normalized Value of Growth Rate 1991-01 (b)	Literacy Rate 2001 (Percent)	Normalized Value of Literacy 2001 (Percent) (c)	Non-Agricultural Workforce 2001	Normalized Value of Non-Agricultural Workforce 2001 (d)	Non-Agricultural Landuse 2001 (Percent)	Normalized value of Non-Agricultural Landuse 2001 (e)	Total Composite Score (a+b+c+d+e)
Chhara	409	0.11	6.51	0.01	60.55	0.70	22.81	0.22	1.92	0.02	1.06
Bhaproda	446	0.12	9.45	0.01	62.68	0.73	22.62	0.22	1.20	0.01	1.09
Asanda	527	0.14	11.64	0.02	63.50	0.74	27.45	0.27	2.62	0.03	1.19
Kharhar	393	0.10	12.32	0.02	60.77	0.70	13.06	0.12	2.51	0.02	0.97
Rohad	469	0.12	20.59	0.03	61.11	0.71	47.85	0.47	1.81	0.02	1.35
Asoda Todran	483	0.13	4.34	0.01	63.69	0.74	41.09	0.40	6.54	0.07	1.35
Dahkora	518	0.14	15.02	0.02	65.43	0.77	35.37	0.35	1.98	0.02	1.29
Loharheri	488	0.13	0.73	0.00	65.50	0.77	35.44	0.35	1.55	0.02	1.26
Jasaurkheri	465	0.12	-4.50	-0.01	64.68	0.76	36.29	0.36	2.76	0.03	1.26
Kheri Jasaur	403	0.11	-2.15	0.00	66.59	0.78	33.53	0.33	1.20	0.01	1.22

Note: Similarly, composite score is calculated for all the villages in the study area.
Source: Calculations are based upon Census of India data

Table 2b: Composite Score of the Settlements Using the Five Indicators (2011)

Name of the Settlement	Pop. Density 2011 PPH	Normalized Value of Density 2011 PPH (a)	Growth Rate 2001-11 (Percent)	Normalized Value of Growth Rate 2001-11 (b)	Literacy Rate 2011 (Percent)	Normalized Value of Literacy 2011 (c)	Non-Agricultural Workforce 2011 (Percent)	Normalized Value of Non-Agricultural Workforce 2011 (d)	Non-Agricultural Landuse 2011 (Percent)	Normalized Value of Non- Agricultural Landuse 2011 (e)	Total Comp-osite Score (a+b+c+d+e)
Chhara	401	0.07	-1.93	0.00	70.82	0.65	39.36	0.39	4.89	0.05	1.16
Bhaproda	469	0.08	5.31	0.00	71.69	0.66	30.13	0.30	6.31	0.06	1.11
Asanda	574	0.09	8.75	0.00	72.90	0.68	46.82	0.47	5.68	0.06	1.30
Kharhar	410	0.07	4.31	0.00	71.86	0.67	42.55	0.43	4.85	0.05	1.21
Rohad	509	0.08	8.52	0.00	69.59	0.64	55.19	0.55	11.76	0.12	1.40
Asoda Todran	509	0.08	5.19	0.00	69.65	0.64	51.65	0.52	16.63	0.17	1.41
Dahkora	530	0.09	2.15	0.00	74.64	0.70	61.64	0.62	5.52	0.06	1.46
Loharheri	513	0.08	5.12	0.00	73.94	0.69	24.36	0.24	7.01	0.07	1.09
Jasaurkheri	516	0.08	10.90	0.01	70.69	0.65	50.85	0.51	8.63	0.09	1.34
Kheri Jasaur	435	0.07	8.03	0.00	72.53	0.67	45.50	0.46	5.90	0.06	1.26

Note: Similarly, composite score is calculated for all the villages in the study area.
Source: Calculations are based upon Census of India data

Table 2c: Composite Score of the Settlements using the Five Indicators (2021)

Name of the Settlement	Pop. Density 2021 PPH	Normalized Value of Density 2021 (a)	Growth Rate 2011-21 (Percent)	Normalized Value of Growth Rate 2011-21 (b)	Literacy Rate 2021 (Percent)	Normalized Value of Literacy 2021 (c)	Non-Agricultural Work Force 2021 (Percent)	Normalized Value of Non-Agricultural Work Force 2021 (d)	Non-Agricultural Land Use 2021 (Percent)	Normalized Value of Non-Agricultural Landuse 2021 (e)	Total Composite Score (a+b+c+d+e)
Chhara	415	0.05	3.50	0.01	79.10	0.71	44.11	0.44	8.16	0.08	1.29
Bhaproda	503	0.06	7.15	0.01	81.49	0.73	30.28	0.30	14.52	0.15	1.25
Asanda	626	0.08	9.07	0.02	85.56	0.76	47.34	0.47	14.18	0.14	1.47
Kharhar	445	0.05	8.39	0.01	78.70	0.70	41.91	0.42	6.94	0.07	1.26
Rohad	575	0.07	13.11	0.02	79.94	0.71	58.81	0.59	24.09	0.24	1.64
Asoda Todran	530	0.07	4.28	0.01	80.05	0.72	58.83	0.59	17.28	0.17	1.55
Dahkora	578	0.07	9.22	0.02	86.65	0.77	78.08	0.78	13.47	0.13	1.78
Loharheri	523	0.06	2.08	0.00	81.12	0.73	22.04	0.22	9.36	0.09	1.11
Jasaurkheri	518	0.06	0.45	0.00	80.17	0.72	46.53	0.47	12.32	0.12	1.37
Kheri Jasaur	440	0.05	1.12	0.00	80.12	0.72	45.04	0.45	8.96	0.09	1.31

Note: Similarly, composite score is calculated for all the villages in the study area.
Source: Calculations are based upon Census of India data

score was calculated for all the settlements after normalization of their actual data of the five indicators and then all the settlements were classified into three categories i.e. peri-urban area, semi-peri-urban area and rural area using the mean and standard deviation technique.

To analyze the relationships between the growth of peri-urban settlements and transport infrastructure buffer analysis and distance matrix have been used with the help of QGIS software.

3. RESULTS & DISCUSSION

3.1 Regional Analysis

Table 3 shows that in 2001, there were a total 56 peri-urban settlements in the study blocks which increased to 79 in 2011 and thus witnessed a decadal increase of 41.07 percent. It further increased to 100 in 2021 and observed a 26.58 percent decadal increase in the peri-urban settlements. Thus, the blocks observed a total 78.51 percent increase in the number of peri-urban settlements between 2001 and 2021.

Table 3: Peri-Urban Settlements (2001-2021)

Blocks	2001		2011		2021		(2001-11)	(2011-21)	(2001-21)
	No. of Peri-Urban Settlements	Percent to Total	No. of Peri-Urban Settlements	Percent to Total	No. of Peri-Urban Settlements	Percent to Total	Percent Change	Percent Change	Percent Change
Bisrakh	12	21.43	22	27.85	29	29	83.33	31.82	141.67
Loni	12	21.43	16	20.25	16	16	33.33	0.00	33.33
Faridabad	7	12.50	10	12.66	14	14	42.86	40.00	100.00
Gurugram	5	8.93	6	7.59	11	11	20.00	83.33	120.00
Rai	6	10.71	7	8.86	10	10	16.67	42.86	66.67
Razapur	6	10.71	6	7.59	7	7	0.00	16.67	16.67
Kherka	4	7.14	4	5.06	5	5	0.00	25.00	25.00
Farrukhnagar	1	1.79	3	3.80	3	3	200.00	0.00	200.00
Bahadurgarh	2	3.57	3	3.80	3	3	50.00	0.00	50.00
Kharkhoda	1	1.79	2	2.53	2	2	100.00	0.00	100.00
Total	56	100	79	100	100	100	41.07	26.58	78.57

Source: Author

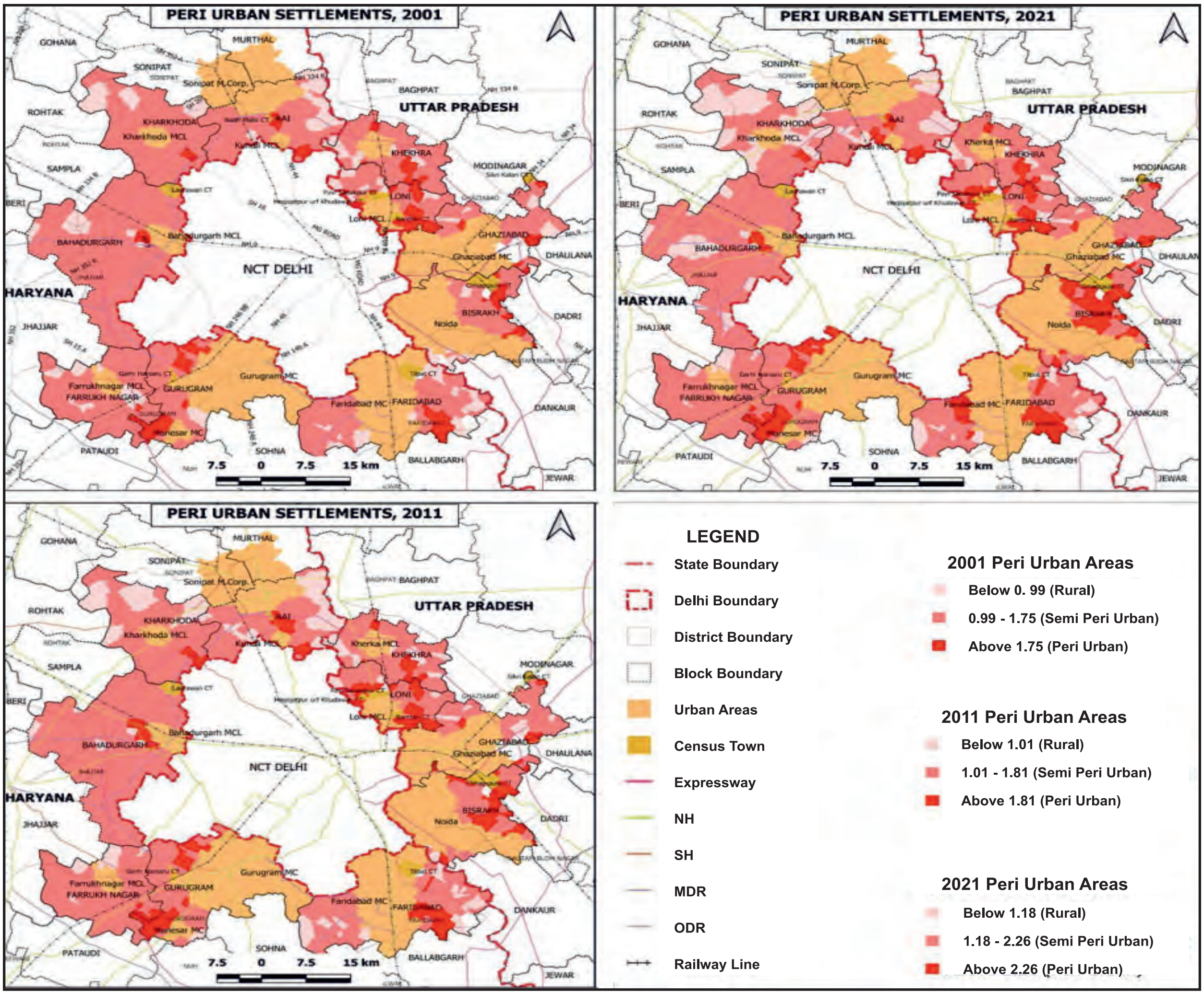
3.2 Block-Level Analysis

Table 3 reveals varying degrees of peri-urbanisation and growth in peri-urban settlements across different blocks. Blocks like Bisrakh, Gurugram, and Faridabad have experienced significant urban expansion, while Bahadurgarh and Rai have shown more moderate to low growth in the number of peri-urban settlements. All the blocks have been divided into the following categories: (figure 2)

- Blocks with a higher number of peri-urban settlements – having above 15 peri-urban settlements
- Blocks with a moderate number of peri-urban settlements – having 6 to 15 peri-urban settlements
- Blocks with a lower number of peri-urban settlements – having less than 5 peri-urban settlements
- **Blocks with higher number of peri-urban settlements in 2021 and higher growth in the number of peri-urban settlements between 2001 and 2021.**

Bisrakh had 12 peri-urban settlements in 2001 accounting for 21.43 percent of the total settlements, which increased

Figure 2: Peri-Urban Settlements in the Study Area, 2001, 2011, 2021



Source: Author

to 22 in 2011 and further to 29 in 2021. This block experienced substantial growth, with the number of settlements nearly doubling from 2001 to 2011. The percentage change in number of peri-urban settlements from 2001 to 2021 was an impressive 141.67 percent. In 2001, there were 12 peri-urban settlements in Loni block, accounting for 21.43 percent of the total settlements. In 2011, this increased to 16 settlements, which was 20.25 percent of the total and in 2021, it remained the same i.e. 16 settlements, representing 16 percent of the total. The percentage change from 2001 to 2011 was 33.33 percent, and there was no change from 2011 to 2021, resulting in a 33.33 percent change from 2001 to 2021.

In 2001, there were seven peri-urban settlements, accounting for 12.50 percent of the total settlements and in 2011, this increased to 10 settlements, which was 12.66 percent of the total. In 2021, it further increased to 14 settlements, representing 14 percent of the total. The percentage change from 2001 to 2011 was 42.86 percent, and from 2011 to 2021, there was a 40 percent change. The percentage change from 2001 to 2021 was 100 percent. Thus, this block showed steady growth in the number of such settlements.

Gurugram had five peri-urban settlements in 2001 accounting for 8.93 percent of the total settlements., which increased to six in 2011 making up 7.59 percent of the total and significantly expanded to 11 in 2021 representing 11 percent of the total. The percentage of these settlements relative to the total also increased over time. The percentage change from 2001 to 2021 was 120 percent, indicating substantial urbanization in Gurugram.

- **Blocks with lesser number of peri-urban settlements in 2021 but higher growth in the number of peri-urban settlements between 2001 and 2021**

In 2001, there was one peri-urban settlement in Farrukhnagar, making up 1.79 percent of the total settlements but it experienced substantial growth in the number of peri-urban settlements between 2001 to 2021. In 2011, this increased to three settlements, which was 3.80 percent of the total. In 2021, there were still three settlements, representing 3 percent of the total. The percentage change from 2001 to 2011 was 200 percent, and there was no change from 2011 to 2021, resulting in a remarkable 200 percent change from 2001 to 2021.

- **Block with moderate growth in the number of peri-urban settlements between 2001 and 2021**

Kherka and Razapur saw modest changes in their peri-urban settlements. Kherka had no change from 2011 to 2021, while Razapur had a 16.67 percent increase from 2011 to 2021. In 2001, there were four peri-urban settlements in the Kherka block, accounting for 7.14 percent of the total settlements and remained at four settlements in 2011, which was 5.06 percent of the total. In 2021, there were five settlements, representing 5 percent of the total. There was no change from 2001 to 2011, a 25 percent change from 2011 to 2021, and a 25 percent change from 2001 to 2021.

In 2001, there were six peri-urban settlements in Razapur block, accounting for 10.71 percent of the total settlements. In 2011, this remained at six settlements, which was 7.59 percent of the total. In 2021, there were seven settlements, representing 7 percent of the total. There was no change from 2001 to 2011, a 16.67 percent change from 2011 to 2021, and a 16.67 percent change from 2001 to 2021. In 2001, there were six peri-urban settlements in Rai block, accounting for 10.71 percent of the total settlements. In 2011, this increased to seven settlements, which was 8.86 percent of the total. In 2021, there were 10 settlements, representing 10 percent of the total. The percentage change from 2001 to 2011 was 16.67 percent, and from 2011 to 2021, there was a 42.86 percent change. The percentage change from 2001 to 2021 was 66.67 percent.

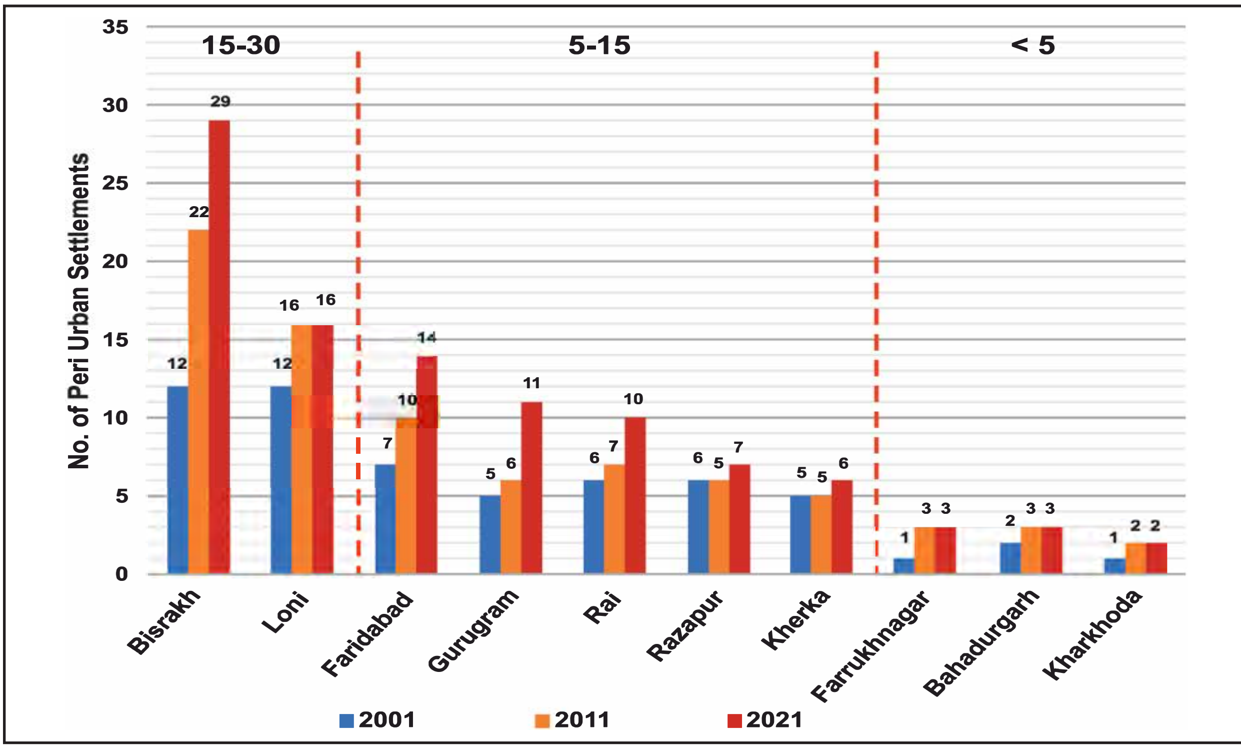
- **Blocks with lesser number of peri-urban settlements in 2021 and lower growth in the number of peri-urban settlements between 2001 and 2021**

Kharkhoda also saw growth in such settlements, though to a lesser extent. In 2001, there was one peri-urban settlement in Kharkhoda block, making up 1.79 percent of the total settlements. In 2011, this increased to two settlements, which was 2.53 percent of the total. In 2021, there were still two settlements, representing 2 percent of the total. The percentage change from 2001 to 2011 was 100 percent, and there was no change from 2011 to 2021, resulting in a 100 percent change from 2001 to 2021. Thus, Kharkhoda had a 100 percent increase from 2001 to 2011, but it did not observe any growth of peri-urban settlements during the next decade. Bahadurgarh had a consistent number of peri-urban settlements from 2001 to 2021, with three settlements. However, its percentage relative to total settlements increased slightly from 3.57 percent to 3.80 percent from 2001 to 2011, remaining the same in 2021. The percentage change in peri-urban settlements from 2001 to 2011 was 50 percent.

3.2.1 Decadal Changes in Peri-Urban Settlements (2001-2021)

Figure 3 indicates the changes occuring in the number of peri-urban settlements during 2001-2021.

Figure 3: Growth of Peri-urban Settlements, Block Level



Source: Author

- **Growth (percent) in the number of peri-urban settlements (2001 to 2011)**

  Farrukhnagar had the highest growth rate in terms of the number of peri-urban settlements with a 200 percent increase whereas Kharkhoda and Bisrakh also had substantial growth rates of 100 percent and 83.33 percent, respectively (figure 4). Gurugram and Loni had moderate growth rates of 20 percent and 33.33 percent, respectively. On the other hand, Faridabad and Rai had growth rates of 42.86 percent and 16.67 percent, respectively. Kherka and Razapur had no growth of peri-urban settlements during this period.

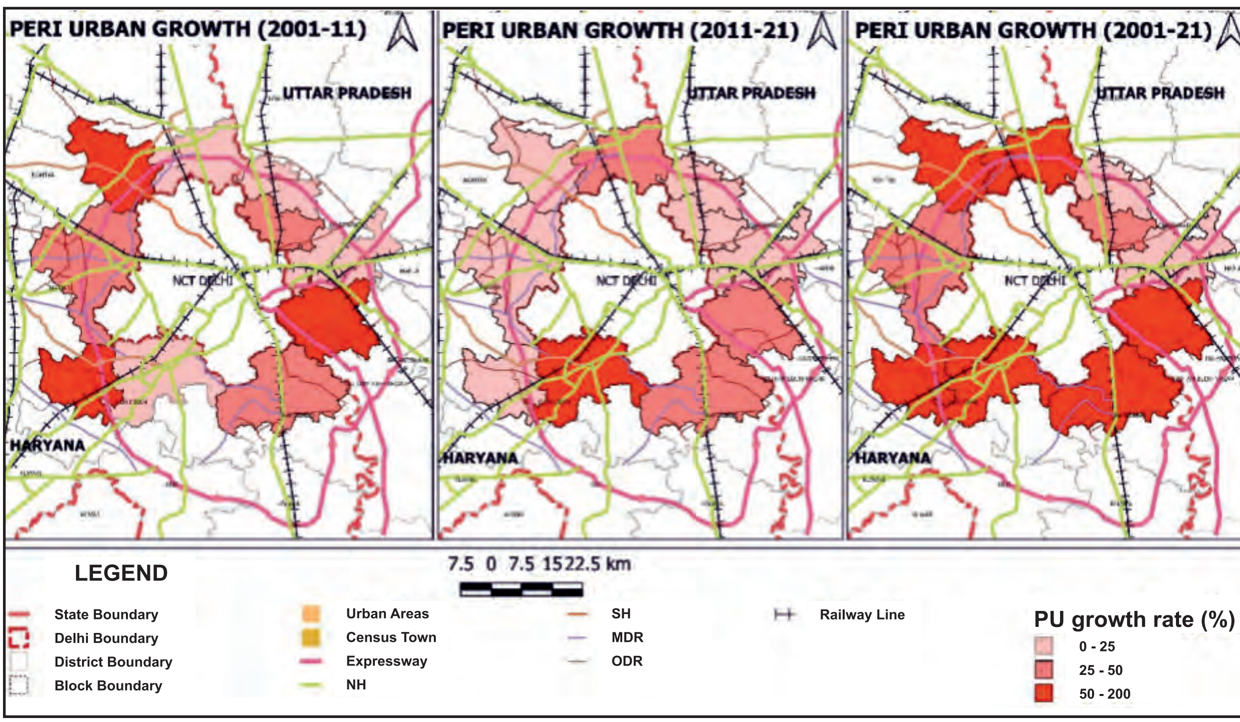
- **Growth (percent) in the number of peri-urban settlements (2011 to 2021)**

  Gurugram had the highest growth rate in terms of the number of peri-urban settlements with an 83.33 percent increase (figure 4). Bisrakh and Rai also had significant growth rates of 31.82 percent and 42.86 percent, respectively. Faridabad had a substantial growth rate of 40 percent. Kherka had a 25 percent growth during this period. Loni, Bahadurgarh and Kharkhoda had no growth of peri-urban settlements during this period.

- **Growth (percent) in the number of peri-urban settlements (2001 to 2021)**

  Bisrakh had the highest total growth rate in terms of the number of peri-urban settlements with a 141.67 percent increase (figure 4). Farrukhnagar and Kharkhoda also had substantial total growth rates of 200 percent and 100 percent, respectively. Gurugram had a total growth rate of 120 percent. Faridabad had a total growth rate of 100 percent. Rai had a total growth rate of 66.67 percent. Kherka had a total growth rate of 25 percent. Loni had a total growth rate of 33.33 percent. Bahadurgarh and Razapur had the lowest total growth rates of 50 percent and 16.67 percent, respectively. In 2021, out of 494 villages around 100 villages fall into the category of peri-urban settlements which means about one-fifth of the studied settlements are peri-urban settlements.

Figure 4: Peri-urban Growth (2001-21)



Source: Author

3.3 Causal Factors for the Growth of Peri-Urban Settlements

3.3.1 Distance from the Centre of Delhi

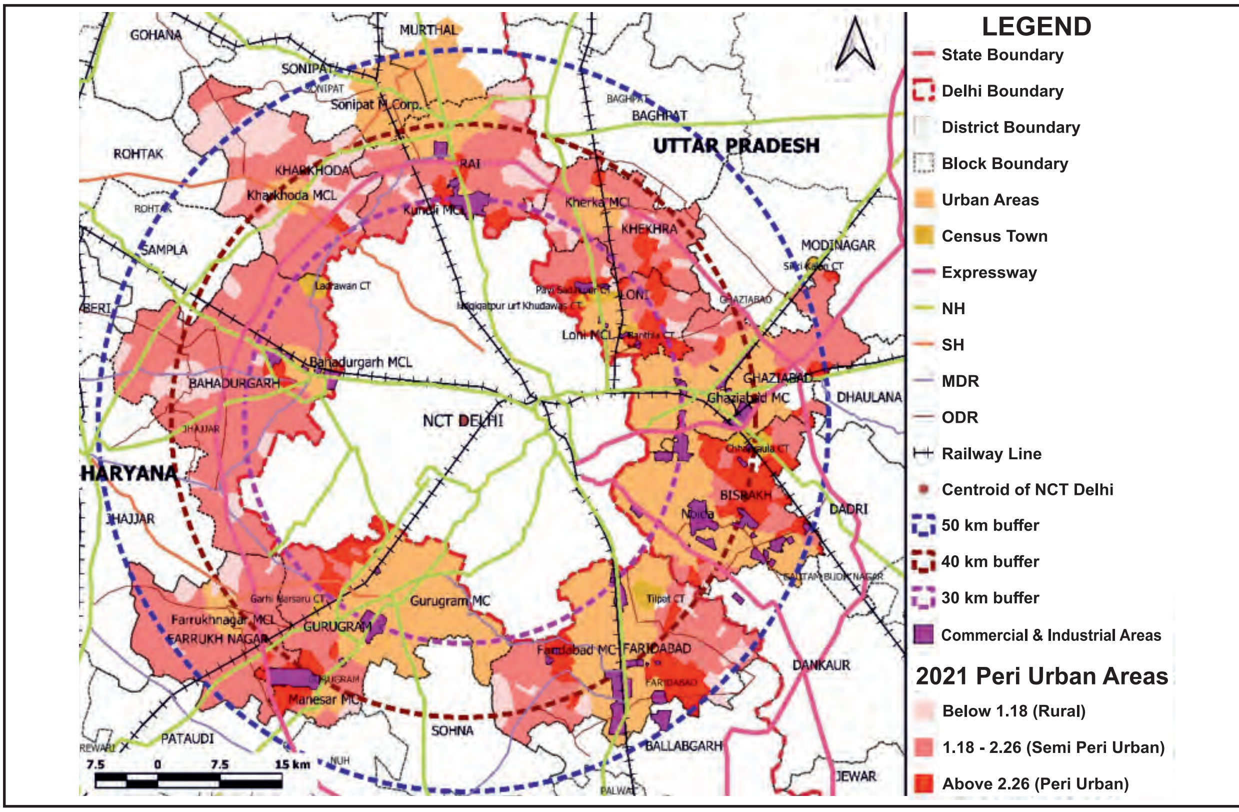
Table 4 and figure 5 indicates that in 2021 within 30 Kms from the city centre of Delhi, there are 28 peri-urban settlements, accounting for 28 percent of the total whereas there are 68 peri-urban settlements within 40 Kms, making up 68 percent of the total. Moreover, up to 50 Kms are 98 peri-urban settlements, constituting 98 percent of the total. The total number of peri-urban areas in 2021 is reported as 100.

Table 4: Distance of Peri-urban Settlements from the Centre of Delhi, 2021

Distance	Up to 30 Kms	Up to 40 Kms	Up to 50 Kms
No. of Peri-Urban Settlements	28 (28 percent)	68 (68 percent)	98 (98 percent)

Source: Author

Figure 5: Location of Peri-Urban Settlements from the Centre of Delhi, 2021



Source: Author

It seems like the majority of peri-urban settlements are within 50 kilometers, with the highest concentration being within the 40 kilometer range. Beyond 50 kilometers, there are still peri-urban settlements, but it seems unusual compared to the closer distances.

3.3.2 Location of Commercial and Industrial Centres and their Relationship with the Location of Peri-Urban Areas

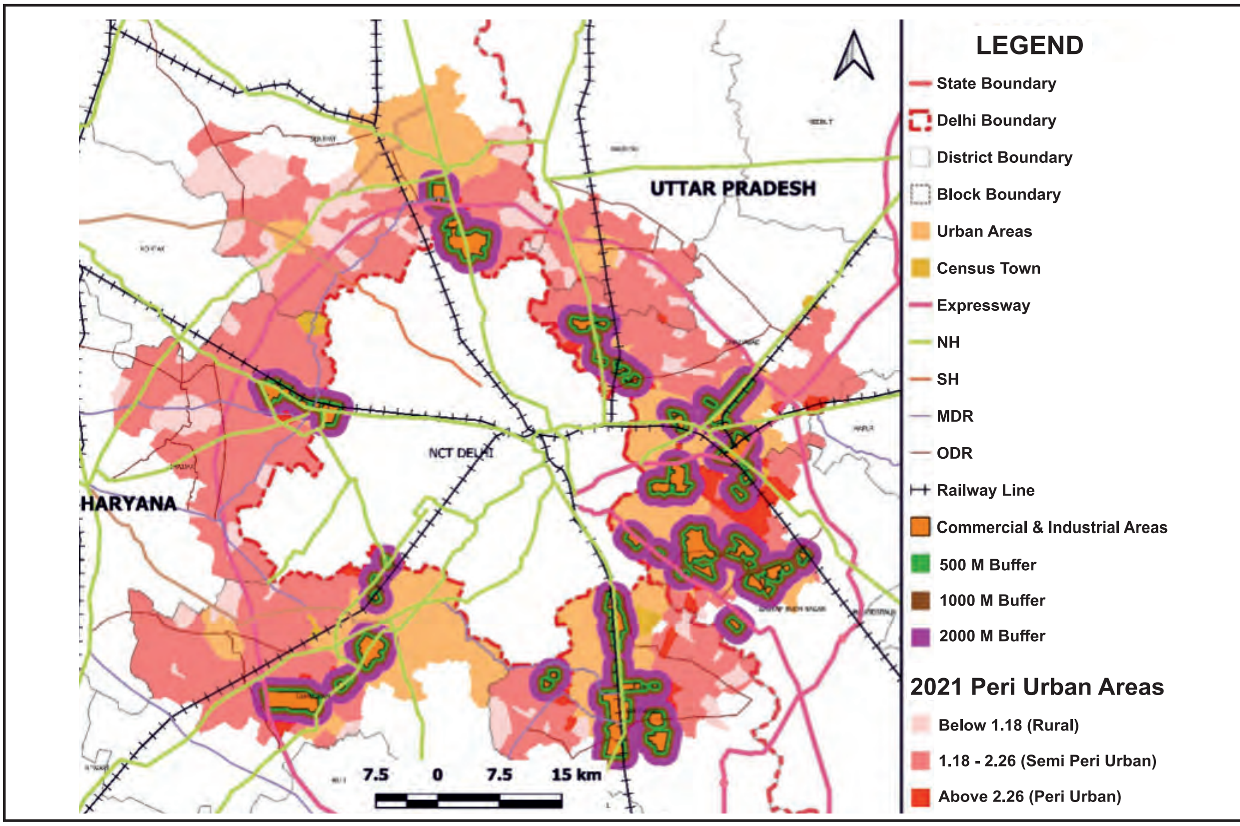
Table 5 and figure 6 depicts the location of peri-urban areas based on their proximity to commercial and industrial centres. There are 35 peri-urban areas within 500 meters, constituting 35 percent of the total whereas between 500-1000 meters are 12 peri-urban areas, constituting 12 percent of the total. Moreover, between 1000-2000 meters are 19 peri-urban areas, constituting 19 percent of the total and beyond 2000 meters are 34 peri-urban areas, constituting 34 percent of the total. Thus, about 66 percent of the total peri-urban areas are found within 2000 metres of the commercial and industrial centres. In summary, the majority of peri-urban areas (35 percent) are within 500 meters of commercial and industrial centres, and the percentages decrease as the distance increases.

Table 5: Location of Peri-Urban Areas around Commercial & Industrial Centres, 2021

Infrastructure	Upto 500 Metres	500 - 1000 Metres	1000 - 2000 Metres	Beyond 2000 Metres
Commercial & Industrial Centres	35 (35 Percent)	12 (12 Percent)	19 (19 Percent)	34 (34 Percent)

Source: Author

Figure 6: Location of Peri-Urban Settlements around Commercial & Industrial Centres, 2021



Source: Author

3.3.3 Distance of Peri-Urban Areas from Major Roads (Expressway, NH, SH, MDR & ODR) and Rail Infrastructure

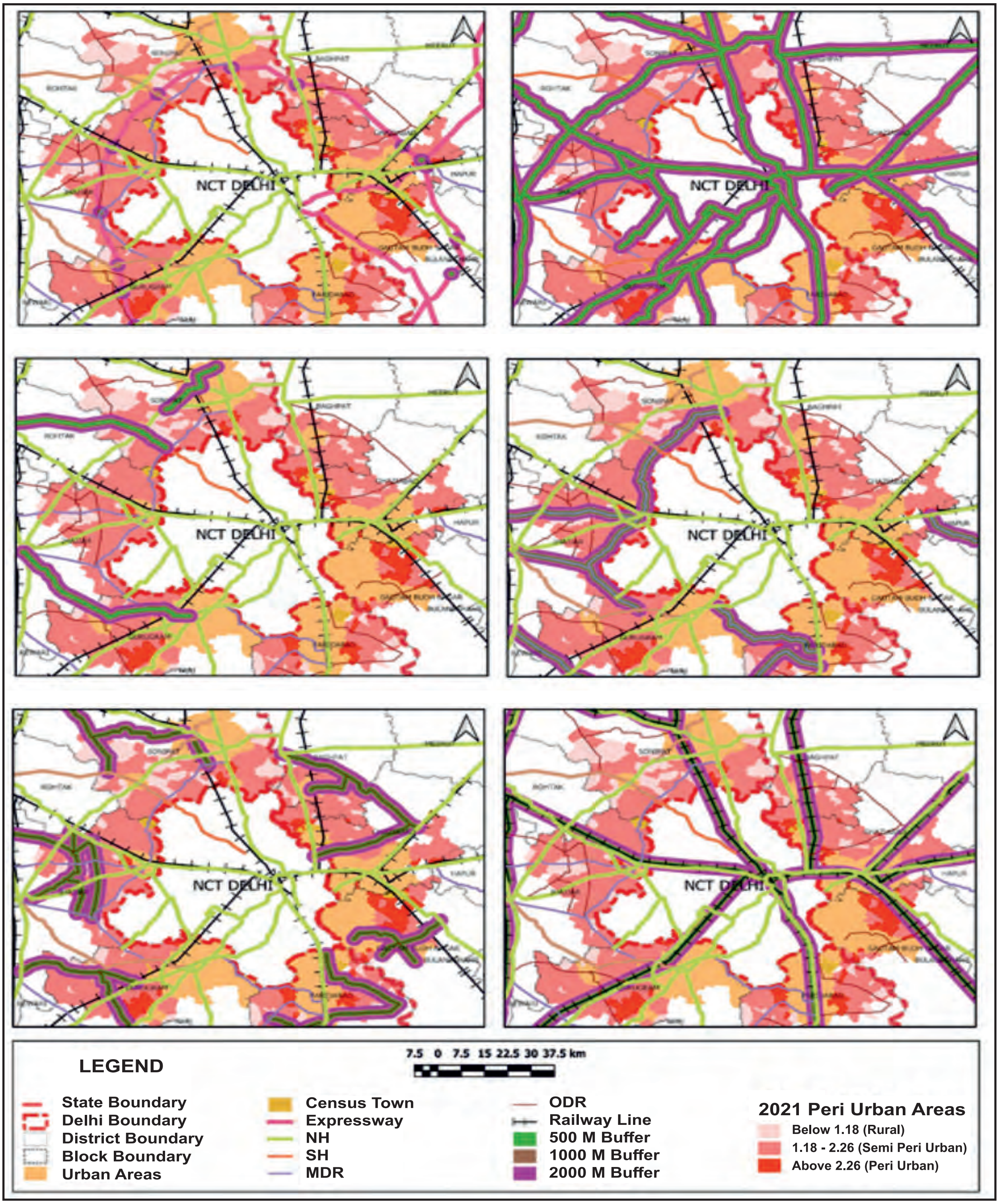
Table 6 and figure 7 provides a detailed overview of peri-urban areas categorized by their proximity to various types of transport infrastructure. The data is presented in three distance ranges: within 500 meters, within 1000 meters, and within 2000 meters. Regarding expressways, a small proportion of peri-urban areas (3 percent) are located within 500 meters, with the percentage increasing to 10 percent within 2000 meters. National Highways exhibit a higher presence, with 26 percent of peri-urban areas within 500 meters and 41 percent within 2000 meters. State Highways show a relatively lower impact, while major district roads and other district roads follow a similar trend of increasing percentages

Table 6: Location of Peri-Urban Settlements around different Transport Infrastructure, 2021

Transport Infrastructure	Within 500 metres	Within 1000 metres	Within 2000 metres
Expressway	3 (3 percent)	5 (5 percent)	10 (10 percent)
National Highway (NH)	26 (26 percent)	30 (30 percent)	41 (41 percent)
State Highway (SH)	2 (2 percent)	3 (3 percent)	3 (3 percent)
Major District Road (MDR)	8 (8 percent)	10 (10 percent)	12 (12 percent)
Other District Road (ODR)	12 (12 percent)	16 (16 percent)	26 (26 percent)
Railway	14 (14 percent)	16 (16 percent)	30 (30 percent)

Source: Author

Figure 7: Location of Peri-Urban Settlements around different Transport Infrastructure, 2021



Source: Author

with proximity. Railways also have a notable influence, with 14 percent within 500 meters rising to 30 percent within 2000 meters. This data underscores the varied spatial distribution of peri-urban areas concerning different types of transport infrastructure, providing valuable insights for urban planning and development strategies.

4. DISCUSSION

The identified peri-urban areas in the present research also meet the criterion for the identification of peri-urban areas given by Thirumurthy, 2005. The present study confirms that the fringe area would include as many as 100-200 villages (R. Ramachandran, 1989, pg. no. 299) because about 100 villages were identified as peri-urban areas in 2021 in the present study. In the present study, peri-urban areas were identified as far as 50 km distant from the centre of Delhi as opposed to the 18 km maximum distance given by R. Ramachandra, 1989. The result of the present study also aligns with the finding that the transport infrastructure plays an important role in peri-urban development, particularly along national highways and rail infrastructure (Thirumurthy, 2005). Singh Dinesh & Vyas Anjana (2014) in their study in the Indore Metropolitan area also found out that peri-urban villages located along the major roads like national highways were growing rapidly. The present also confirms that areas of attraction/opportunities like industrial centres act as a significant driving force behind the growth of peri development (Zambon Ilaria et al. 2019) (Arulbalaji et al., 2020).

5. CONCLUSION

The study finds significant peri-urbanisation in the study area between 2001-21 as it experienced a total growth of 78.51 percent in peri-urban settlements from 2001 to 2021. In the study blocks, every fifth settlement was found to be peri-urban settlement. Bisrakh block has observed the highest growth of such settlements among all the blocks during the last two decades in the study area. As for causative factors for the growth of these settlements, about 98 percent of the total identified peri-urban settlements were found to be located within 50 kms distance from the centre of New Delhi in 2021. About 66 percent of the total peri-urban settlements were found to be located within 2000 meters distance from the commercial and industrial centres in 2021 and thus showing them as an important causative factor. Among all the transport infrastructure national highway was found to be the most dominant factor causing the peri-urban growth as 41 percent of the total peri-urban settlements were found to be within 2000 meters of the national highways in 2021. The findings of the present study should be further verified by conducting studies on peri-urbanisation in different metropolitan areas. The limitation of the present study is that it does not make a distinction between commercial and industrial areas as a causative factor and therefore, future studies should do that while studying the relationship of peri-urbanisation with these areas. The study also does not take into account the factors of social infrastructure driving the peri-urbanisation process and thus should be considered by the future studies.

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Spatio-Temporal Dynamics of LULC in Baruipur Municipality around South Kolkata

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Abstract

Being restricted in the East and West, and saturated along the North, the urban sprawl of Kolkata is mostly directed southward – towards the Baruipur municipality, altering its original role of being a major source of fruits and vegetables catering Kolkata. The objective of this study is to monitor any efforts to replace the pockets of water bodies, greeneries, orchards and crop fields with built-up facilities resulting in fragmented land use that would need longer haul to connect them to end-users, which calls for additional travel-related congestion and pollution load; instead a unified hierarchical neighbourhood facility planning is recommended to enhance local accessibility and reduce travel. Multi-temporal images of Baruipur are analysed by FRAGSTATS to generate landscape-level and class-level metrics and study splitting and land fragmentation. Shannon's entropy and Land Surface Temperature are used to show the direction of sprawl and gradual rise of temperature. There could be other factors that may be studied as well. This methodology could help planners to keep constant vigil and intervene at the right point of time.

1. INTRODUCTION

Development and urbanisation of countries bring gradual changes in national landscape (Henderson, J. V., and Wang, H.G., 2007). Increasing settlement density, (McGranahan, G. and Satterthwaite, D., 2014), conversion of land from non-urban to urban uses (Weith, T., et al, 2021) mark urbanisation. Urbanisation effects landscape-structure and pushes rural/ urban fringes outward (Weng, Q., 2019). It involves economic growth and development in urban and regional areas (Chaolin, G., 2019, Nguyen, H. M., and Nguyen, L. D., 2018). But urbanisation and development need sustainability (Simon, D., 2008). Developments due to urbanisation beyond the limits of the city-municipalities and spilling of population from the cities into the peripheral areas lead unplanned development (Shilpa, S. J., 2021). Unplanned urban growth brings land use changes, which results into losses in agricultural land (Maheshwari, B., et al., 2014), water bodies (Mitra, D., and Banerji, D., 2018), forest land (Ancha, P. U., 2021), etc. Government officials and city planners need to know the current scenario of land uses for the better management of problems and planning. Spatio-Temporal urban growth and sprawling pattern can be monitored (Megahed, Y. et al., 2015, Pham, M. H. et al., 2010) and predicted (Megahed, Y. et al., 2015) using remote sensing data (Getu, K., 2021). Supervised classification technique helps in quantitative analysis of remote sensing data where segmentation of spectral bands assist into classification of ground cover classes (Richards, J. A., 2012) and Maximum Likelihood Classifier (MLC) method helps in land use classification to detect LULC changes (Singh, K. T., et al., 2022). Shannon entropy measures LU change pattern outlining urban sprawl (Chong, C. H., 2017). To scale the entropy value, relative entropy is used by researchers to understand the urban growth pattern (Bhatta, B., and Giri, B., 2012). The statistical programme FRAGSTATS measures the urban growth, composition of LUs (Pham, M. H., et al, 2010) and estimates the changes

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of landscape pattern (Borana, S. L., et al., 2017). Many researchers studied urban morphology to understand the direction of urban development with the help of landscape indices (Jia, Y., et al., 2019, Getu, K., 2021, Keita, M.A., 2021).

LULC changes have various facets of effects on environment such as on LST (Jiang, J., and Tian, G., 2010), water balance (Schilling, K. E., et al, 2008), climate (Duveiller, G., et al., 2020) etc. Urban growth causes increase in local land temperature (Kanga, S., et al., 2022) and affects environment from local to global level (Turner, B. L., et al., 1994). The structural change in LULC in urban areas intensifies LST. Solecki, W. D., et al., 2004, examined the urban heat island effect at Camden, (Mallick, J., et al., 2008) worked on LST in Delhi, (Wongsai, N., et al., 2017) worked on Phuket Island. Scientists (Buyadi, S.N.A., et al., 2014) have worked on the cooling effect of parks by measuring the temperature difference in and outside a park depending on landscape. Urban green-spaces could reduce the high radiant temperature of the surrounding developed areas.

Many researchers have analysed the planned and unplanned peripheral growth of a city as a whole (Jat, M. K., et al., 2008), whereas some researchers have delved on smaller administrative unit (Herold, M. et al., 2003). Urban dynamics regarding large scale changes for LULC depend on nature of land use (LU) and intensity of growth (Ramchandra, T. V., 2012) from the smaller unit.

Kolkata, more than 300 years old (Chakraborty. S., and Shiva. J., 2022), is experiencing peripheral urban growth in south-eastern part of the Kolkata Municipal Corporation (KMC) (Mehebub, S., 2018). It has diverse nature of urban growth for urban core and rural periphery part (Mithun, Sk., 2016). KMC outskirts manifest certain striking characteristics but they are seldom studied. Baruipur municipality, a metropolitan outfit of the city of Kolkata, is situating in such a peripheral part of south-eastern fringe of Kolkata Metropolitan Area (KMA). To mitigate this gap of studies, the Baruipur municipality, located 27 km away from the heart of Kolkata on the south-eastern expansion corridor and still having room for expansion, has been chosen to study the immediate impact of urban expansion. The locational uniqueness of Baruipur municipality in the proximity of urbanised Kolkata on the northern side and backward Sundarban (Ghosh, U., 2018), on the southern side (68 km by road) make the area important. Spatial pattern of urbanisation shows relatively more urbanisation towards its northern part while the eastern and southern boundaries of the study area remain less urbanised.

With the southward extension of the Eastern Metropolitan (EM) bypass, accessibility of Baruipur has increased and rate of urbanisation has flourished at a faster pace engulfing the open spaces. Increase in built-up spaces and unplanned development in and around the municipality area has rendered Baruipur into a suburb of Kolkata. Development of such a peripheral area, developed to support KMC and presently under the impact of metropolitan expansion around KMC, currently suffers from loss of vegetation and water body, population increase and land surface temperature rise.

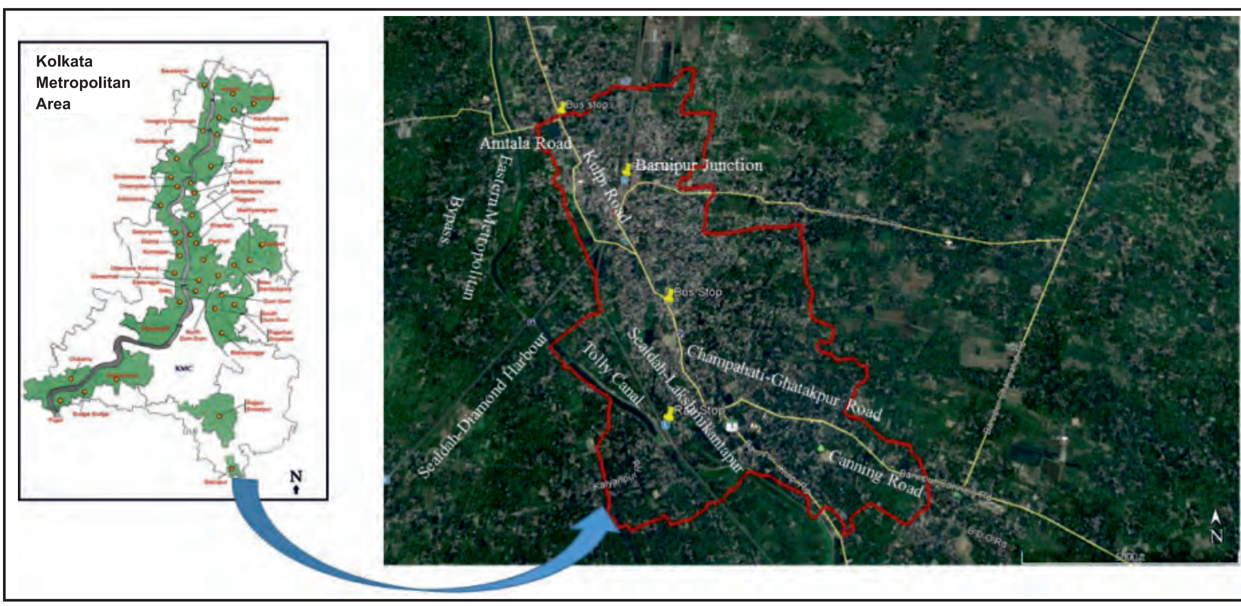
Lot of literature is available on change detection studies, however, studies on Baruipur are scanty. In this study, a freeware, FRAGSTATS, has been used to identify the splitting and land fragmentation using freely available high-resolution data that has been manually digitized and manually classified as well. A relationship on loss of vegetation and water body to LST has been drawn. The study area is also unique since this South Kolkata neighbourhood had drawn attention in recent times as substitute for Alipore district headquarters to Kolkata, as a prospective metro centre and as a prospective recipient of metro services. Urban growth pattern, direction of sprawl, land surface temperature, splitting and fragmentation of land use at Baruipur has been studied for a period of thirty years.

2. DATABASE AND METHODOLOGY

In step I, with the help of remote sensing data and GIS, study area is delineated. In step II, changes in LULC are detected. In step III, Shannon's entropy, class level and landscape level metrics are computed. These provide the urban growth pattern of the study area. Step IV studies the effect of urbanisation by deriving population and household maps from census data and LST scenario.

Baruipur municipality, divided into 17 wards, is located 27 kilometres south of Kolkata, West Bengal, India. It is located in between 22°39'N to 22°33'N latitude and 88°42'E to 88°46'E longitude, approximately and positioned at the extreme southern side of KMA on the banks of Tolly's canal. Baruipur is connected to Kolkata by Kulpi Road via EM Bypass. Other significant roads include Canning Road radiating from the south-eastern extremity and Amtala Road radiating from the north-western extremity (figure 1).

Figure 1: Study Area



Baruipur Junction railway station is connected to Sealdah railway station; one of the three major railway stations of KMA, located 25 kms away, by more than 80 pairs of suburban Electric–Multiple-Unit trains (https://indiarailinfo.com/station/map/baruipur-junction-brp/7850?tt=0). The railway station, situated at the intersection of Sealdah-Diamond Harbour and Sealdah-Lakshmikantapur sections of suburban railway lines, serves Baruipur and its surrounding areas. Accessibility provided by the Metro rail service, located within 7 km, is also a point of attraction of development of this area. Thus, connectivity of this area has drawn attention of the common people and the real estate builders alike. It is believed that an extension of metro rail, namely Airport-Kavi Subhas link upto Baruipur connecting Netaji Subhas Chandra Bose International Airport, Kolkata, approximately 34 km away (https://indiarailinfo.com/station/map/baruipur-junction-brp/7850), will further escalate the attraction potential and growth of Baruipur.

The present research uses multi-spectral and multi-temporal images, census data and field survey data as input. Multi-temporal satellite images of Landsat 5 Thematic Mapper™ for the years 1991, 2001, 2010, 2011 and Landsat-8 Operational Land Imager Thermal Infrared Sensor (OLI_TIRS), 2021, are downloaded from United States Geological Survey (USGS) Earth Explorer (https://earthexplorer.usgs.gov) official website.

Table 1 shows the detailed specifications of used satellite data. All the images, administrative maps, collected from administrative offices were registered in UTM, Zone 45 and WGS 84.

Table 1: Detailed Specifications of Imageries Used Here

Image	Date of Acquisition	Spectral Band	Thermal Band	Cell Size
Landsat 5 TM	02.02.1991	1,2,3,4,5,7		30m
	12.01.2001	1,2,3,4,5,7		-Do-
	24.01.2011	1,2,3,4,5,7		-Do-
	21.01.2010	2,3,4,5	Band 6	(120m) 30m
	06.02.2010	2,3,4,5	-Do-	-Do-
	11.04.2010	2,3,4,5	-Do-	-Do-
	23.12.2010	2,3,4,5	-Do-	-Do-
Landsat 8	03.01.2021	4,5,3,6	Band 10	(100m) 30m
	04.02.2021	4,5,3,6	-Do-	-Do-
	25.04.2021	4,5,3,6	-Do-	-Do-
	21.12.2021	4,5,3,6	-Do-	-Do-
	04.02.2021	1,2,3,4,5,6,7,8,9		30m

Image processing, subsetting (extracting a smaller area from a larger image) and supervised classification (categorizing pixels with supervised technique), accuracy assessment has been done in ERDAS Imagine 2014. Supervised classifications of Baruipur municipality, extracted from the downloaded images, for the years 1991, 2001, 2011 and 2021, has been conducted considering three classes – built-up area, vegetation and water body. In this municipality, fruit orchard and vegetable farming are very important landuse, and green area can be identified round the year.

Though vectorisation is time consuming and costly, still it is the most accurate way of data extraction of land use (McGargical, K., and Marks, B.J., 1995). In supervised classification, misclassification of pixels creates problem. Hence, this technique has been avoided for detail study. LULC maps for 2010 and 2020 have been generated by digitisation in ArcMap 10.2.1 for change detection with the help of freely available google earth images having high resolution new and historical image data. Thereafter, the data is being exported to ArcGIS as a.kml file and converted to.shp file. These maps classify agricultural land separately which give a detailed accurate picture of the municipality that helps in future policy delineation.

To compute Shannon Entropy, Fishnet (creating grid of any size) of rectangular cells, along with IDs have been generated in ArcGIS. Entropy and relative entropy values are computed for every cell. These values are incorporated in the map on the basis of their identification numbers (IDs). These maps reflect the growth pattern of Baruipur.

Yeh and Li (Yeh, A. G., Xia, and Li, X., 2001) used Shannon's entropy to measure the extent of urban sprawl. After extracting the built-up area, the ward has been divided into four parts taking the centroid of the ward area. Then Shannon's Entropy has been calculated to measure the degree of concentration or dispersion of built-up area among n (n=4) zones. It is calculated by

$$H_n = -\sum_i^n P_i * ln(P_i) \quad (1)$$

Here is the proportion of the variable (built-up area) in the ith zone (i= individual zone) and n is the total number of zones. The value of entropy ranges from 0 to 1. If the distribution is compact, the entropy value will be 0 or near zero. Mosammam (Mosammam, H. M., et, al., 2017) worked on relative Shannon Entropy, where,

$$H_n = -\sum_i^n P - ln(P_i) / ln n. \quad (2)$$

Relative or Normalized Shannon's entropy value is used to scale the entropy value from 0 to 1. If closer to 0, distribution is compact and if closer to 1, it implies a dispersed distribution or sprawling.

Classified raster data helps in analysing the landscape metrics at class level and landscape level with the help of open-source statistical software FRAGSTATS. It has been used to quantify the LU structure (McGargical. K. and Marks, B.J., 1995). Changing LU-structure results in changing landscape metrics (Sertel, E., et al, 2018). FRAGSTATS provides the fragmentation status, (Siti Yasmin, Y., and Muhammad, A. M., 2019) of the landscapes which helps in analysing the sprawling pattern of the area. To quantify landscape structure, classified raster data transferred to Geotiff format to use it in FRAGSTATS and.fcd files are prepared. Landscape metrics are calculated to understand the fragmentation of the built-up area expansion (Mithun, Sk., 2016, Herold M., 2003). The details of landscape metrics are provided in table 2.

Table 2: Property of Metrics

Metrics	Description	Units	Range
Class Level Metrics			
CA – Class Area	The sum of the areas of all urban patches, that is, total urban area in the landscape	Hectares	CA>0, no limit
NP - Number of Patches	The number of urban patches of each class.	None	NP≥1, no limit
LPI- Largest Patch Index	The area of the largest patch of every class		Percent
Precent Land - Percentage of Landscape	Sum of all patch areas divided by total landscape area multiplied by 100.	Percent	0< percent LAND≤100
Landscape Level Metrics			
SPLIT - Splitting Index	Total landscape area squared divided by the sum of patch area squared, all patches in landscape	None	1≤SPLIT≤number of cells in the landscape squared
LPI - Largest Patch Index	Percent of landscape of the largest patch	Percent	0<LPI≤100
NP- Number of Patches	Number of patches in the landscape	None	NP≥1, without limit, NP=1 when landscape has only 1 patch
TE- Total Edge	Sum of lengths of all edge segments involving the corresponding patch type	Meters	TE≥0, without limit

The derived landscape metrics helped in quantifying the spatial pattern of the Baruipur municipality. Quantified land use pattern and their changes over time, calculated from the images would help the planners. Eight metrics were considered. Class level metrics include CA, LPI, percent LAND, NP and landscape level metrics include SPLIT, LPI, NP and TE. CA and total area of the landscape becomes equal when entire image comprises a single patch. LPI shows the patch with which the landscape is covered, NP shows number of corresponding patch types. At landscape level SPLIT equals to 1 when landscape is covered by a single patch. SPLIT increases as the landscape is maximally divided. It means every cell will become a patch. LPI becomes 100 at landscape level when largest patch embraces the total landscape. It shows the dominance of class type in the area. NP does not show distribution of patches but shows fragmentation. TE includes landscape boundary area covering the edges. It shows the sum of the lengths of all edges in the landscape.

Census data of the population and number of households at the ward level has been accounted here to understand the relationship between changes in population and urban expansion.

Images of nearly same dates with 0 percent cloud cover have been used to extract LST and accounted to understand the changing temperature pattern in Baruipur. The thermal bands for Landsat 5 TM cells are resampled and cells of 120m are transformed into 30m. Same thing happened for Landsat 8 data. Cells of Thermal band of Landsat 8 are resized into 30m from 100m. Cloud cover increases temperatures at the surface of the earth by absorbing and trapping heat, released by the surface of earth, on it. Monsoons are also avoided as cloud cover distorts the thermal effect. No atmospheric correction was performed since the images used are cloud-free at the time of acquisition (Deng, C., et al, 2013).

LST is the radiative skin temperature of the land derived from solar radiation. Using the radiance rescaling factors provided in the metadata file, digital numbers of the images are converted to top of atmosphere radiance (at sensor) considering the thermal bands of the particular images. To calculate LST, formulae 1, 2 and 3 shown below have been adopted (Ayanlade, A., et al., 2021):

$$L_\lambda \frac{(LMAX_\lambda - LMIN_\lambda)}{(QCALMAX - QCALMIN)} \times (DN - QCALMIN) + LMIN_\lambda \quad (3)$$

Here, $L\lambda$ = Spectral radiance at the sensor

$LMAX\lambda$ = Spectral radiance scaled to in QCALMAX (Watts/(m^2 * sr* μm))

$LMIN\lambda$ = Spectral radiance scaled to in (Watts/(m^2 * sr* μm))

QCALMAX = Maximum quantized calibrated pixel value in DN

QCALMIN = Minimum quantized calibrated pixel value

The radiance is expressed as the top of atmosphere brightness temperature (in Kelvin) using the thermal constants provided in metadata file

$$TB \frac{K_2}{L_n(\frac{K_1}{L_\lambda} + 1)} \quad (4)$$

Where, TB = At-satellite brightness temperature in Kelvin (K)

$L\lambda$ = Spectral radiance in (Watts/ (m^2 * sr* μm))

K_1 and K_2 = Band specific thermal conversion constant from the metadata

Conversion of temperature from Kelvin to degree Celsius,

$$TC = TB - 273.15 \quad (5)$$

In ArcToolbox, all calculations are done in Map Algebra. 8 individual images of nearly the same dates have been taken for the year 2010 as 4 cloud-free images of 2011 of the same period could not be gathered. 4 images of each set of 2010 and 2021 are averaged as individual image of any particular season do not satisfy the explanation of temperature change. Availability of more cloud-free images would give much better results. But unavailability of data from USGS became a constraint. Temperature distribution has been calculated in Microsoft Excel.

3. RESULTS AND DISCUSSION

KMC has grown linearly along the east bank of River Hooghly in the north-south direction. The northern part of KMC is near saturation because of its earlier unplanned urban growth. Westward expansion of KMC is negated by the presence of River Hooghly and the Ramsar site of East Kolkata Wetland stops legal eastward growth. Northbound expansion is delimited by the presence of settlements along the railway corridors. But the population density along the railway corridor to the southeast was low and presently show tremendous growth potential. Improved connectivity and expansion of the Metro Railway have paced this growth rate.

The built-up area of KMC has been progressing along the State Highway 1 (SH1), West Bengal, along Southeast towards Baruipur area and beyond. Analysed satellite maps for LULC for the years 1991, 2001 and 2011 clearly manifest this south-bound urban sprawl. The numeric outcomes of the change detection maps are provided in the form of transition matrix provided in table 3, showing the transitions from 1991 to 2001 and 2001 to 2011. The most prominent changeover happened from water body and vegetation to bare surface.

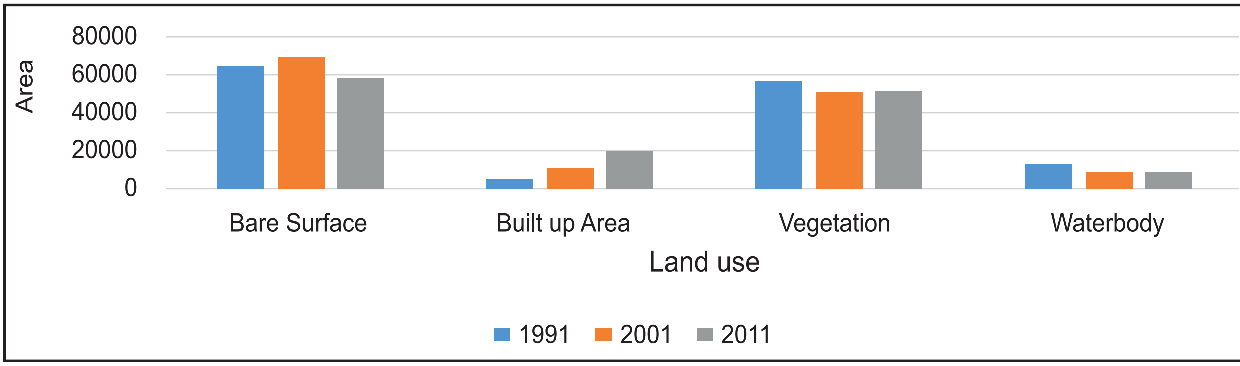
Table 3: Transition Matrix in Percentage Showing Land Conversion of KMC's South-Eastern Part from 1991 to 2001 and 2001 to 2011

Land-Cover in 1991		Land-Cover at Time 2001				Land-Cover in 2001	Land-Cover at Time 2011			
	Nature of Land Cover	**Bare Surface**	**Built Up Area**	**Vegetation**	**Water Body**		**Bare Surface**	**Built Up Area**	**Vegetation**	**Water Body**
	Bare Surface	83.28	5.71	9.65	1.36		74.83	10.22	12.57	2.37
	Built up Area	0.37	99.41	0.12	0.11		1.37	97.82	0.54	0.27
	Vegetation	19.07	2.11	75.22	3.6		9.47	5.15	83.32	2.06
	Waterbody	41.05	5.78	11.77	41.4		17.56	7.24	13.77	61.4

Table 3 may be interpreted thus, considering the first four terms in the first row, of the 100 percent of bare surface available in 1991, 83.28 percent remains bare in 2001, 5.71 percent has been converted to built-up area, 9.65 percent has been transformed into agricultural land and the remaining 1.36 percent was converted to water body.

KMC is expanding in area beyond its existing boundary and major push is reflected towards south which is reflected in the landuse distribution (figure 2). In these three time periods the main conversion of land is observed from water bodies to bare land that implies the scope for further conversion to more urban uses. Expansion of built-up area

Figure 2: Landuse Distribution in between KMC and Baruipur in Hectare (1991 - 2011)



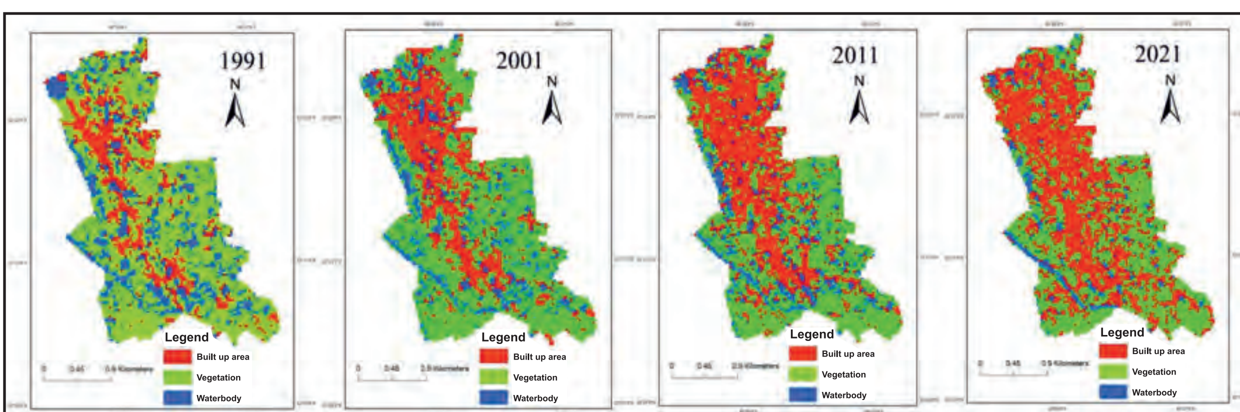
along SH1 or Baruipur-Kulpi Road towards south should be noticeable.

A large part of the area is covered by agricultural lands which coalesce with vegetation. Hence, increase in the share of vegetation is observed. Thus, bare surface has been considered as a landuse category instead of agricultural land.

Urban expansion of KMC towards south, conversion of bare surface, water bodies and vegetation into built-up area is quite evident. Since Baruipur is located on this path of expansion, its urban growth pattern, as a peripheral area of KMC, definitely needs to be studied.

Transformation of crop-fields to built-up areas is being noticed in many places. However, Baruipur claims special attention since it has been a potent source of vegetables and fruits that are being supplied to Kolkata and its neighbourhood. The transformation of agricultural lands to built-up areas has not only changed the job pattern, but, set the food supply chain in jeopardy and a challenge for the planners. From figure 3, distribution of lands in Baruipur Municipality shows that the built-up area has increased from 16.58 percent in 1991 to 47.70 percent in 2021 and water body and vegetation have decreased.

Figure 3: LULC Map of Baruipur - 1991, 2001, 2011 and 2021



	Area in Percentage			
Classes	**1991**	**2001**	**2011**	**2021**
Built-up area	16.58	27.60	38.88	47.70
Vegetation	61.57	53.30	47.20	45.00
Water Body	21.85	19.10	13.92	07.30

Accuracy assessments on the basis Google Earth imageries for the years 2001 and 2011 have been done. They are of 97 percent and 98 percent respectively. For 2001 and 2011 overall Kappa statistics are 0.9819 and 0.9819 respectively.

The change detection map in figure 4A shows main conversion from vegetation land to built-up area (yellow patch) which is noteworthy. Reduction in water body has considerable detrimental effect on the local environment of the study area. Spatial metrics have been derived for built-up area from these classified images to determine changes in spatial structure and monitor urbanisation.

Figure 4: Change Detection Map of Baruipur, Urban Growth of Baruipur

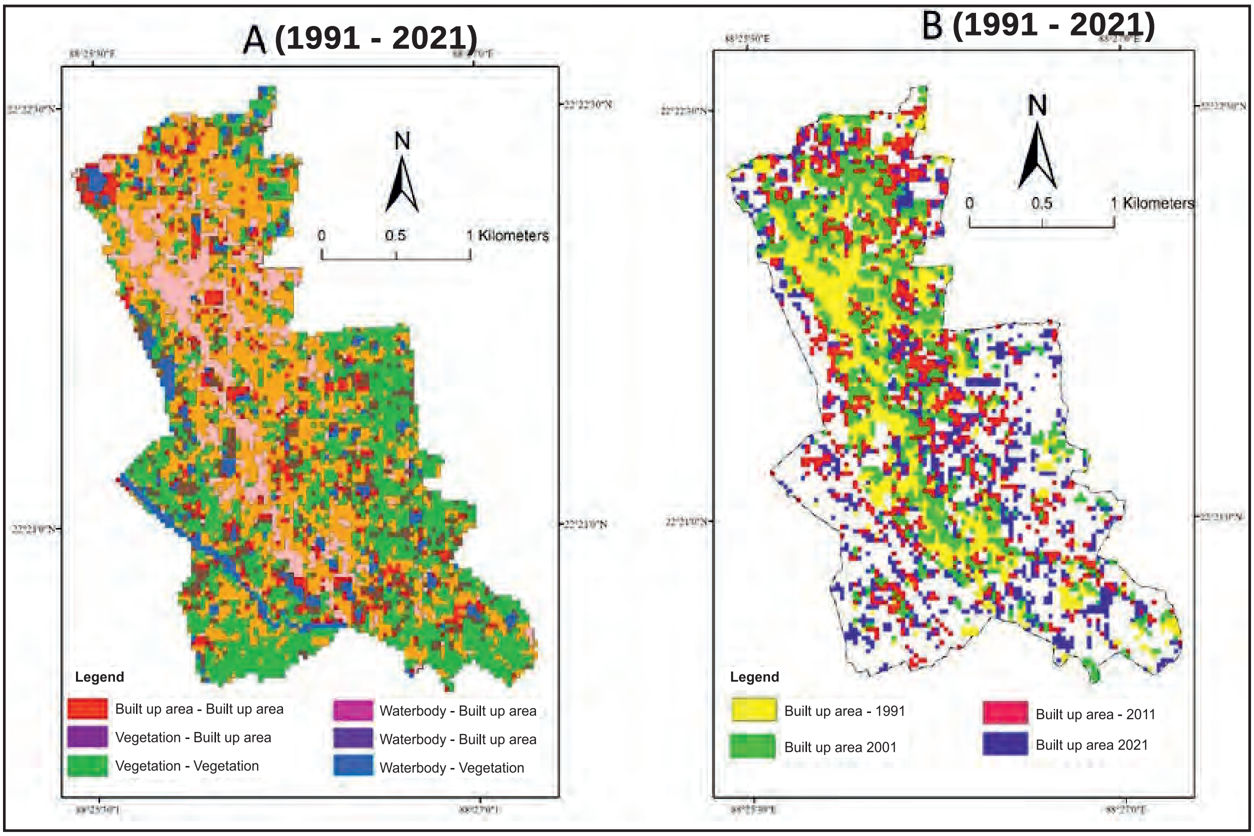
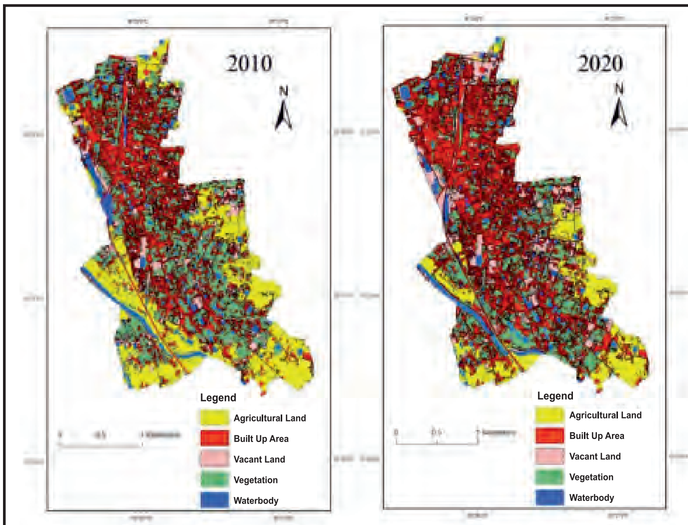


Figure 4B shows this urban growth between 1991 and 2021. Yellow colour denotes the distribution of built-up area in 1991. Northern part of the municipality is gradually getting saturated. Expansion of the built-up area by infilling and fragmenting the vegetation cover can be seen in north to south direction. The reason behind these changes or increment of urban space is the population increase and government planning. In the Comprehensive Mobility Plan, KMC, 2001-2025, Baruipur has been decided to be a Trans Metro City System where population has been projected at 3.0 million in 2025. To manage this population various plans have been taken for Baruipur, such as construction of flyover, extension of EM Bypass up to Baruipur, area wide traffic management and operation system, etc.

Extension of EM Bypass to Baruipur played a big role in providing a high-speed traffic corridor in the south to establish better accessibility in the south-eastern part of KMA and its adjoining vast hinterland. This road has helped in the movement of vehicles for the passengers and perishable commodities such as fruits, vegetables and milk, etc.

Detailed land use distribution maps of 2010 and 2020 have been prepared (figure 5) to ascertain the situation of vegetation. Since the maps are prepared manually by digitisation, vacant land, agricultural land and vegetation have been categorised separately. The problem of mixing of vegetation with agricultural land has been circumvented here. Landuse distribution shows that agricultural land, vegetation and vacant land have decreased in 2010 and 2020.

Figure 5: Land Use Map of Baruipur, 2010 and 2020



Land Use	2010	2020
Built Up Area	33.59	42.73
Vegetation	23.32	19.14
Vacant Land	11.68	10.80
Water Body	6.13	4.99
Agricultural Land	25.29	22.34

Note: Figures are in percent

Impact of vegetation loss and water body shrinkage on urbanisation have been studied in many places. In China, expanding urban areas are facing loss of vegetation (Zhang, Z., et. al., 2023); in Mexico, level of urbanisation is effecting plant communities (Meléndez-Jaramillo, E., et. al., 2023). Adverse impact of urbanisation on water body depletion (Beura, D., 2017), contamination and pollution (Vani, M., and Kamraju, M., 2016) have researched. Spatio-temporal changes in built-up area and subsequent conversion or encroachment upon vegetation and water body (Mitra, D., and Banerji, S., 2018) causes environmental degradation. Along with change detection, edge density, patch index, land fragmentation of the lands has been studied here that make the paper unique from others.

The yellow patches in the outer fringe of Baruipur Municipality and green patches in the central and southern part have steadily receded. But built-up area has increased from 33.59 percent in 2010 to 42.73 percent in 2020. Small patches of water bodies are shrinking.

Shifting of occupation towards non-agricultural activities (Mallik, G., 1990), increase in population (Census of India), southward expansion of KMC, urbanisation at the periphery are the root causes of this reduction in agricultural land.

The pattern of urbanisation can be understood by Shannon's entropy. The value calculated for Shannon entropy ranges from 0.00 to 0.17 for the grids 0 to 12. The value of built-up area for every grid (table 4) shows urban growth pattern. Values of the entropy ranges from 0 to 1. Here equals to 12 as area is divided into 12 grids. Other than grids 5, 8, 9, 11 and 12, relative entropies are close to zero, which indicates that the distribution of built-up area is compact at individual grid level. Half way mark of is considered as threshold.

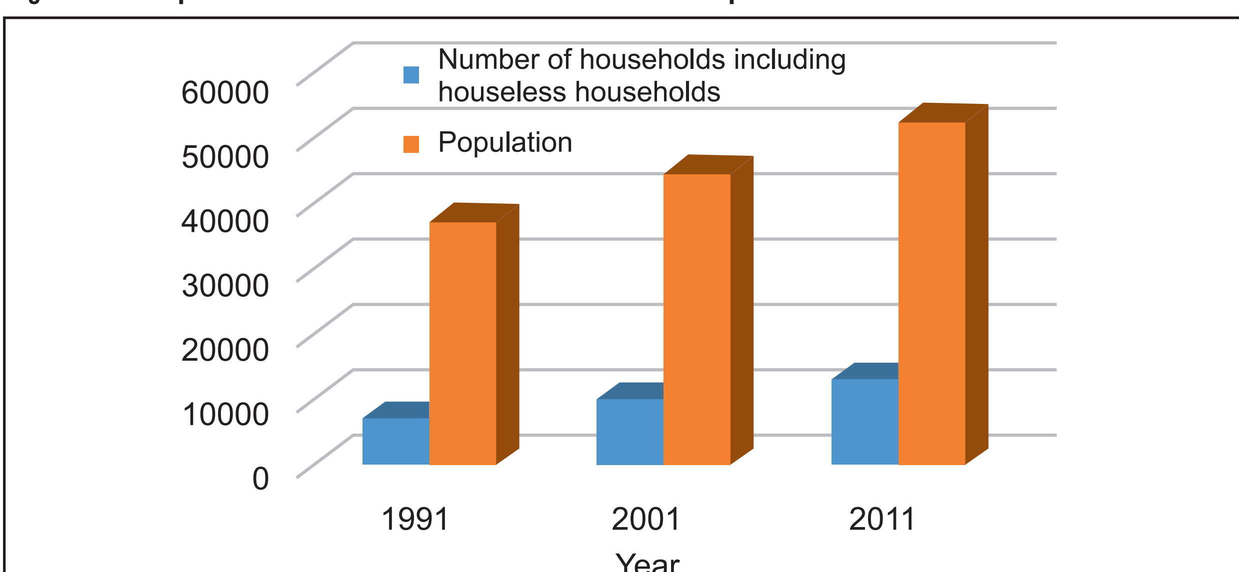
Table 4: Year Wise Relative Shannon Entropy

	Year Wise Relative Entropy					Year Wise Relative Entropy			
ID	**1991**	**2001**	**2011**	**2021**	**ID**	**1991**	**2001**	**2011**	**2021**
0	0.000	0.000	0.000	0.003	7	0.007	0.013	0.013	0.014
1	0.048	0.051	0.060	0.077	8	0.089	0.094	0.100	0.148
2	0.065	0.065	0.070	0.090	9	0.052	0.138	0.140	0.154
3	0.023	0.049	0.050	0.057	10	0.026	0.039	0.039	0.046
4	0.003	0.003	0.010	0.028	11	0.092	0.095	0.096	0.142
5	0.133	0.141	0.150	0.168	12	0.087	0.102	0.110	0.125
6	0.079	0.069	0.070	0.087	Total	0.833	0.859	0.908	1.139

Here is 1.11. Half of is equal to 0.55. Grids 9, 5, 11 and 12 locating in the central and northern part of Baruipur shows higher relative entropy value though below half way mark of threshold. The relative entropy value is lower in 1991 and increased to 2021. This indicates gradual urban growth in the area. Values show a compact and homogenous central part that has extended northward. Increased entropy values indicate increase in built-up area and expansion of urban sprawl. Overall entropy values for the whole municipality confirm a compact distribution of built-up area at grid level. But as time progresses, dispersed growth at Municipality level becomes evident. Total entropy value at municipality level shows that it is always sprawling as the total entropy value is always higher than the half-way mark of and crosses the upper limit of, i.e., 1.1. Calculated Shannon's entropy for built-up area definitely confirms that the urban growth is highly dispersing from 1990 to 2021 and need proper management to achieve sustainable development.

Figure 6 shows population growth and number of households from 1991 to 2011 in Baruipur. From 1991 to 2001 and from 2001 to 2011, the population growths were 19 percent and 18 percent, respectively. Whereas from 1991 to 2001, the increase of number of households including houseless households were 40 percent and 31 percent. Increasing number of population and household along with

Figure 6: Population and Number of Households in Baruipur



increasing entropy level indicate the horizontal growth of Baruipur. Since this municipality is located in the fertile agricultural land, this horizontal growth of the municipality needs to be monitored and properly managed, so that the area would not lose its characteristics.

Increasing entropy value shows that the area is developing and gradually expanding mainly because of real estate sector other than locational effect. Metric analysis at spatio-temporal scale helped in understanding the concentration, dispersion, fragmentation of built-up areas and other land uses mathematically. The result of FRAGSTATS at Class and Landscape level has been portrayed in eight metrics in figure 7A and 7B and a quantitative description of composition and arrangement of urban settings and growth has been shown in table 5.

Figure 7: Metrics: A. Class Level Metrics B. Landscape Level Metrics

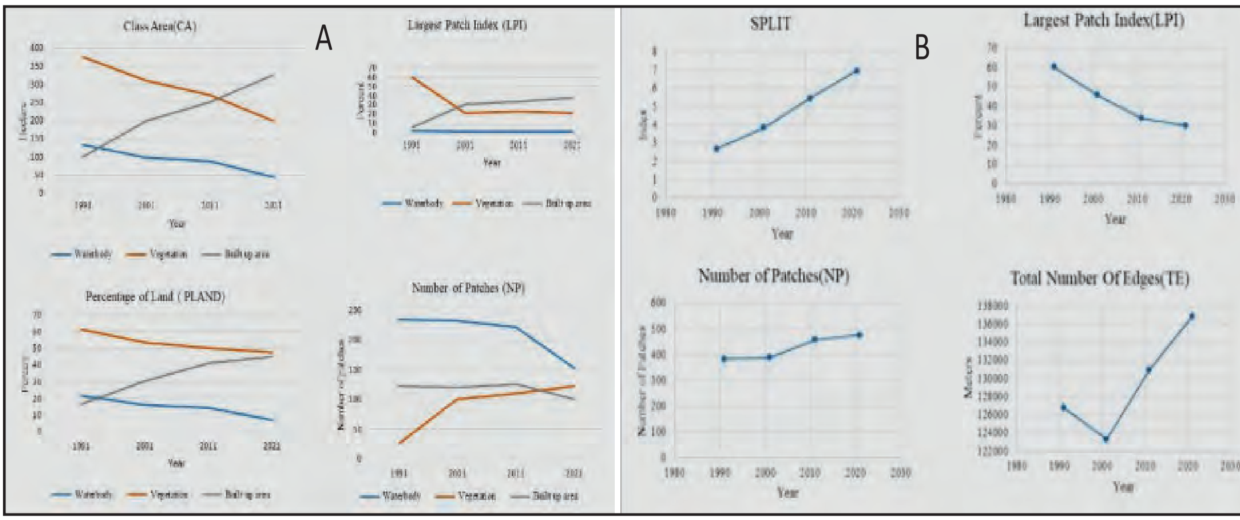


Table 5: Class Level and Landscape Level Metrics of Baruipur Municipality Showing Pattern of Landscape Changes

Class Level Metrics									
	1991	2001	2011	2021		1991	2001	2011	2021
CA					LPI				
Waterbody	133.11	97.92	88.11	44.19		2.2311	1.5514	1.5071	1.3298
Vegetation	375.03	311.12	270.72	200.26		60.36	21.52	22.90	21.72
Built Up Area	100.98	200.08	250.29	325.67		5.69	30.83	33.80	38.08
Percent Land					NP				
Waterbody	21.85	16.07	14.46	7.25		234	232	221	153
Vegetation	61.57	53.60	50.44	47.49		26	101	111	123
Built Up Area	16.58	30.33	41.09	45.26		123	120	126	101
Landscape Level Metrics									
Year		**SPLIT**		**NP**		**TE**		**LPI**	
1991		2.71		383		126810		60.36	
2001		3.84		389		123330		45.83	
2011		5.44		458		130920		33.80	
2021		6.95		477		136810		30.07	

CA shows the composition of the landscape. Table 5 shows that from 1991 to 2021, CA of built-up area increased while vegetation and water body have decreased. Percent land shows that the built-up area has increased from 16.58 percent in 1991 to 45.26 percent in 2021. Area under water body and vegetation has decreased from 21.85 percent to 7.25 percent and from 61.57 percent to 47.49 percent respectively. To accommodate has the increased population built-up area has increased. LPI represents the dominance. In 1991, the dominant class was vegetation. It had 60.36 percent LPI in 1991 and turned to 21.71 percent in 2021. In case of built-up area it was 5.69 percent in 1991 and became 38.07 percent in 2021. The vegetation was containing 26 NP at class level in 1990 which increased to 123 in 2021. It means fragmentation occurred for vegetation (LPI decreased). But in case of water body, NP decreased, representing lower CA. LPI of water body decreased due to filling and sometimes due to fragmentation of water bodies. Hence, number of water bodies are getting lesser and gradually replaced by built-up area at class level. Due to fragmentation, NP at class level increased mainly for vegetation. Due to urban expansion NP for built-up area increased.

SPLIT increases as the NP increases (Jaeger, J. A. G., 2000). Increment of SPLIT index at landscape level (table 5) with an increasing trend (figure 7B) more than threefold proves fragmentation of the area by scattering of patches. New built-up areas are added and vegetation areas are fragmented. SPLIT Index increased from 2.71 to 6.95 between 1990 and 2021. Along with NP at class level, TE, representing the increase of length of edges at landscape level, indicates porosity and fragmentation of the area. TE becomes zero when landscape has no edge, which means single patch will cover the entire area. The porous spaces are supplying areas for built-up purposes. Infilling of built-up areas makes the area more compact with urban space. Hence NP at class level of built-up area is reducing. LPI is the percentage of landscape that largest patch has. It approaches 0, when largest patch in the landscape gets smaller. Here patch size of the vegetation is getting smaller as LPI is decreasing from 60.36 (1991) to 21.72 (2021).

At class level LPI of built-up area is increasing and landscape level LPI is decreasing. This incident proves the losing dominance of vegetation and water body to built-up area. This confirms the urban expansion from 1991 to 2021. This happened mainly because of low land value, availability of larger land holdings, improved transportation, etc.

Fragmentation measuring the landscape division performs an important role in understanding the process of landscape degradation resulting in environmental and socio-economic change.

Figure 8: Shannon Entropy for Baruipur Municipality, from 1991 to 2021

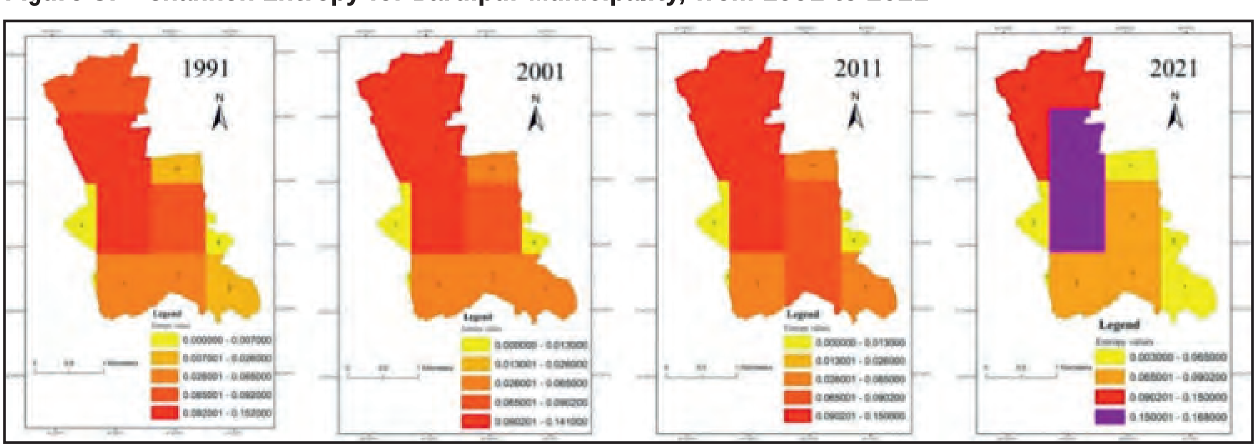


Figure 8 shows central Baruipur municipality had high entropy value as transportation junction of Baruipur lies here. This gradually extended to northward. In 2021, grid 6 and 10 show growth. Urban growth is higher in the north than the south. Gradually it extends southward.

Figure 9A shows that in 2001 the minimum population density of Baruipur was 37-44 persons per hectare which rose to 45-48 persons per hectare in 2011. Maximum density also rose from 142-183 persons per hectare to 183-186 persons per hectare. In wards 1, 3 and 14 population density rose from 142-183 persons per hectare in 2001 to 183–186 persons per hectare in 2011 (figure 9B). In 2001, under 142–183 persons per hectare were present in wards 1, 13, 17, 3, 14, 11 and 15. Household density has also been increased between 2001 and 2011.

Figure 9: Density Maps of Baruipur Municipality

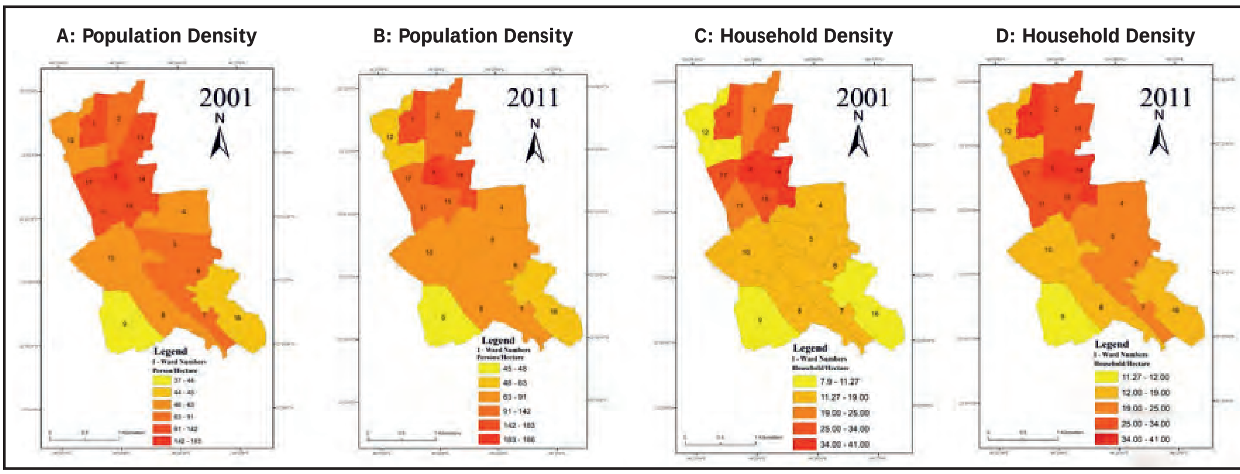


Figure 9 shows that ward 9 has the lowest density (population and household) since it mainly has agricultural land still its density is increasing. In case of ward 12, due to proximity to EM Bypass population and household density (figure 9C and 9D) increased, showing transformation of vacant lands into built-up areas. Same happened in ward 16 where too large amount of vegetated land has been converted into built-up area. This southward expansion is following the transportation network. Census reports along with eight metrics are showing spatio-temporal urban growth, all emphasizing urbanisation in Baruipur municipality, as well as a fragmented landscape because of urban expansion. Due to good connectivity of road wards 5 and 6 show increased household density with same range of population density (though population density increased). Champahati-Ghatakpur road is connecting Baruipur-Kulpi Road or SH1 with Baruipur Canning Road and SH3. This road connectivity helps in supply of perishable and non-perishable items to city. Ward 3 has the highest density for both the cases. It is due to the availability of all the facilities of road, railway station, and healthcare, etc.

As a result of built-form and artificial land coverage expansion, urban area experiences spatial variation of LST at micro level which contribute to the urban heat island effect to any city or area (Morabito, M., et al, 2016). LST is the surface temperature of the ground under the pixel scale with different fraction of surface type as different surface materials have different thermal properties. Present study searched the effect of urbanisation on LST in the said municipality. Images for two years 2010, 2021 have been taken.

Figure 10 and 11 are showing the LST maps of Baruipur for the years 2010 and 2021. Figure 12, derived from figure 10 and 11, shows the average LST maps for the years 2010 and 2021. Temperature interval taken is 1°C. Same degree difference for both the years 2010 and 2021 is maintained, however, the maximum LST varied.

Figure 10: LST Maps of Baruipur, 2010

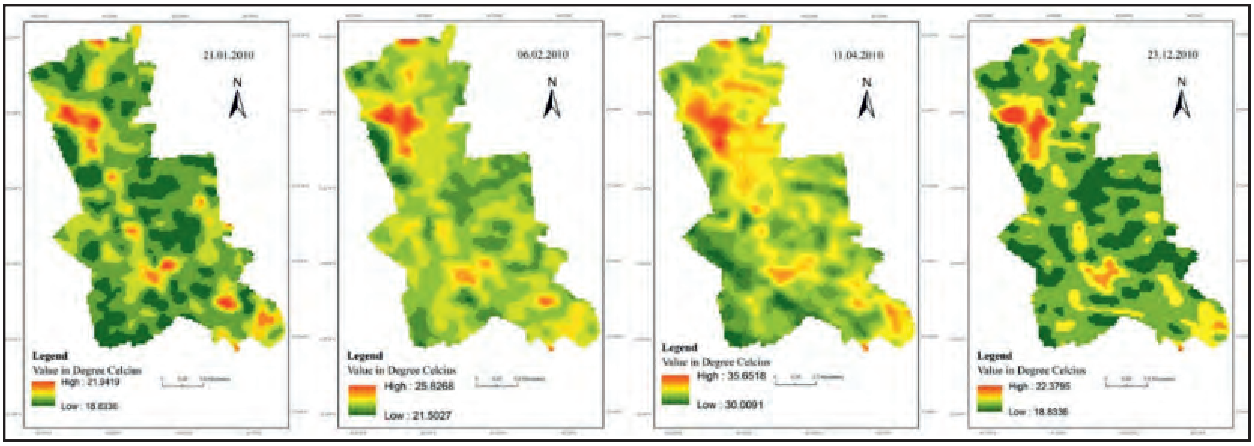
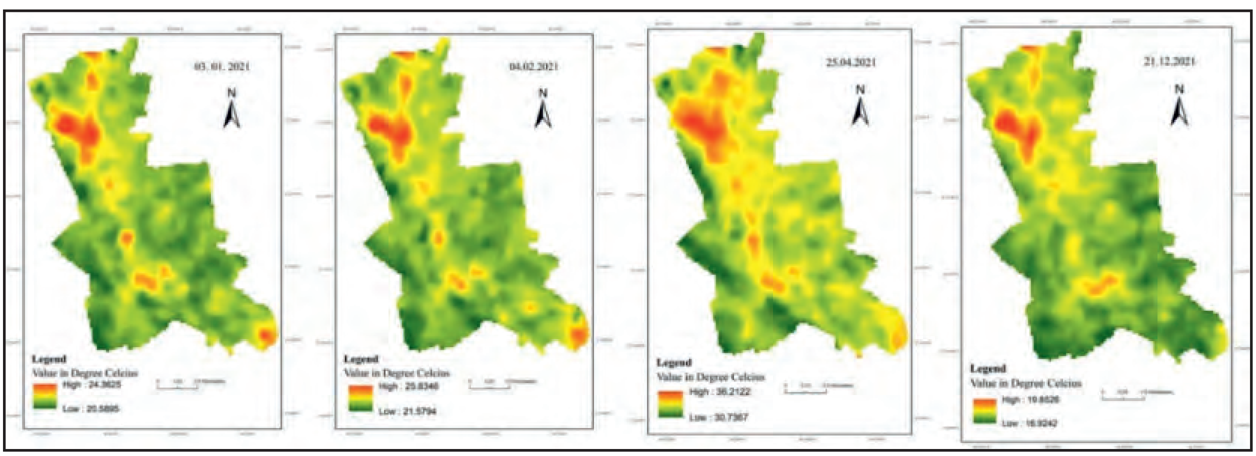


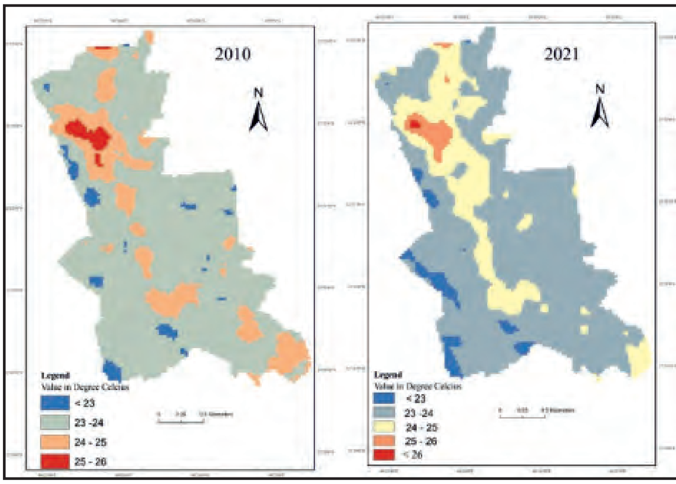
Figure 11: LST Maps of Baruipur, 2021



In figure 12 increase of yellow patch proves that the area covering temperature 24°C - 25°C has increased. The high temperature areas are covering the transportation features, large commercial areas, bare surfaces. Scene centre time is at 4.30 am GMT or 10.00 am. Hence, the LST calculated from the images are not the maximum temperature of the day. The area under 25° C to 26 °C has increased. In 2010 the maximum temperature was 25.8 °C. But in 2021 the maximum temperature rose to 26.4° C. A bare surface is present in this patch. The temperature can be controlled by planting trees along the boundary of the plot. The area under 25° C to 26 °C is highly urbanised. This triangular area is covered by road and railway network. Dark coloured asphalt roads emit high temperature, release heat into the atmosphere and contribute to the LST.

A linear relationship is already found by the researcher between road development and increasing LST (Sameh, K. A., et al, 2022). In 2021 area under 22° C to 23 °C has increased. This area mainly covers the part of Adi Ganga or Tolly Canal which is polluted by people, and its banks are illegally encroached. After

Figure 12: Average LST maps of Baruipur and Distribution of LST from 2010 to 2021 in Hectare 2010 and 2021



Temperature (^{0} Celsius)	Year	
	2010	2021
< 23	16.03	24.71
23 - 24	479.51	435.40
24 - 25	102.80	132.79
25 - 26	9.93	14.58
> 26	0.00	1.00

National Green Tribunal's (NGT) direction canal has been cleaned and illegal constructions are removed. The bench instructed Kolkata Police to be on surveillance (Times of India, 2017). Thereafter, the zone of under 23 ^{o}C has grown and that within 23^o C to 24 ^{o} C has shrunk, showing an efficient way to systematically combat urban heat.

4. CONCLUSION

The study shows a southward push of KMC resulting in fast urban growth and development of Baruipur municipality. Land fragmentation and undesirable filling of land parcels by built-up area, shrinkages of waterbodies and unwanted occupancies have been noticed. Increment of LST affects ecology, precipitation and humidity, etc., and needs to be monitored on a regular basis.

The three decisions, first, to shift the district headquarter from Alipore to Baruipur, secondly, the proposal to convert Baruipur into a Metro Centre by 2025, and finally, a plan to extend metro rail to serve Baruipur, has attracted various infrastructural facilities, that is transforming Baruipur into an attraction centre. Though, the first proposal was withdrawn, it triggered land acquisition by the realtors in various pockets. Fragmented availability of space hinders proper planning of facilities, which in turn forces more distance to be travelled, more congestion, fuel consumption and pollution load.

Following Atal Mission for Rejuvenation and Urban Transformation (AMRUT) policies is essential for sustainable development. Further, the following recommendations may be adopted:

Through proper hierarchical neighbourhood facility planning, establishment of compatible land uses with increased accessibility could be the primar y goal.

Adding to urban landscape, rain water harvesting, kitchen garden, and roof top cultivations be practised to create a cooler microclimate, as corroborated by the case of rejuvenating Tolly canal.

The agrarian land use must be relocated to barren lands and introduce improved agricultural techniques to substitute the supply of fruits and vegetables for the city.

Conservation of space earmarked for future infrastructural development must be planned on priority.

Continuous public sensitization and public-private joint governance is an efficient way of conserving the open spaces retained for future use and controlling air, water, noise and thermal pollution by keeping strict vigil on the waterbodies and greeneries too.

Limitation: This study has only observed the effect of LU changes on LST. Other environmental components such as rate of precipitation, ground water level, arsenic level and socioeconomic factors could have been studied. Overlaying the distribution of LST maps on LU maps and finding out the hotspots at micro-level will help in better planning.

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An Assessment of Relationship Between Industrialization and Urbanization in Bhiwadi Region of Rajasthan: A Spatio-Temporal Analysis

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Abstract

The primary objective of this research is to identify the relation or interlink between industrialization and the urbanization process in Bhiwadi industrial area. The present research is based on both qualitative and quantitative information which are collected and analysed from different satellite images and an in-depth study of literature review. This paper employs various indicators and aspects, namely the capacity of workers, trends in urban population, industrial status, and the extent of built-up or infrastructure areas in order to conduct a spatio-temporal analysis of the Bhiwadi industrial area. To differentiate between the land covers of urban and industrial areas, the land use and land cover (LULC) of the region for two decades from 2000 to 2020 are constructed, whilst normalized difference built-up index (NDBI) is utilized to detect changes within the area. Results of map and data tables illustrate the changes in the occupation of land due to industrial and urbanization activity during the last few decades. Moreover, the expansion of built-up areas comprising industrial or urban domains has been stimulated through the development of new residential societies and an increase in workers of urban populations.

1. INTRODUCTION

The development process in any nation leads to growth of urban expansion on the one side and industrialization on the other and because industrialization and urbanization are the two sides of the same coin of economic development. Urbanization is a wide process that changes society through cultural, social and economic transformation. It includes the movement of people, increasing urban areas and changing the demographic dimension of society. In urbanised society, people live crowded together in cities and a large number of populations comprise a social complexity within a small area (Hussain, M., & Imitiyaz, I. 2018). Urbanization mainly begins when enterprises or a small factory is set up within a particular point, thus starting a cycle of demand of labour, transportation and infrastructure development. All this demand and development cycle leads to the building of housing for the urban facility. Industrialization is a comprehensive process of social integration and economic structure and it is the foundation of recent urbanization. All the factors of industry like social hierarchy among labourers, raw material availability, the production structure, road network, pattern and linkage of market etc create a field of force that leads to the development of spatial patterns of urban areas (Scott, A.J. 1986). After the eighteen-century, industrial revolution era, industry started to set up and the majority of towns and cities started changing their structure and form, gradually with rapid migration of people concentrated in the urban area (Kim; 2005, Rees; 2016, Xiong, et. al; 2020). After the revolution, industrialization had a significant effect on the urban area because the industrial setup is the basic deriving

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force for city development. Generally, urbanization and industrialization are parts of the same family that grow together and develop each other. Industrialization is the driving force for the outer expansion of the city region, transforming suburbs to complete urbanization due to a set of many transforming factors. Industrialization is impracticable without a certain amount of capital, technology, skilled labour, transportation, etc. This condition is not developed in rural or agrarian society. Certain level of urbanization is essential to attain them. If we see the global industrial city which initially evolved in Europe and northern America in the nineteenth century was accompanied by the rapid growth of population and colonial trade in ancient cities. The first metro or mega-city was developed in Europe and America due to the driving force of the industrial revolution, another side in India, Europe set up firms or industries in the area which had a population as useful labour and connectivity to transport their good. The global city of India, Bombay, also developed as a port city for transportation of raw cotton product to Europe. According to the world population prospect of United Nations Organisation (UNO), 55 percent of the population lived in urban areas worldwide in 2018. According to data on urbanization from 1950 by UNO, only 30 percent of the population was urbanized. However, in 2018 the world population is living in urban areas has been estimated to 68 percent. According to the United Nations Industrial Development Organization industry sector shares 31.2 percent of the country's GDP and comprises 22 percent total workforce of the country. Bhiwadi city had the highest urban growth rate in the whole of Rajasthan during the 2001-2011 and its annual growth rate is 11.3 other side Rajasthan average growth rate is only 2.55 percent. Bhiwadi City along with Alwar City together constitutes 87 percent of the district's urban population. The urban population of Bhiwadi City with Alwar City is the second-largest contributor in the state's domestic product. Bhiwadi has 444 overall ranking in the urban development area. In 1970, the government of Rajasthan decided to develop Bhiwadi as an industrial growth centre due to some industrial advantages like proximity to Delhi, connection to state and national highways, land and labour and counter impact of Neemrana and Khuskheda industrial town and it has successfully established itself on the industrial map of state and nation. Bhiwadi industrial city faces several urban difficulties like deficiency of infrastructure and housing for industrial employees. It has great urban development and new industrial potential because at present private investors are gradually developing a housing society or Aasiyana for industrial employees and industries are also expanding themselves due to availability of the living facilities in the city for the workers, capital, trade and consumer.

2. STUDY AREA

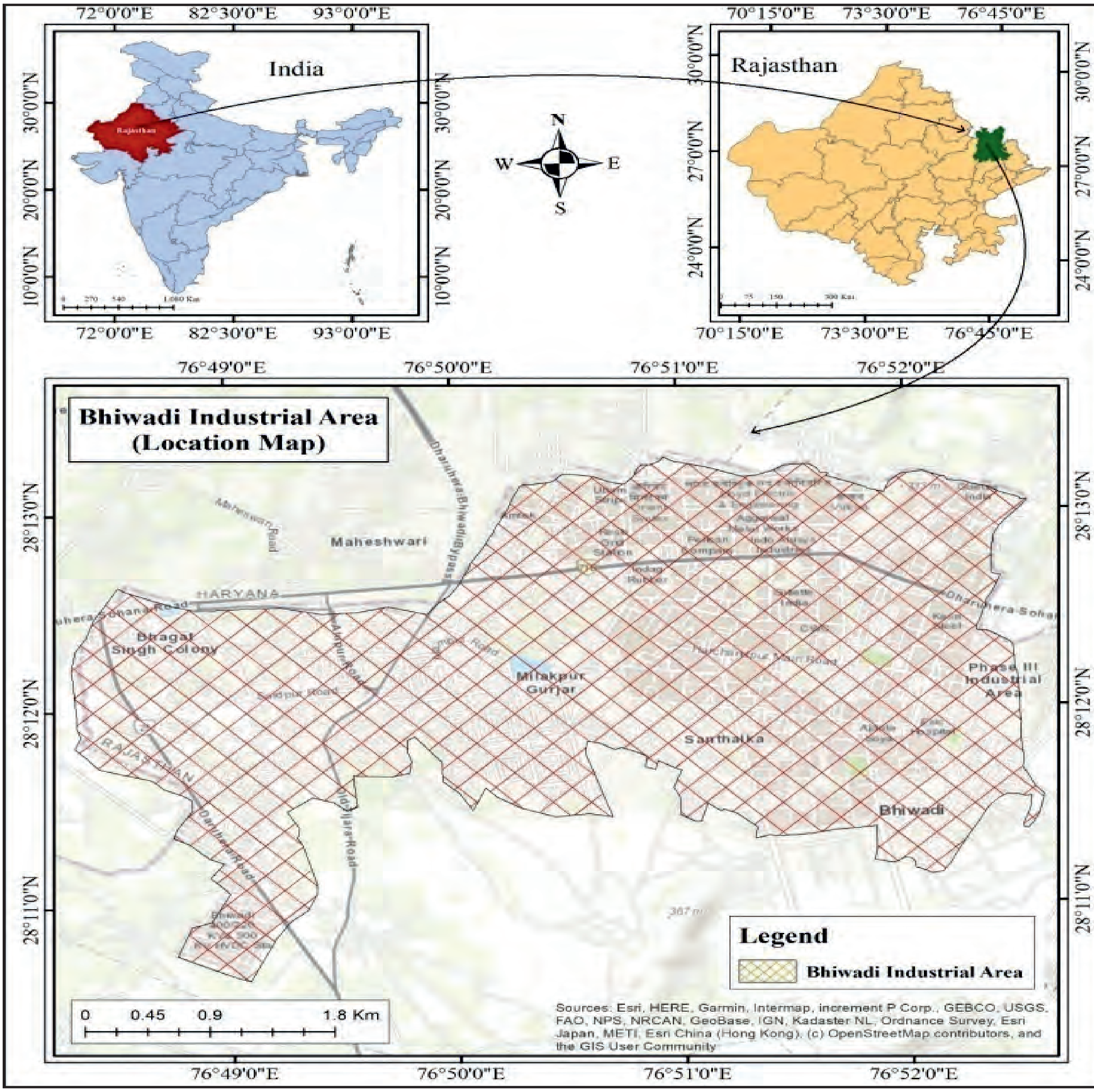
2.1 Location and Extent

Bhiwadi is an industrial region located at the north-eastern boundary of Rajasthan state in Alwar district (figure 1). It spans to an area of approximately 2144.834 hectares and is situated between 28°7′10″ N–28°13′40″ N latitude and 76°45′ E–76°55′50″ E longitude, with an average elevation of 268.70 meters above sea level (Rajput, 2020).

2.2 Geology

The region's elevation ranges from 193 to 386 meters, with an average height of approximately 268.70 meters above sea level (Rajput, 2020). The primary rock group found in Bhiwadi is Pre-Aravalli, which consists of quartzite, schist and granite. Additionally, there are deposits of building stones, soapstone, and quartz. A seasonal river named Sabhi flows through Kotkasim and Tijara block in the area.

Figure 1: Location and Extent of Study Area



Source: Bhiwadi industrial area master plan 2031

2.3 Climate

Bhiwadi is highly reputed for its semi-arid climate, characterized by intense cold in winter and extreme heat in summer. The monsoon season is brief, lasting from July to mid-September, with an average temperature of 26˚C and maximum and minimum temperature readings of 47°C and freezing point, respectively. The wind speed varies throughout the year, with June having the strongest gusts at around 13.1 km/hr, whereas November has the lightest at about 5.6 km/hr. The dominant wind directions are SW, NW, NE, and SE. The average annual rainfall is estimated to be within 600-650 mm per year.

2.4 Soil

The predominant soil types in the region encompass sand, sandy clay, clayey loam and loam. The primary soil type identified in the area is loam. In the north-eastern part of Bhiwadi, the soil type is Alluvial Sandy soil. However, the region's micro-topographic features exhibit internal micro-level variations as well.

2.5 Drainage System

The district does not have any perennial rivers, but it is adorned with seasonal rivers that originate from the hills and traverse the region, including Sahibi, Ruparel, Chuhar Sidh, and Lohdoha. The natural drainage system operates from the southeast to the northeast. Sahibi is the most extensive river in the area, flowing through the western part of Bhiwadi, roughly 20 km away from the study site. It flows towards the north-east, traversing the Bansur, Behror, Mandawar, Kishangarh, and Tijara block, carrying water from the western slope of the Aravali hills. Groundwater is the primary source of water for all activities, primarily present in the soil made up of the Old Alluvium layer. It is a promising groundwater resource zone, with good potential that is uniform across the region, due to evenly distributed rainfall, effective porosity, and geometrical properties of the aquifers. According to the Groundwater Department of the Alwar district, groundwater in Bhiwadi is over-exploited and its quality in the industrial area ranges from medium to low.

According to new National Capital Region Development Plan of 2021, Bhiwadi will be developed as a substantial regional centre in the NCR boundary. Bhiwadi industrial area is situated on the north east side of Alwar district that is 55 km away from the IGI Airport of Delhi and it is 200 Km away from State Capital Jaipur, 40 Km from Gurgaon, 90 Km from Alwar, and 60 Km from Faridabad city. According to 1971 census, its total population was 1624. Due to its proximity to Delhi and other location advantages, Rajasthan Government decided to develop Bhiwadi as an industrial centre and for the first time in 1975, it registered its presence on the industrial map of the country.

In 1975 Rajasthan State Industrial Development and Investment Corporation (RIICO) developed Bhiwadi as an industrial town. The main industrial development of this area was started around 2000 when RIICO and government of Rajasthan took special initiatives for industry along NH8. Bhiwadi is the fastest growing city in the country, with a population of 15000 in 1991 when it was proclaimed as a census town first time and it reached 33877 in 1991. According to 2011 census data, It has a total area of 44.06 sq km and 1,04,921 total population (including institutional and houseless population) of this region.

3. RESEARCH METHODOLOGY

3.1 Materials and Methods

For precise measurement of the association between industrial development and urban expansion, it is essential to calculate the level of urbanization development and industrialization. In the present research work, data for some indicators of urbanization and industrialization through primary and secondary value indicators have been collected (table 1). In order to emphasise the correlation between urbanization and industrialization pilot study was conducted and two indexes are formulated first one is the urbanization index and another one is industrial factor index.

3.2 Construction of Coordination Indicator

In order to examine the correlation between the urbanization and industrialization of the Bhiwadi industrial area, various primary and secondary indicators were used to measure the correlation between these two facets of development. The selection of indicators focused heavily on those that are deeply associated with both urbanization and industrialization. Through correlation analysis, the influence of industrial development on

Table 1: Index System for Urbanization and Industrialization

Primary Indicators	Secondary Indicators
Urban Status and Economic Development	• Urban population • Urban employment and unemployment rate • Demographic aspect • Urban built-up/ house and basic infrastructure • Per capita income in urban area • Import and export amount • Industrial manufacturing goods and percent in export • Banking and communication facilities
Industrial structure and status	• Industrial sector in GDP • percentage of industrial workers in total worker • Secondary and tertiary activity in GDP • Employment in secondary activity • Employment in tertiary activity
Industrial Enterprise	• Large and medium size enterprises • Industrial labour productivity • Interlink, transport infrastructure indicator • Attainment rate of industrial effluent waste

urbanization was evaluated. The index system employed encompassed both primary and secondary indicators.

3.3 Indicators of Urbanization and Industrialization

As per the Bhiwadi Master Plan, certain areas within the city have been developed by the Urban Improvement Trust (UIT). These urban areas, situated outside of the primary city regions, are exclusively developed by UIT. The Bhiwadi-Gurugram State Highway has emerged as a significant site for the development of new housing apartments or societies, which have been developed exclusively by private investors (table 2). Bhiwadi was officially designated as a Class III city and subsequently achieved the status of a census town following the 1991 census. The city is overseen by a civic body, namely the Nagar Parishad, which is responsible for the upkeep and enhancement of the municipal environment.

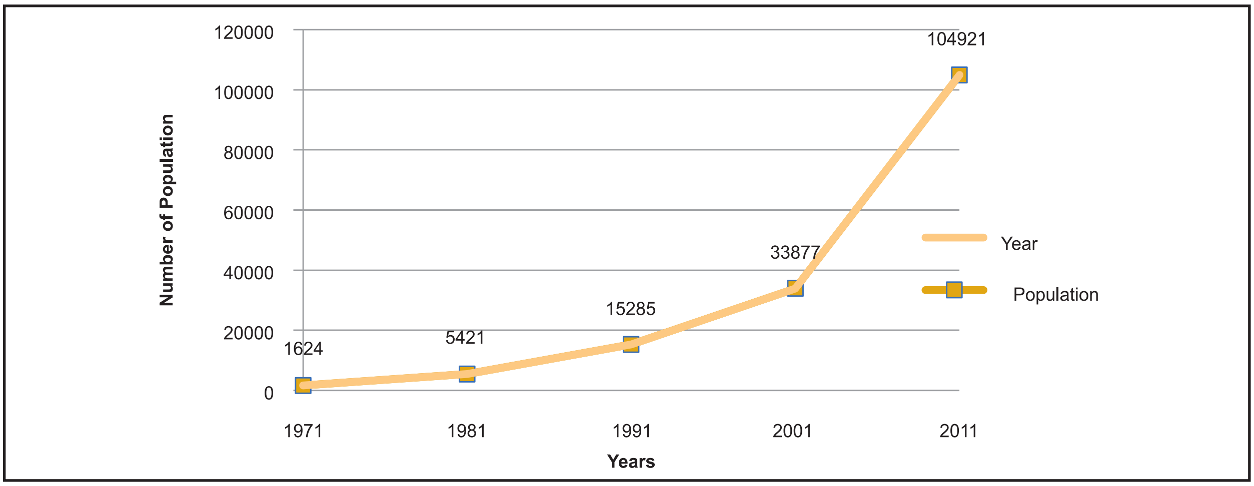
Table 2: Urban House Built Up

Residential Colonies Developed by UIT			
S. No.	**Name of Sector**	**No. of Plots**	**Area (sq.)**
1.	Bhagat Singh Colony	835 + 54 (EWS)	379500
2.	Vasundhara Nagar	110	545600
3.	Total	4834	1786900
4.	Sector-9	200 + 160 (MIG + 201 (LIG)	133000
5.	Sector-9 Extension	75	65000
6.	Sector-8	450 + 181 (LIG)	100000
7.	Sector-6	800	133000
8.	Group Housing Sector-6	100 + 89 (LIG)	53000
9.	Sector-5	800	133000
10.	Group Housing Sector-5	79 (LIG)	22500
11.	Sector-1	300	45000
12.	Sector-2 & 2A	200	82300
13.	Sector-3 & 3A	200	95000

Source: Greater Bhiwadi Master Plan 2011- 2031

Bhiwadi was developed by the RIICO in 1975 as a favoured hub for industrial activities. At the time of its inception, the city had a population of merely 1500 individuals. However, its population grew rapidly and reached 15000 after being declared as a census town in 1991. According to the latest data obtained from the 2011 census, the size of Bhiwadi's population has now surged to 104921 (figure 2).

Figure 2: Decadal Urban Population Growth Rate in Bhiwadi Region

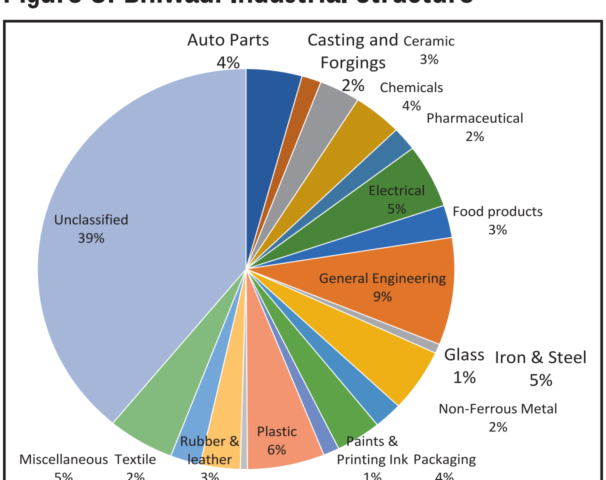


Source: Census of India

3.4 Industrial Structure

Bhiwadi industrial area is divided into four industrial regions namely Bhiwadi (phase I-IV), Jhiwana, Khijuriwas, and Kahrani with around more the 800 industrial units operating in this area. Generally, Bhiwadi industrial sector comprises auto, paint dye, fabrication, chemical, pharmaceutical synthetic, plastic etc. kind of commercial services (figure 3, table 3, table 4).

Figure 3: Bhiwadi Industrial Structure



3.5 Land Use / Land Cover Change Detection

Land use and land cover (LULC) are techniques that involve an analysis of the amount of land covered by forests, agricultural practices, urban infrastructure, wetlands, impervious surfaces, water bodies, and any remaining land use that reflects how people occupy the land. LULC serves as a crucial tool for resource management and any planning activity, where land cover helps in mapping and delineating the land cover. Land use technique plays an important role in obtaining time-based information about the types of land useds, current status, and changing patterns over time. Determination of land cover is possible through the analysis of aerial and satellite imaging data which helps us to understand the current status of a particular area. Information generated from LULC can assist in estimating past decisions and gaining insight into the possible consequences of planned actions before they are implemented. LULC maps also improve our understanding of the impact of natural phenomena and human interference on

Table 3: Types and Number of Industries in Bhiwadi

S. No.	Type of Product	Number of Industries
1.	Casting and Forgings	22
2.	General Engineering, Bearing, Dye, Fabrication etc.	126
3.	Plastic	87
4.	Electrical & Electronic Components Cables	75
5.	Miscellaneous	75
6.	Iron & Steel	74
7.	Auto Parts, Allied Items & Service Station	63
8.	Chemicals, Cosmetics & Allied Items	55
9.	Packaging	51
10.	Cement Products, Crockery Moulding Powder & Marble Products	46
11.	Rubber, Leather & Foam Products	45
12.	Food products, Cattle Feeds, Soft Drinks, Mineral Water etc.	38
13.	Textile, Yarn, Readymade Garments etc.	34
14.	Non-Ferrous Metal, Aluminium, Bathroom Fittings	32
15.	Pharmaceuticals, Insecticide, Fertilizers, Drugs, Surgical Instruments etc.	28
16.	Paints & Printing Ink	18
17.	Glass, Wood Paper & Allied Items	11
18.	Printing Press, Stationary Items	8
19.	Unclassified	567
	Total	1455

Source: Bhiwadi Manufacturer's Association

Table 4: Growth of Industries in Greater Bhiwadi Complex (Including Tapukheda & Khuskhera)

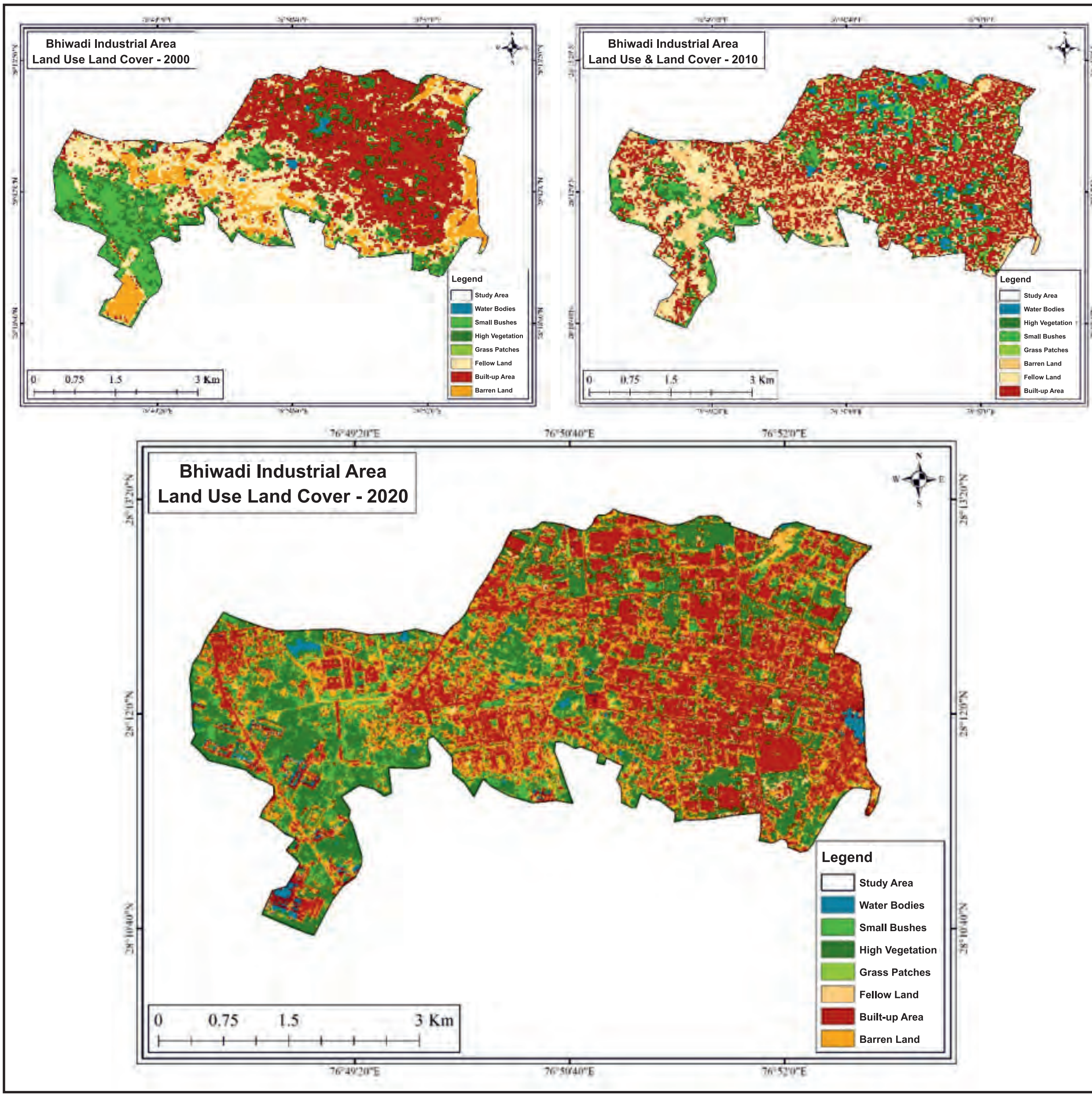
Years	Number of Units
1997	724
2003	1280
2006	1362
2009	2453

Source: Bhiwadi Manufacturer's Association

natural landscapes. Furthermore, LULC maps are helpful in developing an understanding of the time-dependent urban expansion, industrial firms, and infrastructure setup.

The LULC of the Bhiwadi region has undergone significant transformations due to infrastructure development, anthropogenic activities, deforestation, and planned or unplanned development. The 2000 LULC map reveals a mass level built-up area situated on the north western side, while the eastern side exhibits minimal development and vegetation cover (figure 4). The eastern side primarily comprises a vegetation area, indicating a dearth of urbanization or industrialization at that location. The 2010 LULC map illustrates the westward expansion of infrastructure cover, gradual degradation of vegetation coverage, and the conversion of barren land into fellow land. Moreover, the barren land located on the outer east or southern west side has been converted into a green belt or built-up area. The 2020 map highlights the change detection in land use and land cover in the Bhiwadi industrial area, demonstrating a complete transformation of all segments of the study area. The areas formerly characterized by high vegetation, barren land, and fellow land have decreased, while the area devoted to infrastructure has increased. A temporal analysis of the

Figure 4: Decadal Change in LULC of Bhiwadi Area



region in the table indicates an increase in urban or infrastructure development areas from 2000 to 2010, after which there was a decrease in infrastructure development areas. The impact on population growth rate was influenced by societal and economic conditions, as well as the level of infrastructure that had already been achieved in accordance with the existing natural surroundings and infrastructure, which had reached a point of saturation.

The LULC changes in the Bhiwadi industrial region over the past three decades, as depicted in table 6, reveal a significant transformation in the area's land use patterns. The built-up Area, which includes urban and industrial infrastructure, has witnessed a gradual increase from 567 hectares in 2000, reaching 730 hectares in 2010 and subsequently decreasing slightly, to 669 hectares, by 2020, indicating urbanization and industrialization trends within the region during this period of time.

Table 5: LULC Change of Bhiwadi Region in Three Decades

S. No.	Class Names	Area in Hectares				Area Change (in percent)
		2000	2010	2020	Changes (2000 - 2020)	
1	Built-up Area	567.89	730.08	669.78	101.89	17.94185494
2	Fellow Land	111.09	419.22	447.84	336.75	303.1325952
3	Barren Land	410.76	259.92	195.03	-215.73	-52.51971954
4	Grass Patches	37.44	37.35	45.36	7.92	21.15384615
5	Small Bushes	129.88	125.82	158.13	28.25	21.75084694
6	High Vegetation	490.16	194.67	270.36	-219.8	-44.84250041
7	Water Bodies	72.06	53.28	33.84	-38.22	-53.03913405

Fellow Land: Which refers to agricultural land, forest, and other undeveloped land, has undergone a substantial increase, from 111 hectares in 2000 to 419 hectares in 2010 and further expanding to 447 hectares in 2020, suggesting that there may be a shift towards agricultural activities in the region or an increase in forest cover. The residential population in proximity to industrial establishments was increasing due to the convenience of commuting to work, which enhanced overall economic viability for workers in these industries. This trend is commonly referred to as industrial agglomeration or industrial clustering.

Barren Land: It has decreased considerably, from 410 hectares in 2000 to 259 hectares in 2010 and then to 195 hectares in 2020, indicating that this land has been converted into other land use purposes, such as industrial area, fellow land, or grass patches. In the western sector of this region, there has been a notable influx of industrial development on previously unutilized, barren land.

Grass Patches: They have increased slightly, from 37 hectares in 2000 to 45 hectares in 2020, while small bushes have increased significantly, from 129 hectares in 2000 to 158 hectares in 2020, suggesting that there has been an increase in vegetation cover in the region.

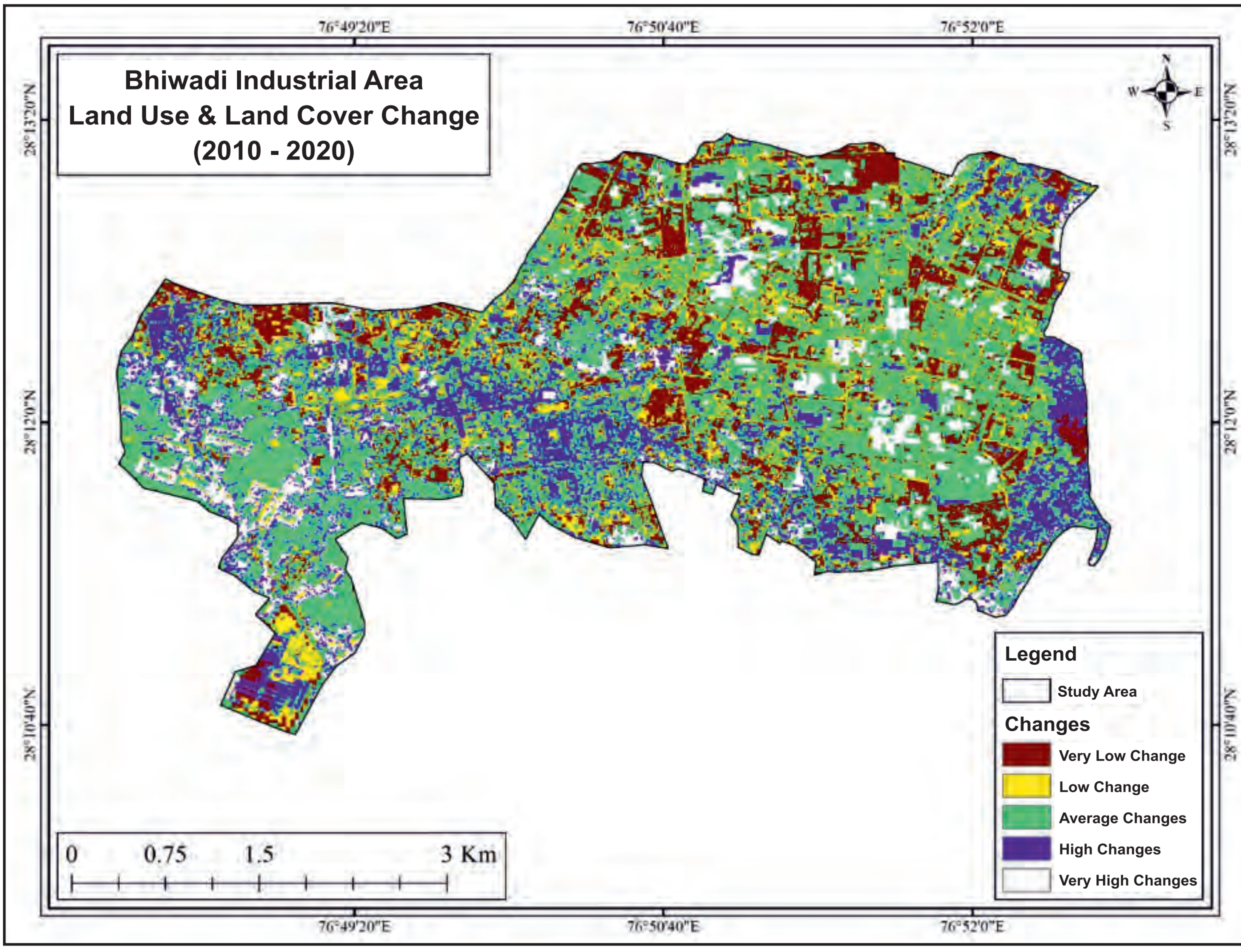
High Vegetation: It includes dense vegetation, witch has experienced a significant decline from 490 hectares in 2000 to 194 hectares in 2010, but then slightly increased to 270 hectares in 2020, possibly due to land use changes or natural factors.

Water Bodies: It include lakes, ponds, and other bodies of water, witch has decreased substantially from 72 hectares in 2000 to 53 hectares in 2010 and then to 33 hectares in 2020, indicating a decline in the availability of water resources in the region.

Overall, the LULC changes in the Bhiwadi industrial region reflect a complex interplay between urbanization, agricultural activities, vegetation cover, and water resources, highlighting the need for sustainable land use planning and management in the area.

The change detection data in figure 5 depicts the transformations in the Bhiwadi industrial area over the past decade. The analysis indicates that most of the changes have occurred at an average level, with only selected areas along the west and east margins experiencing high levels of change. The reason for the changes in these areas is that the east and west margins were formerly comprised of vegetation or barren land that provided areas for industrial development or urban settlement. The main reason for land use and land cover change of Bhiwadi is the increasing rate of urbanization and rapid industrialization growth in this area.

Figure 5: LULC Change Detection (2010-2020)



The availability of uncultivated and barren land on the western side attracted the new industrial setup because Bhiwadi mostly has a low-cost industry that wants to set up in the cheapest cost area. Another reason for land use and land cover change is the NCR effect, that pushes Bhiwadi into the NCR real state epicentre, residential town of commuter zone of nation capital Delhi.

In contrast, the eastern area of the RICCO Bhiwadi industrial zone has undergone minimal change as much of it was permanently covered with industrial or urban infrastructure before 2010. According to the 2000 LULC map (figure 6), the western side of the study area was an entirely untouched area, but after 2010, industry or urban infrastructure development began to bring about changes in this region.

3.6 Normalized Difference Built-up Index

The Normalized difference built-up index (NDBI) is used for extracting the built-up feature on the land surface (figure 7). In NDBI index data and images of satellites are ideally used to observe and perceive land cover change repeatedly in urban areas. Built up index is not only used to detect built up features on the surface but also explain urban sprawl, urban growth, bare soil and barren land cover. NDBI index compares with higher reflectance in the shortwave infrared region (SWIR) to near infrared (NIR) region (Zhang, 2009; Varshney, 2013; Guha, 2018).

The NDBI value of the Bhiwadi industrial area in 2000 ranged from -0.16 to 0.398 for built-up or urban areas. The NDBI value was very low (-0.419 to -0.16) for areas covered in high

Figure 6: Decadal Change in NDBI of Bhiwadi Industrial Area

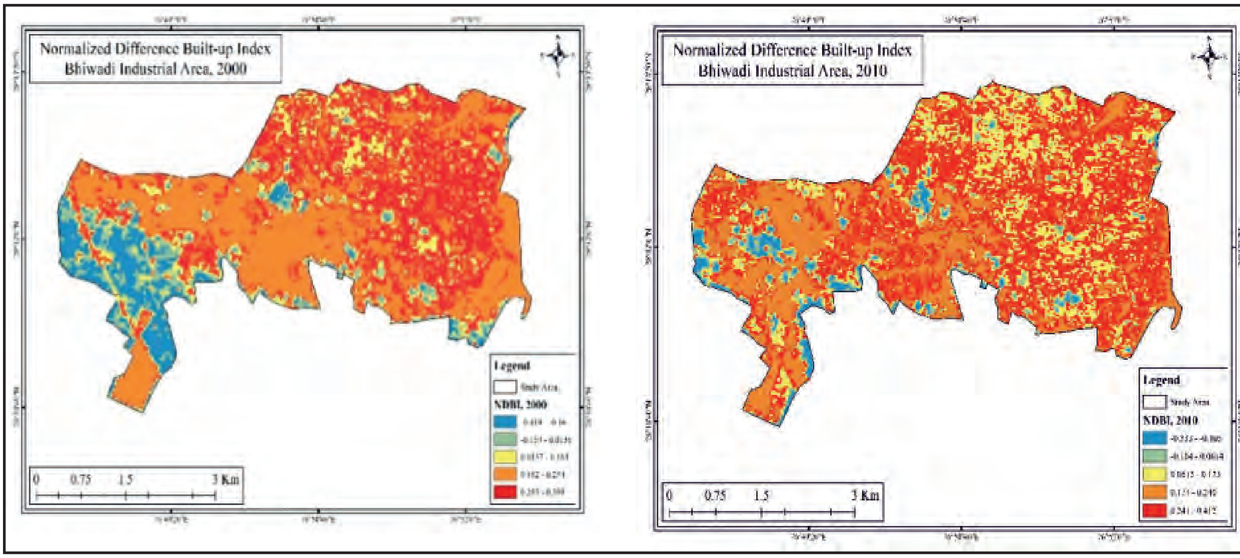
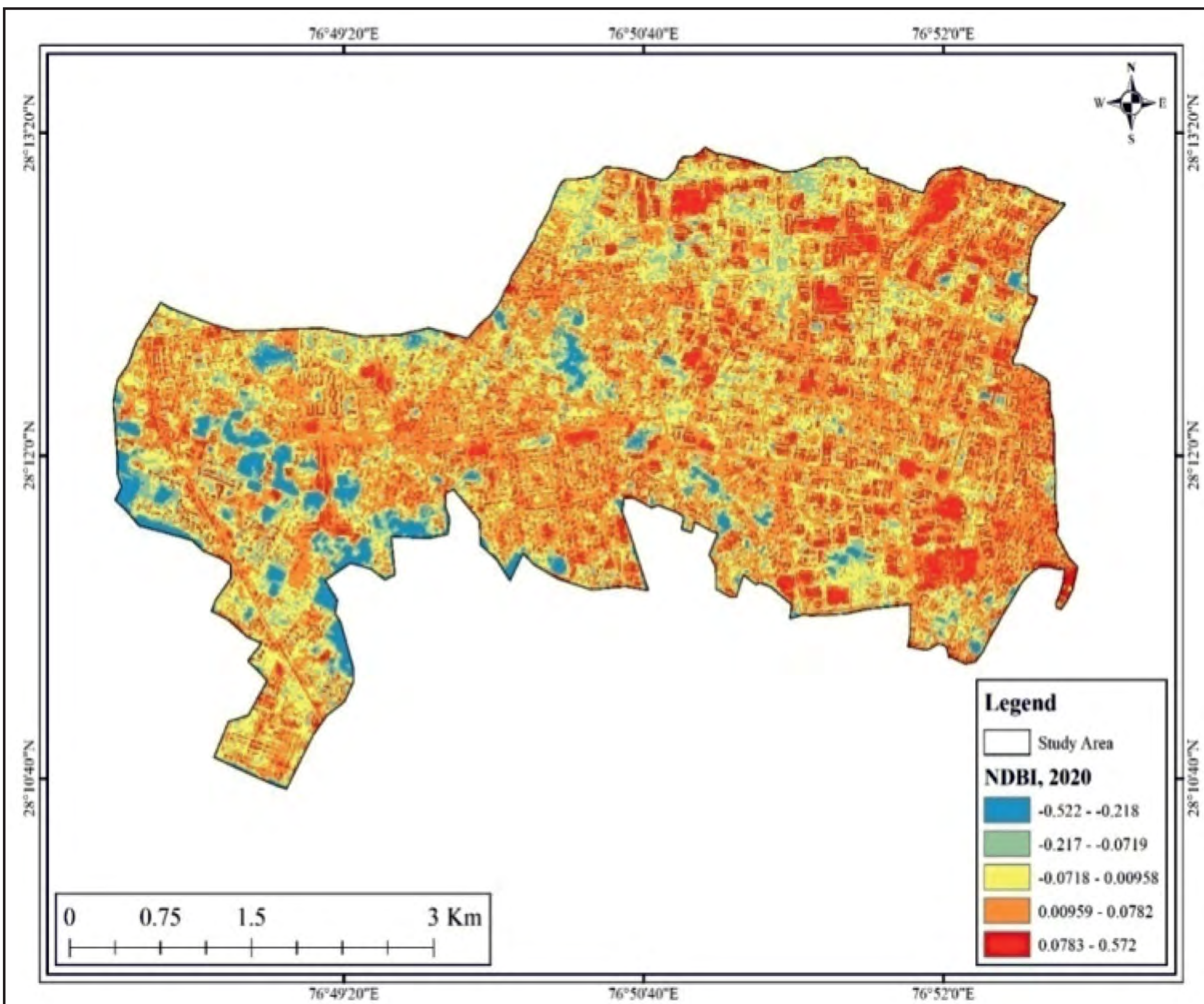


Figure 7: Normalized Difference Built-up Index Bhiwadi Industrial Area, 2020



vegetation, mainly in the western region. The NDBI value was moderate (-0.159 to 0.0136) for fellow and barren land areas. The highest built-up or urbanized areas were identified in the north or northeast regions, where the main Bhiwadi and RIICO industrial areas phases I to IV were located.

In 2010, the NDBI map showed the highest built-up value (0.241-0.412) expanding towards the west, leading to a decrease in vegetation cover in the western areas. Urbanization and industrialization continued to increase on barren land, resulting in its gradual conversion into built-up areas. The range of values for the west-central part was between 0.171-0.224, indicating moderate levels of urban development. The value of areas with less urban development was -0.333 to -0.105.

After review of the 2020 map, the NDBI values for all cover-up areas were found to fall within a range of -0.522 to 0.572. Further analysis identified that highly-developed areas fell within the range of 0.0783 to 0.572. Meanwhile, the built-up index of moderately urbanized or industrialized areas was found to range between -0.0718 to 0.0958. This observation indicates that the Bhiwadi industrial area has undergone substantial urbanization and industrialization during the period under review, leading to significant changes in the landscape. This indicates that the Bhiwadi industrial area has undergone significant transformations over the years, with increases in built-up areas resulting from urbanization and industrialization, leading to the gradual disappearance of vegetation and barren land cover.

4. RESULTS AND DISCUSSION

The assessment of LULC change within the Bhiwadi industrial area was carried out using the 2000, 2010, and 2020 maps. The LULC map for the year 2000 indicates that the western part of the study area was characterized by high vegetation cover and fellow land, while the eastern portion was mostly covered by infrastructure. Comparison between the 2010 and 2020 maps reveals that the industrial and urban infrastructure expanded towards the western side, leading to the conversion of barren and fellow land into built-up areas. The change detection map highlights that the eastward region of the study area experienced more changes compared to other regions. Additionally, the central-east area also underwent significant changes due to the westward expansion of industrial and urban setups, facilitated by the availability of non-agricultural and barren land. The land use and land cover changes in the Bhiwadi area have been driven by various factors, with the primary cause being the rapid urbanization and industrialization of the region. The availability of uncultivated and barren land on the western side has attracted new industrial developments due to the low-cost industrial sector prevalent in Bhiwadi. Additionally, the influence of the National Capital Region (NCR) has led to Bhiwadi becoming a residential town within the commuter zone of Delhi. Agriculture and vacant land have been converted into residential complexes and buildings, facilitated by government promotion of industrialization along the national highway post-2000. The Delhi-Mumbai Industrial Corridor has further impacted the land use of Bhiwadi, promoting urbanization and industrialization through improved road connectivity.

For the analysis, the NDBI was utilized, and the study concludes that highly built areas exhibit higher values, while areas with low urban concentration have lower values. The NDBI map for 2020 reveals a red colour in specific zones, indicating the highest urban concentration. Thus, the study provides a comprehensive understanding of the temporal changes occurring within the Bhiwadi industrial area and highlights the interplay between urbanization and industrialization.

5. CONCLUSION

Present research has revealed that Bhiwadi industrial area is undergoing rapid urbanization and industrialization at an unprecedented pace. The city's annual growth rate of 11 percent makes it one of the fastest-growing urban areas not just in Rajasthan but also in India. The interconnectedness of various indicators such as workers, transport, infrastructure development, demography, and land use changes highlights the profound relationship between industrial and urban growth. Transport infrastructure has facilitated both industrial and urban development in the region by providing excellent connectivity with major industrial areas like Delhi, Gurugram, Neemrana, and Jaipur. The availability of non-agricultural and barren land on the western side has attracted new industrial developments due to the low-cost industrial sector prevalent in Bhiwadi. The influence of the National Capital Region (NCR) has also led to Bhiwadi becoming a residential town within the commuter zone of Delhi. The study's findings indicate that as urbanization increases, industrialization rates also increase, as highlighted in the statistical data on population growth and industrialization. Private investors have created communities for those working in these industries, making it a new urban setup in the industrial area. The Delhi-Mumbai Industrial Corridor further impacts the LAND use of Bhiwadi, promoting urbanization and industrialization through improved road connectivity. Therefore, it is imperative to devise sustainable strategies to manage the rapid urbanization and industrialization in Bhiwadi, ensuring that it is inclusive, equitable, and environmentally sustainable.

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Eco Tourism Concept: A Case for Ottappalam-Shoranur Region

Hasna P.[1]

Abstract

Tourism is a major social phenomenon and important in many ways as it can be for leisure, business, education, and culture. Contributions of tourism include regional development, employment generation, livelihood empowerment, infrastructure development, hospitality services, transportation, health, and education. Haphazard and unplanned growth of tourism causes harmful results, with irreparable damage to the environment and socio-cultural values of the society. So, planning for tourism is essential. A best tourism development plan helps to develop all facets of a region such as socio-cultural and environmental aspects. Ottappalam-Shoranur region has many unutilized tourism potentials, which are areas with scenic beauty in the backdrop of the Nila River, degradation of tangible and intangible heritage seeks endurance, lack of infrastructure facilities and publicity, improper management of destinations, etc. seeking out a tourism development plan. This paper deals with the eco-tourism initiatives for the Ottappalam-Shoranur region. Tourism is a vibrant and significant contributor to the sustainable development and livelihood empowerment of the Ottappalam-Shoranur region and a viable tool for the development of the region with due consideration of environmental, social, and economic aspects.

1. INTRODUCTION

Even though Kerala is one of the most praised tourist destinations in the country, several factors led to the decline of tourism. Unfamiliar destinations, lack of tourism infrastructure facilities, lack of publicity, improper management of destinations, etc. There are many unutilized tourism potentials in Ottappalam-Shoranur region. A proper tourism plan focused on improving the attractions without damaging the environment should be introduced to promote tourism. The region has a unique selling point Ottappalam known as the “new film city of India”, Shoranur is the “railway town of south India”. The region has a rich cultural history that thrives on the banks of the Nila river, scenic beauty in the backdrop of Nila is attractive. Degrading tangible and intangible heritage which seeks efforts in conservation.

The study methodology includes the identification of the tourism assets in the region and the study of the tourism scenario in detail through primary surveys along with expert interviews. It includes analyzing both macro-level and micro-level strengths, weaknesses, opportunities, and threats. Inferring what are the possible measures to be taken for the development of the region as an eco-tourism destination through analysis and case studies.

2. LITERATURE REVIEW

2.1 Profile of the Region

The region is fully comprised of the midland region of Kerala on the banks of Nila. It has good road and rail connectivity. Railways link the northern and eastern parts of the country and the southern part of Kerala. The Ottappalam Shoranur region was part of the ancient Valluvanad Swaroopam dynasty, and was the cultural capital of Valluvanad. Nila is the cultural lifeline of the southern Malabar part of Kerala.

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2.2 Tourism in the Region

According to the integrated District Development Plan of Palakkad, the region comprises high heritage, health tourism potential and high eco-tourism and adventure tourism potential compared to other midland regions of Palakkad district.

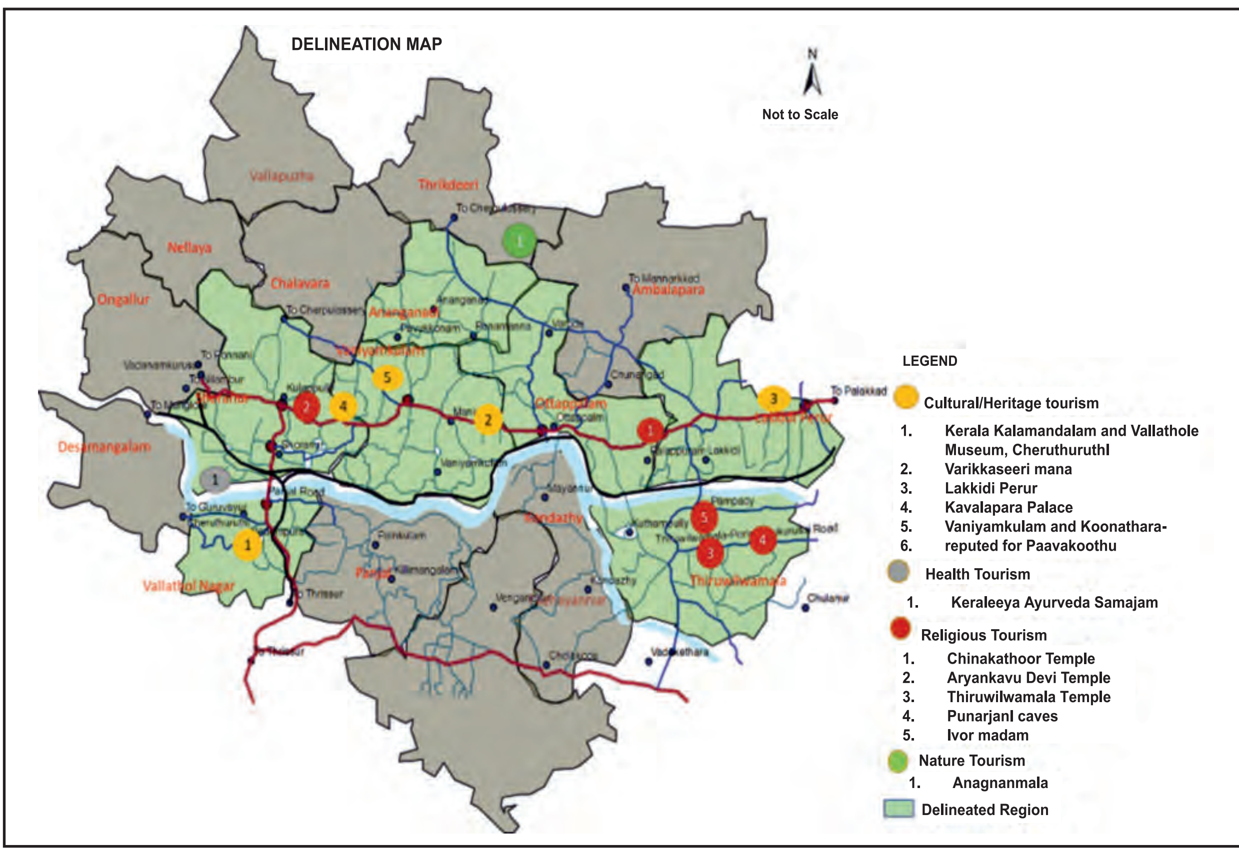
There is a huge difference in terms of the international tourists in Palakkad and Thrissur districts compared to other districts. The share of Palakkad is 0.18 percent and Thrissur is 1.03 percent proportion to the total in 2018 foreign tourist statistics.

2.3 Delineation of Area

To derive a more specific area within the region and for context of the detailed study, selected local administrative boundaries sharing boundaries with Ottappalam and Shoranur municipal area after that located various forms of tourism destinations identified by the Kerala tourism department.

Delineated area includes seven local bodies. That is Ottappalam, Vaniyamkulam, Lakkidi Perur, Ananganady, Shoranur, Vallathol Nagar and Thiruvilwamala (figure 1).

Figure 1: Delineation of the Study Region



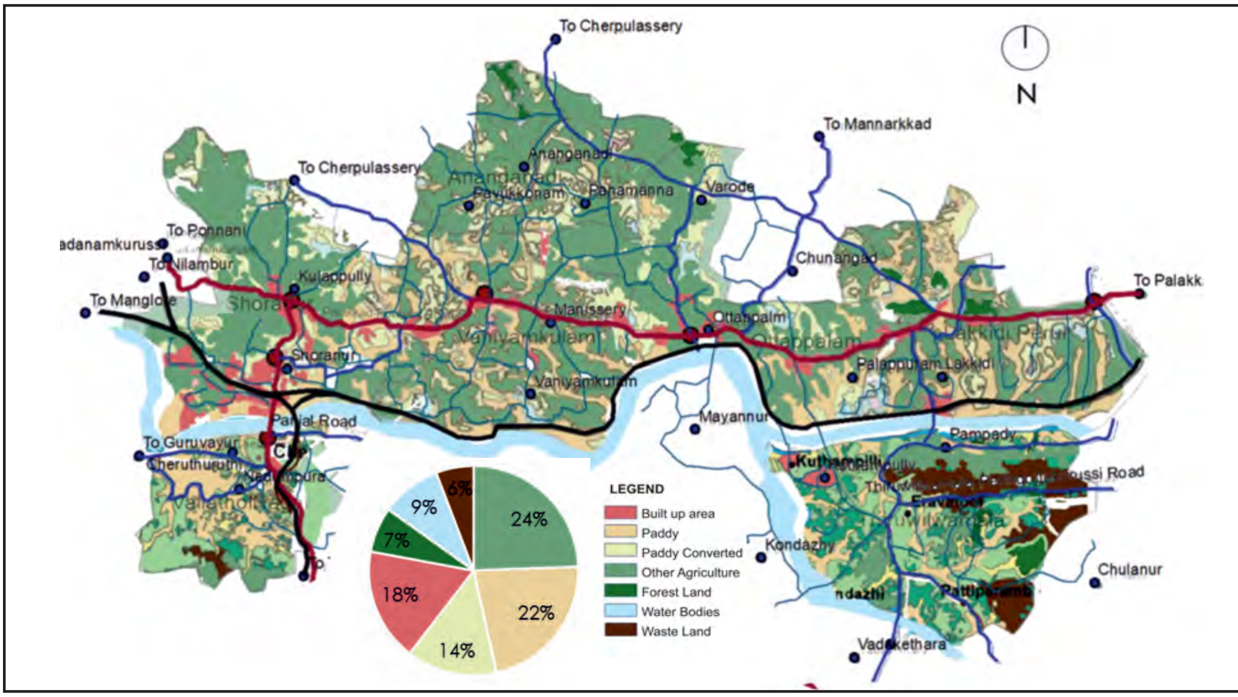
Source: Self-generated

2.4 Detailed Study of the Region

The detailed study of the region comprises land use, demographic details, the general infrastructure, and employment status. The analysis of the same is attempted in the subsequent sections.

Major land use in the region is agriculture. 46 percent of the land is agricultural land. Of this agricultural land, about 22 percent is paddy land and 24 percent is other agriculture including coconut, plantain, pepper, rubber, etc (figure 2).

Figure 2: Land Use of the Study Area

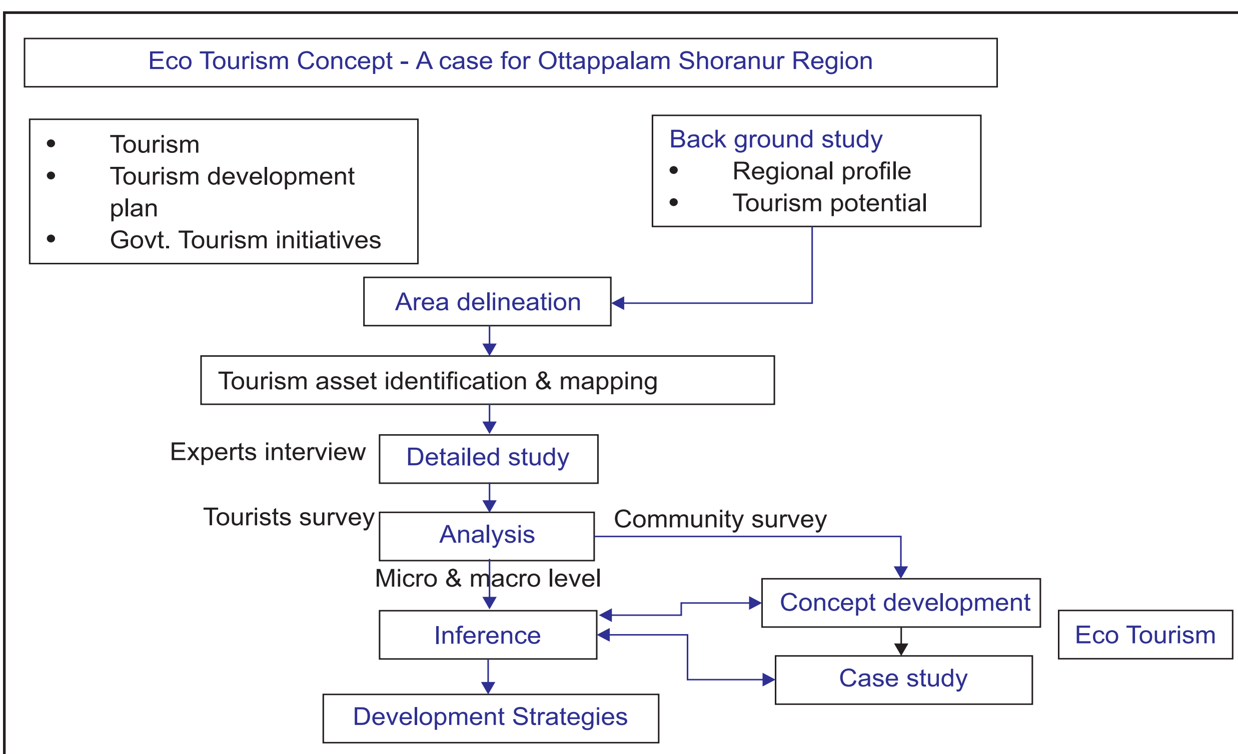


Source: Self-generated (Land Resource Information System, Kerala)

3. DATABASE & METHODOLOGY

Figure 3 depicts the methodology adopted for the present study.

Figure 3: Methodology of the Study



3.1 Demography

The study area is 145.52 sq km. The total population is 236941. Population density of the study area ranges from 830-1505 per sq km.

3.2 Employment Status

According to the socio-economic survey in Ottappalam and its influence zone. 12.36 percent of the population are unemployed and trying for jobs and 18.06 percent of the population are unemployed and trying for jobs in Shoranur municipal area.

3.3 Detailed Study of Tourism Assets

Tourism assets in the region are identified and mapped then classified as environmental, social, and cultural assets according to the objectives of the National tourism policy.

Detailed study of tourism destinations is done through primary tourist survey. Study of other tourism assets is done by experts' interviews along with site visits. Through expert interview, various ethnic communities in the region and their indigenous products as well as flora and fauna peculiar for the region, committed tourism projects were understood. Tourism product analysis was done according to 5 A's of tourism (accessibility, accommodation, activities, amenities, and attractions). The tourists' survey reveals the lacking tourism products in the region as well as in each destination.

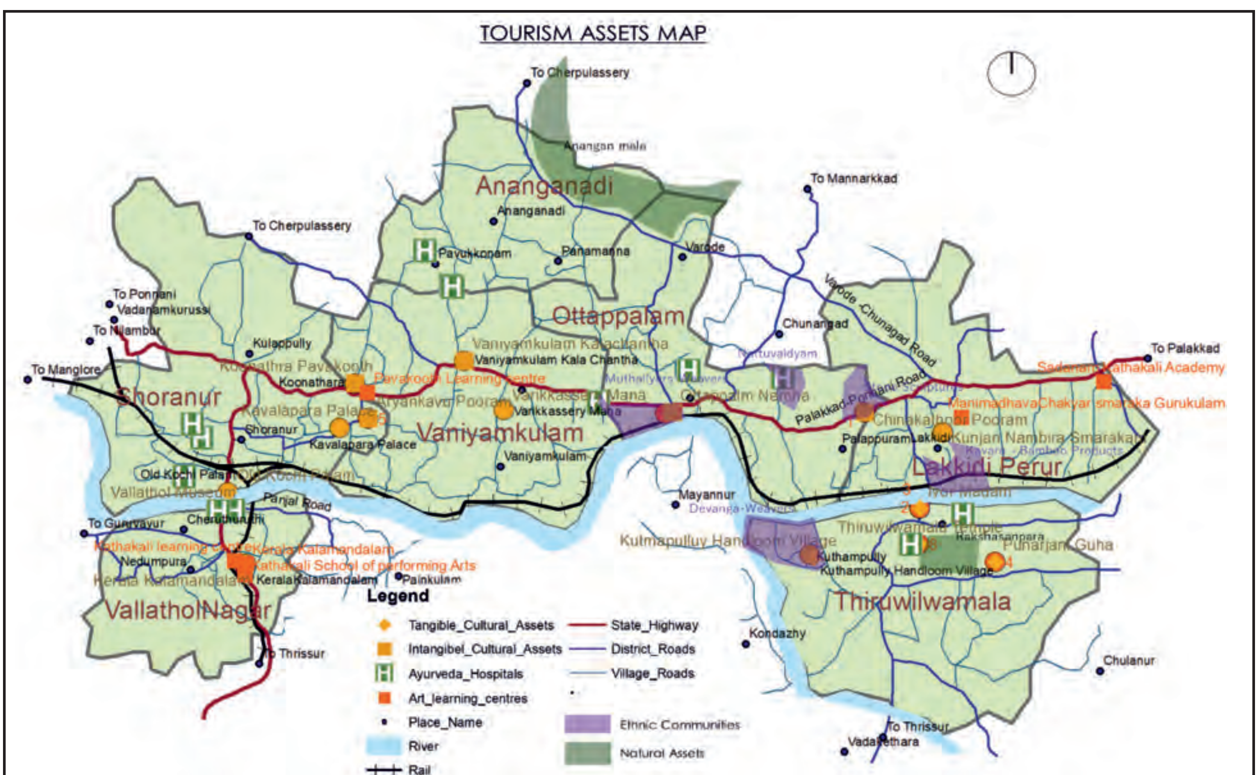
3.4 Environmental Assets

Includes scenic beauty, that are rural character, paddy fields, long stretch of Nila, undulating terrain, and tourism destinations such as Anagnanmala and Rakshasa para. Flora and fauna are peculiar for the region. Vilwadri cow, the rare indigenous cattle breed in Thiruvilwamala.

3.5 Cultural Assets

The major portion of the region is part of ancient Valluvanad Swaroopam, having a prestigious cultural tradition. Figure 4 depicts tangible cultural assets

Figure 4: Tourism Assets Map



Source: Self-generated

include historical buildings such as Kerala Kalamandalam, Kunjan Nambiar Smarakam, Kavalapara Palace, Varikkasseri mana, Kochi Palam, Ivor Madam, Punarjani Guha, Kuthampully Handloom Village, Worlds 1st ayurvedic treatment centre-Keraleeya Ayurveda Samajam etc. Intangible cultural assets include festivals such as religious events like Chinakkathoor pooram known as the cradle art of Malabar, Aryankavu pooram, and Nercha. Arts confined to the region are Tholpavakooth, Thullal, Kooth, Kathakali, Mohiniyattam, Kummattikkali etc. These are part and parcel of every Valluvanadan life. Other intangible cultural assets are strong Ayurvedic tradition, Cattle fair at Vaniyamkulam and world renowned Valluvanadan hospitality culture.

3.6 Social Assets

Social assets are human resources and their livelihood varieties. Agriculture is the main occupation in the region so cultivators and agriculture laborers are key social assets in the region. Human resources peculiar for the region are various ethnic communities engaged in traditional livelihood activities which include khadi/handloom by Kaniyampuram Muthaliyans. Nattuvaidyam is practiced in Kayarampara, Metal vessel using brass (Varp) for ayurvedic medicine preparation in traditional methods. Stone sculptures. Kavara community – bamboo product makers in Lakkidi weavers in the Kuthampully Region.

Detailed study of these ethnic communities and their livelihood was done through primary sample community survey.

3.7 Committed Projects and Programs

- ***Mini Film City***: A film city with the latest amenities at Ottappalam as a joint venture of the tourism department and Kerala state film development corporation Bharathapuzha conservation efforts under river management fund by State Government.
- ***Ananganmala Eco-Tourism Project:*** It started functioning in March 2011. The project area is approximately 100 Ha, and the number of stakeholders is 200, Project is under River Forest Protection Fund Scheme (RFPF).
- ***Vaniyamkulam Mega City Project:*** A multifaceted focal point comprising of organized cattle market with well-furnished infrastructure facilities by Vaniyamkulam Panchayath.
- ***Sustainable Tourism Plan of Nila River:*** A project by Kerala Tourism Department. The Plan focuses on an integrated and sustainable tourism development of Nila to uplift tourism as a tool for promoting overall socio-economic development of the region giving due consideration to river conservation.
- ***People's Participation for Participatory Planning and Empowerment through Responsible Tourism Thiruvilwamala:*** A platform for selling its GI-tagged products to a global audience. Further, to promote experiential tourism beyond sight-seeing.
- ***Kudumbasree Programs:*** These programs assisted low-cost tourism cottages in Ottappalam with the help of district mission and DTPC. Haritha Kudumbasree farm in Vaniyamkulam. Value added products from farms in Lakkidi Perur-bamboo products, pickle, jam etc. Agro production, selling out let of Ayurveda medicines, Vanitha hotel in Shoranur municipal area. Micro enterprices such as weaving, pappad, pot, umbrella production units are there in Vallathol Nagar panchayath. Cultivation of Kummatty pullu which is used to make robe of Kummatty-an art form facing threat of extinction due to the disappearance of the grass Kummatti pullu in Thiruwilwamala Panchayath.

3.8 Analysis

Analysis of regional tourism assets reveals that there are lots of unutilized potential tourism resources. The vast stretch of farmlands can be used for farm tourism which does not require many additional investments.

Nila is the lifeline of the region. Degradation and pollution of Nila due to extreme sand mining in the past years cause extreme dryness and water scarcity during summer and flooding during the rainy season.

Destination-level SWOT (strength, weakness, opportunity, threat) analysis is done to arrive at the micro-level interventions needed to improve the attractiveness and amenities required.

Degradation of tangible and intangible heritage. Heritage building seeks conservation efforts and art forms facing the threat of extinction should be revived through cultural events.

The community survey of ethnic settlements reveals that the majority of people are not satisfied with their income from traditional jobs and they are seeking a more profitable job. To avoid the threat of extinction of this intangible knowledge tourism can be used as a profitable way to improve the livelihood of these ethnic communities.

Film tourism is already a prevalent tool in the region that can be taken advantage of by marketing and branding.

3.9 Inference

The region is located in a strategic position. The railway links the northern and eastern parts of the country and the southern part of the state.

The region has high eco-tourism potential compared to other midland regions of Kerala due to the presence of environmental assets such as the Nila river, agricultural lands, and areas with scenic beauty.

Livelihood empowerment of ethnic communities can be attained by incorporating their activities with tourism.

Infrastructure facilities such as information kiosks, hop-on hop-off services, tourist warden etc. create job opportunities.

As the region is rich in farm land, farm tourism does not require much additional investment river a side walkway with a promenade.

Lack of diversification of destinations like lakes, beaches, backwaters etc., as the region consist completely midland region of Kerala, and is in proximity to the cultural capital of Kerala, Thrissur seeks more variety of attractions to bring more repeat customers.

3.10 Concept Development

The region is rich in cultural, social and natural assets and is relatively unexplored compared to other parts of Kerala. The Nila River is the lifeline of the region; it caters to drinking water needs and agriculture of the area. Social, economic and environmental aspects should be considered for better tourism development. So, eco-tourism has evolved as a concept.

Vision is to develop tourism as a vibrant and significant contributor to the sustainable development and livelihood empowerment of the Ottappalam-Shoranur region. Missions are the deep-rooted relationship between culture and tourism to be realized and promote cultural tourism. Special emphasis on ethnic communities and their livelihood needs to be given. Special thrust on environmental assets is required.

3.11 Case Study

Thenmala eco-tourism destination was selected for a literature case study, which is the first planned eco-tourism destination in India. It is popular because of its unique variety, biodiversity, and functionality. Its land, rich in forests has been selected by the World Tourism Organization as one of the most important eco-friendly projects in the world. The destination is located at a strategic position for transportation. The region is divided into various zones such as adventure zone, socio-cultural zone, deep wood zone, and leisure zone. Tourism products are studied according to the 5A's of tourism. The case study inferred the possible attributes that can be adopted for the Ottappalam-Shoranur region such as community-led tourism development program; livelihood empowerment for the indigenous people, as the Ottappalam-Shoranur region is rich in ethnic communities; Kudumbasree incorporated tourism activities, and women empowerment through tourism; exposing the art, architecture, cuisine, etc. of the region. Well-placed en-route signages and information desks/ Kiosks. accommodation facilities, tourism facilitation center, afforestation, riverside walkways, and trails elevated walkways/canopy walkways.

4. RESULTS & DISCUSSIONS

Development strategies based on the eco-tourism concept for the Ottappalam-Shoranur region.

The eco-tourism concept includes three pillars that are social, environmental and economic pillar.

4.1 Social Pillar

Involvement of ethnic communities in tourism. Saleable products made by these communities can be utilized as tourism catalysts and in turn economic development and livelihood empowerment of these communities. Community training centres for these communities can be provided. Promote experiential tourism beyond sightseeing. Showcasing the art of crafting and developing options to experience the process onsite by being part of skilled craftsmen. E-commerce can be utilized for selling products to Global audiences such as weaver's fest, bamboo fest, and stone sculpture fest. Kuthampully weaving village is one of the world's reputed destinations. Provide a platform for selling its GI-tagged (geographical indication act-it is the right given to intangible creations of the human intellect to a global audience).

4.2 Environmental Pillar

Nila's environmental and hydrological revitalization through restricting activities like illegal sand mining, land encroachment, pollution, etc. reduce the chances of contamination of the river. Clean river campaigns should be conducted at regular intervals with the partnership of NGOs and educational institutions.

Remove water hyacinth from the river and it can be utilized for the preparation of biofuel, manure, water purifier, and compost.

Plant vetiver grass on the banks of the river which is an environmentally friendly plant, that can be utilized to endure groundwater table, prevents soil erosion and important ingredient of Ayurveda medicines, perfumes, soaps, and shampoos, there is a large commercial market for it. Linking rivers to tourists by providing riverside walkways and promenades. Social forestry.

4.3 Economic Pillar

To augment the agriculture sector, farm tourism can be introduced. Much additional investment is also not needed to promote farm tourism. Kudumbasree assisted farms and selling outlets. Community training centres for farmers to interact with tourists and teach rice paddy art (Tambo art).

Tourism infrastructure development includes international quality tourism facilitation centers with inquiry counters, refreshing facilities, tourism information centers/kiosks in major nodes, and proper en-route signages. Alternative modes of transportation linking tourism destinations to reduce private modes of transportation such as hop on hop off services, and amenity centers for pilgrimage tourism. These activities create more employment and generate income.

Tourism products like accommodation facilities, and restaurants should be of international standards for attracting more foreign tourists and create more job opportunities

Use the web as a marketing communication media, Film tourism is already prevalent, which can be used as a marketing tool. Branding the region through arts, festivals, hospitality culture, and special cuisines.

5. CONCLUSION

Eco-tourism can be a vibrant and significant contributor to the sustainable development and livelihood empowerment of the Ottappalam-Shoranur region by eliminating chances for environmental degradation and incorporating communities in tourism-related activities, with due consideration for environmental, social, and economic aspects of the region. Environmental and hydrological revitalization of the Nila River. Tourism in small settlements of ethnic communities where the sizable assets of intangible knowledge exist. By providing diversified attractions based on the eco-tourism concept the Ottappalam Shoranur region can be augmented as one of the praised tourist destinations in Kerala.

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Integrating Green Infrastructure for Resilient Cities: A Review Paper

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Abstract

Green infrastructure (GI)., a network of natural and semi-natural features integrated into urban areas, is pivotal in building resilient cities. The concept of resilient cities has gained prominence, emphasizing the need for urban areas to adapt, withstand, and recover from environmental and socio-economic stressors. The core principle of GI is to mimic or restore natural processes within cities. The study aims to investigate the role of GI in building resilient cities, exploring the multifaceted contributions of nature-based solutions in enhancing urban resilience to environmental, social, and economic challenges. It explores GI's role in urban resilience, tackling rapid urbanization and climate change impacts through case studies. Further, it explores GI principles and components like parks, green roofs, and permeable pavements, emphasizing their benefits. The paper will conclude with a holistic approach to building urban resilience based on GI by addressing a fuller range of ecosystem disturbances and disasters to create outcomes that develop urban sprawl's environmental and ecological benefits.

1. INTRODUCTION

In an era marked by rapid urbanization, cities are increasingly recognized as focal points for innovation, economic development, and cultural exchange. However, this accelerated urban growth brings with it a confluence of challenges that test the resilience of urban systems (Vargas-Hernández & Zdunek-Wielgołaska, 2021). Climate change, population surges, and socio-economic disparities compound the complexities faced by urban areas, necessitating a paradigm shift in how cities are planned, developed, and sustained. At the forefront of this shift is the transformative concept of green infrastructure a strategic and nature-based approach that emerges as a fundamental pillar in the pursuit of resilient cities (Korkou et al., 2023). Green infrastructure is more than a set of ecological solutions; it embodies a holistic philosophy that embraces the inherent resilience of natural systems. From urban parks and green roofs to permeable pavements and sustainable water management, green infrastructure integrates elements of nature into the urban fabric. It unravels the profound significance of green infrastructure as a dynamic and adaptable strategy for cultivating resilience within the urban milieu (Dhyani et al., 2021). Cities, by their very nature, are intricate ecosystems where the environment, society, and economy intersect. Green infrastructure leverages the interconnectedness of these elements, offering a suite of solutions that mitigate environmental risks, enhance social inclusivity, and fortify urban resilience (Dhyani et al., 2021).

As we navigate an era defined by unprecedented challenges where the frequency and intensity of climate-related events rise, where social disparities persist, and where the need for sustainable development is paramount green infrastructure emerges as an ethical and strategic imperative (I. Mell, 2020). The exploration of green infrastructure's diverse dimensions, traversing its role in environmental sustainability, its transformative impact on social dynamics, and its nuanced integration

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into urban governance (Wang & Banzhaf, 2018). In India, urbanization has surged, with over 30 percent of the population now residing in cities. This rapid growth presents significant challenges, exacerbated by climate change, population increases of over 25 percent in some urban centers, and widening socio-economic disparities. As cities grapple with issues like air and water pollution , urban heat island, inadequate infrastructure, and unequal access to resources, the need for transformative solutions becomes paramount (Adlakha et al., 2021). Green infrastructure offers a holistic approach to address these challenges, leveraging the resilience of natural ecosystems. From combating air pollution with urban forests to managing water scarcity through sustainable water management systems, green infrastructure plays a pivotal role in India's urban development. As India navigates these complexities, green infrastructure emerges as an ethical and strategic imperative. It represents a shift towards sustainable and inclusive urban development, where environmental sustainability, social inclusivity, and economic resilience converge. By integrating nature into urban spaces, green infrastructure not only mitigates environmental risks but also enhances social cohesion and fortifies urban resilience (V. Pusalkar, V. Swamy, 2022). This paper aims to explore the diverse dimensions of green infrastructure and its role in building resilient cities in India. Through a meticulous examination of successful case studies, innovative strategies, and emerging trends, this research seeks to illuminate the pathways through which green infrastructure can be harnessed for sustainable urban development. As the study explores, it delves into the dynamic interplay between urban resilience and green infrastructure, seeking to unravel not only the tangible benefits these solutions offer but also the inherent potential they hold to redefine the very fabric of cities. Ultimately, this research contributes to the evolving narrative of resilient cities that not only withstand the tests of time but thrive in the face of complexity, ensuring a sustainable and inclusive urban future for generations to come.

2. HISTORY OF GREEN INFRASTRUCTURE

The concept of Green Infrastructure, which involves planning and managing natural elements in urban areas to promote sustainability and improve the quality of life, has a rich history that spans centuries. While the term "Green Infrastructure" was not coined until the early 1990s, its ideas and principles have been applied long before that (F-Steiner, 2014). In Ancient China, sustainable landscaping practices, such as Chinese literary gardens, date back to the Shang Dynasty, promoting the coexistence of native plant species and human-designed elements to create ecological havens within cities. Greece, in the 8th century BC to 1st century BC, introduced the concept of "agoras," which were social meeting spaces incorporating nature as part of their design, offering a place for public interaction and conversation (Ignatieva, 2021).

Throughout history, different types of sustainable lawns and meadows, like the "flower meads" in Medieval Europe and the "enameled mead" in 20th-century England, showcased how urban green spaces can promote biodiversity and aesthetics while serving practical purposes like stormwater management. In the Renaissance period, urban parks and gardens were established to provide fresh air and relaxation for the public, enhancing the urban environment's aesthetics and reducing urban heating (Trujillo, 2020). Green Infrastructure can be traced back to 17th-century France, where nature was used for social and spatial organization, with large open spaces and lush gardens serving as symbols of power and wealth among French elites. In the 18th century, city walls were torn down to make way for gardens and green walkways, and unique vegetation was incorporated into the city landscape to beautify French cities. In the 19th century, environmental conservation gained prominence, with figures like George Perkins Marsh, Henry David Thoreau, and Frederick Law Olmsted advocating for the preservation of nature and the creation of public parks. Ebenezer Howard's garden city movement in England aimed to balance development with nature through agricultural greenbelts and tree-lined boulevards (Hoover et al., 2023). In the United States, the government became more involved in land preservation and conservation during the late 19th century, leading to the establishment of the first national parks. In the 20th century, the concept of Green Infrastructure continued to evolve, with industrial leaders focusing on improving worker's quality of life through sanitation and outdoor activities (H. Bohemen, A. Fraaij, 2008). This led to the development of industrial parks, integrated landscaping, and suburban gardens that incorporated green elements into urban planning. One notable example is the Anaconda Copper Mining Company's efforts to create green open spaces in Montana, which included a golf course, flower beds, picnic areas, and pedestrian paths, illustrating how industry and nature can coexist for the benefit of both the environment and the community (Bahru & Darul, 2014).

While the focus of green infrastructure planning often revolves around ecological functions, it's crucial to acknowledge the significant social benefits associated with these interventions (Caparrós-Martínez et al., 2020). Green spaces not only provide opportunities for recreational activities, positively impacting people's health and well-being, but they also foster connectivity between urban and rural areas, enhancing local distinctiveness, social inclusion, and community cohesion. Moreover, by reducing health expenses, attracting skilled workers and tourists, and increasing property values, green infrastructure can stimulate economic growth in urban areas (Caparrós-Martínez et al., 2020). However, to achieve these multifunctional objectives, both the quantity and quality of urban and peri-urban green spaces must be considered in planning processes. Developing green infrastructure planning principles is essential as they serve as the foundation for guiding and facilitating planning procedures, ensuring the creation of a network of high-quality and functional green spaces that cater to the specific needs of urban areas. These principles contribute to the sustainability of a region or local area, depending on its scale (Caparrós-Martínez et al., 2020).

3. GREEN INFRASTRUCTURE PRINCIPLES

Green infrastructure, rooted in fundamental principles, represents a holistic urban planning approach that seamlessly incorporates natural elements into the fabric of cities (Pandey et al., 2021). Guided by the principle of nature-based solutions, it underscores the importance of leveraging natural processes and ecosystems to address urban challenges (Dhyani et al., 2021). Multifunctionality is a key tenet, promoting the design of elements that serve diverse purposes, from managing stormwater to supporting biodiversity (García Sánchez & Govindarajulu, 2023a). The principle of connectivity emphasizes the creation of integrated networks of green spaces and corridors, fostering biodiversity and ecological resilience. Sustainable urban drainage practices, including permeable pavements and bioswales, play a pivotal role in minimizing runoff and enhancing water quality (García Sánchez & Govindarajulu, 2023b). Adaptability and flexibility are integral, ensuring that green infrastructure evolves in tandem with changing environmental conditions (Monteiro et al., 2020). Community engagement stands central, encouraging the active involvement of local residents in the planning and upkeep of green projects (I. Mell, 2015). Equitable distribution of green spaces, climate resilience, and the incorporation of blue-green infrastructure are essential components. This comprehensive approach, coupled with features like green roofs, green streets, urban forests, and community gardens, collectively cultivates urban environments that are sustainable, resilient, and visually appealing, promoting both community well-being and environmental health (I. C. Mell, 2018).

The principles underpinning green infrastructure (GI) planning offer valuable guidelines for enhancing urban sustainability and resilience. Connectivity, essential for maintaining species diversity and facilitating ecosystem services, underscores the importance of establishing well-connected green space networks that benefit both humans and wildlife (Syed & Haider, 2022). Multifunctionality, which emphasizes the diverse roles that GI can play in providing social, ecological, and economic benefits, enhances the resilience and effectiveness of green spaces within limited urban landscapes. Embracing a multiscale approach allows for flexible planning that considers GI interventions at various levels, from building-specific features to regional landscapes, thereby optimizing interactions between different spatial scales (Rijal et al., 2011). Integration encourages the harmonious coexistence of green and grey infrastructures, recognizing the interconnectedness between natural and built environments. Diversity promotes the implementation of a wide range of nature-based solutions tailored to address specific urban challenges, including blue infrastructures for water management (Monteiro et al., 2020).Applicability ensures that GI plans are realistic, adaptable, and implementable, avoiding the pitfalls of unattainable goals and unfulfilled projects. Governance fosters collaboration between government entities and citizens in GI planning and management, ensuring community buy-in and long-term success (Monteiro et al., 2020).

4. GREEN INFRASTRUCTURE COMPONENTS

Green infrastructure encompasses a diverse array of components strategically integrated into urban landscapes to promote environmental sustainability, enhance social well-being, and foster economic resilience. Urban parks and green spaces, such as community gardens and public parks, stand as verdant oases within cityscapes, providing recreational areas and mitigating the urban heat island effect (Manggol, 2015). Green roofs, characterized by vegetation cover, not only insulate buildings, reducing energy consumption, but also manage stormwater and offer habitats for wildlife (Molla & Biazen Molla, 2015). The strategic planting of trees and development of urban forests contribute to improved air quality, reduced heat island effects, and aesthetic enhancements. Permeable pavements, designed to allow water passage, mitigate stormwater runoff, preventing flooding, and recharging groundwater. Green walls, vertical structures adorned with vegetation, serve to improve air quality, reduce energy consumption, and contribute to urban aesthetics. Sustainable Drainage Systems (SuDS), innovative stormwater management systems, mimic natural processes, reducing flooding and enhancing water quality (García Sánchez & Govindarajulu, 2023b). The concept of blue-green infrastructure integrates water management with green spaces, managing stormwater, improving water quality, and providing recreational areas. Linear features like green corridors connect green spaces throughout urban areas, facilitating wildlife movement and enhancing biodiversity. Community gardens, cultivated collectively, contribute to local resilience by providing fresh produce and fostering community engagement. Green infrastructure in transportation involves integrating nature-based elements, enhancing aesthetics, improving air quality, and providing shade along roads and walkways (Korkou et

Table 1: Components of Green Infrastructure

Component	Description	Function
Urban Parks and Green Spaces:	Large public parks, community gardens, and green spaces within urban areas.	Enhances biodiversity, provides recreational spaces, improves air quality, and mitigates urban heat islands.
Green Roofs	Vegetated roofs that can be partially or completely covered with vegetation and a growing medium.	Insulates buildings, reduces energy consumption, manages stormwater, and provides habitat for wildlife.
Urban Forests and Tree Canopies	Strategic planting of trees and creation of urban forests.	Improves air quality, reduces heat island effect, provides shade, and enhances aesthetic value.
Permeable Pavements	Pavements designed to allow the passage of water, reducing runoff.	Manages stormwater, prevents flooding, and recharges groundwater.
Green Walls	Vertical structures covered with vegetation.	Improves air quality, reduces energy consumption, and provides aesthetic value.
Sustainable Drainage Systems (SuDS).	Innovative stormwater management systems that mimic natural processes.	Reduces flooding, improves water quality, and enhances biodiversity.
Blue-Green Infrastructure	Integrated approach combining water management with green spaces.	Manages stormwater, improves water quality, and provides recreational areas.
Green Corridors and Connectivity	Linear features connecting green spaces throughout urban areas.	Facilitates wildlife movement, improves biodiversity, and enhances aesthetics.
Community Gardens	Plots of land collectively cultivated by a community.	Provides fresh produce, fosters community engagement, and enhances local resilience.
Green Infrastructure in Transportation	Incorporation of nature-based elements in transportation infrastructure.	Enhances aesthetics, improves air quality, and provides shade along roads and walkways.
Wetlands and Water Features	Creation or preservation of wetlands, ponds, and other water features.	Provides habitat for wildlife, improves water quality, and mitigates flooding.
Bioswales	Vegetated channels designed to manage stormwater.	Filters and slows stormwater runoff, reduces erosion, and enhances water quality.
Green Infrastructure in Brownfield Redevelopment	Incorporating nature-based solutions in the redevelopment of former industrial sites.	Restores ecosystems, improves aesthetics, and enhances community well-being.
Agroforestry in Urban Areas	Integration of trees and agriculture in urban settings.	Combines food production with environmental benefits, enhances biodiversity, and improves aesthetics.

Source: (Suhane & Gajjar, 2021)

al., 2023). Wetlands and water features, preserved or created, offer habitat for wildlife, improve water quality, and mitigate flooding. Bioswales, vegetated channels, filter and slow stormwater runoff, reducing erosion and enhancing water quality. Green infrastructure plays a vital role in brownfield redevelopment, restoring ecosystems, improving aesthetics, and enhancing community well-being. Additionally, agroforestry in urban areas integrates trees and agriculture, combining food production with environmental benefits, biodiversity enhancement, and aesthetic improvements. These interconnected components collectively form a dynamic and resilient green infrastructure network, contributing to the sustainable and inclusive development of urban spaces (Suhane & Gajjar, 2021).

5. GREEN INFRASTRUCTURE BENEFITS

Green infrastructure offers a range of interconnected benefits that extend well beyond its environmental advantages, significantly impacting various facets of urban life. By reducing stormwater runoff and enhancing water quality, it effectively manages stormwater (Manggol, 2015). Additionally, it mitigates the urban heat island effect, lowers temperatures, and contributes to climate resilience by sequestering carbon and reducing energy consumption. Green infrastructure fosters biodiversity, creating habitats for diverse species, while acting as a natural air filter, improving air quality by trapping pollutants. Its contribution to urban aesthetics and design includes visually appealing landscapes, greenery, and recreational spaces, creating a more attractive and liveable urban environment (Molla & Biazen Molla, 2015). Public health benefits abound as it provides spaces for exercise, relaxation, and community interaction, reducing stress and promoting well-being. Economically, green infrastructure increases property values, attracts businesses, and boosts tourism by creating aesthetically pleasing urban environments. Acting as a natural sound barrier, it reduces noise pollution from urban activities (Manggol, 2015). Socially, it fosters community engagement by creating and maintaining green spaces, promoting a sense of ownership and belonging. Green infrastructure enhances property resilience, protecting against extreme weather events like flooding and heatwaves, while improving water quality in rivers and lakes. Supporting urban agriculture and food security, it contributes to local food production and community resilience. It also reduces energy consumption by providing shade, insulation, and cooling effects, lowering the need for air conditioning (Krellenberg, 2015).

6. GREEN INFRASTRUCTURE IN GLOBAL CONTEXT

Green infrastructure, on a global scale, constitutes a diverse array of approaches and initiatives dedicated to integrating nature into urban environments for the promotion of sustainability, resilience, and an elevated quality of life. Its implementation varies across regions, shaped by environmental, cultural, and socio-economic factors (Korkou et al., 2023). Environmental sustainability is a central focus, emphasizing worldwide efforts on biodiversity preservation through the creation of green corridors, parks, and greenways that connect habitats for diverse species. Additionally, green infrastructure plays a pivotal role in climate resilience, employing practices like green roofs, permeable pavements, and rain gardens to manage stormwater, reduce flooding, and counteract urban heat islands. Nature-based solutions, such as tree planting and wetlands, are integral in purifying air and water, mitigating pollution, and fostering healthier urban environments. The social and economic benefits of green infrastructure extend to community well-being, providing spaces for recreation, relaxation, and social interaction, positively impacting mental health. Investments in green spaces generate economic benefits by attracting tourism, increasing property values, and creating job opportunities, particularly in conservation, landscaping, and urban planning (García Sánchez & Govindarajulu, 2023a). Globally, there is a concerted effort through international policies, agreements, and collaborations, including initiatives like the Paris Agreement, the Convention on Biological Diversity, Sustainable Development Goals (SDGs), and the New Urban Agenda, to underscore the significance of green infrastructure in achieving environmental sustainability and resilient cities. However, challenges persist in diverse implementations, with regional adaptations influenced by climate, resources, and cultural practices, and ongoing efforts are needed to integrate green infrastructure into existing urban planning models, ensure equitable access, and drive continued innovation to address emerging environmental and societal challenges (Lin et al., 2021).

7. CASE STUDY: INTERNATIONAL MEASURES FOR GREEN INFRASTRUCTURE IN RESILIENT CITIES

7.1 Curitiba, Brazil

Curitiba, Brazil, has long been celebrated for its pioneering efforts in sustainable urban development, particularly in transportation and green infrastructure. The city's innovative Bus Rapid Transit (BRT) system, introduced in the 1970s, revolutionized public transportation by offering a cost-effective and efficient alternative to traditional bus systems (Bleviss, 2022). The BRT features dedicated lanes, prepaid boarding, and strategically located stations, significantly reducing congestion and air pollution while improving accessibility for residents across the city. In addition to its transportation initiatives, Curitiba boasts a network of green spaces and parks that serve as vital lungs for the city (Caetano et al., 2021). Barigui Park, one of the largest urban parks in Latin America, not only provides recreational opportunities but also serves as a natural buffer against floods, mitigating the impacts of heavy rainfall and preventing urban flooding (Ferreira & da Rocha, 2023). The integration of green corridors and wildlife habitats within the city ensures biodiversity conservation while enhancing the quality of life for residents (Diep et al., 2019). Furthermore, Curitiba's waste management strategies have set a benchmark for sustainable practices. The city implemented an innovative recycling program that incentivizes residents to segregate waste and participate in recycling efforts (Mauricio Jonas Ferreira, 2023). By promoting composting and material reuse, Curitiba has minimized landfill waste and reduced its environmental footprint, setting an example for urban centers worldwide (Suhane & Gajjar, 2021).

7.2 Copenhagen, Denmark

Copenhagen, Denmark, stands as a model of sustainable urban living, characterized by its emphasis on cycling infrastructure, climate resilience, and green spaces. The city's commitment to cycling as a primary mode of transportation has transformed its streets into cyclist-friendly environments, with dedicated bike lanes, traffic signals, and bike-sharing programs (Dhyani et al., 2021). Cycling accounts for a significant portion of daily commutes, reducing carbon emissions and promoting active lifestyles among residents. Copenhagen’s proactive approach to climate resilience is evident in its adaptation strategies and green infrastructure projects (García Sánchez & Govindarajulu, 2023a). The city has implemented green roofs, rain gardens, and permeable pavements to manage stormwater runoff and mitigate the impacts of extreme weather events. These nature-based solutions not only improve urban resilience but also enhance biodiversity and urban aesthetics (Pattanayak et al., 2023). Moreover, Copenhagen prioritizes public spaces and green areas as essential components of urban liability. The city's parks, waterfront promenades, and green corridors provide residents with access to nature, recreation, and cultural events (Pattanayak et al., 2023). By integrating greenery into the urban landscape, Copenhagen fosters community well-being and social cohesion while mitigating the urban heat island effect and air pollution (Suhane & Gajjar, 2021).

7.3 Singapore

Singapore, despite its limited land area, has emerged as a global leader in sustainable urban development and green infrastructure. The city-state's commitment to environmental sustainability is exemplified by projects like Gardens by the Bay, an iconic garden featuring Super trees, lush gardens, and sustainable architectural designs (D. M. Sundara, D. Hartono, E. Suganda, 2017). Gardens by the Bay not only serves as a green oasis in the heart of the city but also promotes biodiversity conservation and environmental education. Singapore's water management strategies are equally remarkable, encompassing rainwater harvesting, water recycling, and desalination technologies (Y. Polianskyi & Khrystyna-Shchuryk, 2023). The city's NEWater initiative, which recycles wastewater to produce high-grade reclaimed water, has reduced Singapore's reliance on imported water sources and ensured a sustainable water supply for its residents (H. Bohemen, A. Fraaij, 2008). Furthermore, Singapore's green building initiatives, such as the Green Mark certification scheme, encourage sustainable construction practices and energy-efficient building designs (Zain et al., 2022). By promoting green buildings and renewable energy adoption, Singapore aims to reduce its carbon footprint and mitigate the impacts of climate change while fostering a greener and more resilient urban environment (Suhane & Gajjar, 2021).

7.4 Melbourne, Australia Melbourne

Melbourne, or Greater Melbourne, situated at 37°49'S and 144°58'E in Victoria, Australia, covers a total area of approximately 9992.5 km², encompassing 31 municipalities. It is renowned as "Australia's garden city" due to its extensive network of parks and gardens (Suhane & Gajjar, 2021). With a temperate oceanic climate (classified as Köppen Cfb), Melbourne experiences mild winters and warm to hot summers. Unlike North America, Europe, and most of Asia, Melbourne's seasons begin later due to its location in the southern hemisphere. High summer months occur in January and February, while winter months are observed from May to August. December typically receives the highest rainfall, around 2.5mm, whereas February records the lowest, approximately 1.6". To combat urban heat island (UHI) effects and cool urban microclimates, Melbourne adopted Urban Green Infrastructure (UGI) strategy, defined as a connected network of natural and human-integrated vegetation, including parks, gardens, trees, green walls, and roofs (Abdulateef & Al-Alwan, 2022). The strategy focuses on several key steps: identifying priority areas based on exposure and vulnerability to UHI, maximizing the cooling effect of existing UGI through measures like irrigation and increasing permeability of built surfaces, prioritizing UGI implementation in streets with intense exposure to UHI, and selecting appropriate UGI assets such as green spaces, trees, green walls, and roofs based on neighbourhood and street-level considerations. These steps aim to mitigate the adverse effects of urban heat and enhance the city's resilience to climate change (Abdulateef & Al-Alwan, 2022) (Suhane & Gajjar, 2021).

8. CASE STUDY: NATIONAL MEASURES FOR GREEN INFRASTRUCTURE IN RESILIENT CITIES

8.1 Urban Forests Initiative, Hyderabad

Hyderabad, one of India's rapidly growing cities, faces challenges related to urban heat island effect, air pollution, and loss of biodiversity. To address these issues, the Urban Forests Initiative was launched to create green spaces within the city. The initiative involves the development of urban forests in vacant or underutilized lands across Hyderabad (D. M. Sundara, D. Hartono, E. Suganda, 2017). These urban forests comprise native tree species, shrubs, and vegetation that are resilient to local climatic conditions and require minimal maintenance. Community participation plays a crucial role in the initiative, with local residents involved in tree plantation drives, maintenance activities, and environmental education programs (Dhyani et al., 2021).Urban forests not only provide essential ecosystem services such as carbon sequestration, air purification, and temperature regulation but also serve as recreational areas and wildlife habitats. By expanding green cover and promoting biodiversity within the urban landscape, the Urban Forests Initiative contributes to enhancing the city's resilience to climate change and fostering ecological sustainability (Suhane & Gajjar, 2021).

8.2 Green Roof Pilot Project, Bengaluru

Bengaluru, known as India's Silicon Valley, grapples with urbanization pressures, rapid development, and diminishing green spaces. To counteract the adverse effects of urbanization, the city initiated a Green Roof Pilot Project aimed at retrofitting existing buildings with green roof systems (Lin et al., 2021). Green roofs involve the installation of vegetation, soil, and drainage layers on building rooftops, creating functional green spaces that help mitigate heat buildup, reduce energy consumption, and improve stormwater management (Dhyani et al., 2021). The pilot project targets government buildings, commercial complexes, and educational institutions to showcase the benefits of green roofs in urban settings. Additionally, the project emphasizes research and monitoring to assess the performance and feasibility of green roof technologies in the local context. Through strategic implementation and stakeholder collaboration, the Green Roof Pilot Project seeks to mainstream green infrastructure practices in Bengaluru's urban development agenda, enhancing the city's resilience to climate variability and promoting sustainable building practices (Suhane & Gajjar, 2021).

8.3 Vertical Gardens Initiative, Mumbai

Mumbai, India's financial capital, faces urban sprawl, overcrowding, and environmental degradation, exacerbating urban heat stress and air pollution. In response, the city launched the Vertical Gardens Initiative to introduce greenery in densely populated urban areas and along infrastructure corridors (I. Mell, 2020). Vertical gardens involve the installation of vegetation panels on building facades, flyovers, and metro rail networks, maximizing vertical space utilization and enhancing aesthetic appeal. The initiative aims to improve air quality, mitigate heat island effects, and create microhabitats for urban biodiversity. Public-private partnerships drive the implementation of vertical gardens, with corporate sponsors, NGOs, and government agencies collaborating on design, installation, and maintenance activities. Through innovative design solutions and community engagement, the Vertical Gardens Initiative contributes to Mumbai's resilience by enhancing urban liveability, promoting green infrastructure adoption, and fostering environmental stewardship among residents and businesses (Suhane & Gajjar, 2021).

8.4 Delhi Breathe Better Program

The Delhi Breathe Better Program, initiated by the Delhi government, addresses the city's severe air pollution crisis through a multi-faceted approach that includes green infrastructure interventions. Delhi, one of the most polluted cities globally, faces significant health risks due to high levels of air pollutants, particularly during the winter months. The Breath Better Program focuses on increasing green cover, reducing vehicular emissions, and promoting sustainable transportation alternatives to improve air quality and public health (Pandey et al., 2021). Tree plantation drives, vertical gardens, and green buffer zones along major roadways are implemented to absorb pollutants, mitigate heat island effects, and enhance urban biodiversity. The program also emphasizes the importance of public awareness, community engagement, and regulatory enforcement to combat air pollution effectively. By integrating green infrastructure measures into its air quality management strategies, Delhi aims to build resilience to environmental hazards and create a healthier, more sustainable urban environment for its residents (Suhane & Gajjar, 2021).

9. APPLICATION OF GREEN INFRASTRUCTURE IN INDIAN CONTEXT

In India, the application of green infrastructure is a response to the complex challenges arising from rapid urbanization, environmental degradation, and the imperative for sustainable development (García Sánchez & Govindarajulu, 2023b). The country's diverse environmental, social, and economic landscape necessitates a multifaceted approach to integrating green elements into urban planning and development (I. Mell, 2015). At the forefront of India's green infrastructure initiatives is the urgent need to counteract the environmental impacts of urban expansion (Suhane & Gajjar, 2021). This involves not only creating green spaces within cities but also prioritizing the preservation of biodiversity and natural habitats. Urban forests, parks, and green belts serve as vital components of this strategy, providing recreational areas for residents while also contributing to ecological balance (Caparrós-Martínez et al., 2020). Climate resilience is another critical driver behind India's adoption of green infrastructure solutions (Lampinen et al., 2023). With the increasing frequency of extreme weather events and rising temperatures, measures such as rooftop gardens, rainwater harvesting systems, and extensive tree plantation drives are being implemented to mitigate the adverse effects of climate change (Mauricio Jonas Ferreira, 2023). These initiatives not only help in temperature regulation but also enhance water conservation and reduce the risk of flooding in urban areas. The government-led Smart Cities Mission has played a pivotal role in mainstreaming green infrastructure across urban development projects in India (Phogole & Yessoufou, 2023)(Pandey et al., 2021). This mission emphasizes the integration of sustainable practices, efficient energy use, and improved waste management systems, thereby promoting environmental sustainability at the urban level (Pandey et al., 2021). Despite significant progress, the implementation of green infrastructure in India faces several challenges. One major obstacle is the need to strike a balance between infrastructure development and the preservation of green spaces, particularly in densely populated urban areas. Innovative approaches such as vertical gardens and compact urban planning are being explored to optimize greenery within limited spaces (Steiner, 2014).

Ensuring equitable access to green spaces is also a priority, with efforts focused on creating community-centric green areas accessible to people from all socio-economic backgrounds. Government initiatives such as AMRUT, JNNURM, and Swachh Bharat Mission underscore the importance of integrating green and sustainable infrastructure into urban development projects nationwide (I. Mell, 2015). At the policy level, frameworks such as the National Forest Policy and the National Green Highways Mission emphasize the integration of green infrastructure into broader development strategies. Additionally, there is a growing recognition of the cultural significance of green spaces, with efforts to blend traditional sustainable practices and incorporate green areas associated with historical or religious sites (Fenner, 2017). Looking ahead, the future of green infrastructure in India will require continued research, innovation, and the incorporation of indigenous knowledge to address the country's unique environmental challenges effectively. Community involvement in the planning and maintenance of green spaces will be essential for ensuring their long-term sustainability and success (Molla & Biazen Molla, 2015).

10. CHALLENGES IN GREEN INFRA-STRUCTURE DEVELOPMENT

Implementing green infrastructure for resilient cities presents several challenges that need careful consideration. In densely populated urban areas, securing adequate space for green projects like parks and green roofs can be difficult due to high-density development (Wang & Banzhaf, 2018). This challenge is compounded by conflicts with other land uses such as housing and commercial development, necessitating meticulous planning and stakeholder engagement to strike a balance (Schiappacasse & Müller, 2015). Moreover, maintaining green infrastructure over the long term and securing funding for ongoing upkeep pose significant hurdles. Equally important is ensuring equitable distribution of green spaces across communities to avoid exacerbating social and environmental inequalities (Pandey et al., 2021). Climate change uncertainties add another layer of complexity, requiring a nuanced understanding of future climate scenarios to design infrastructure that can adapt effectively (Geeta Satiram et al., 2020). Lack of awareness and education among communities about the benefits of green infrastructure can hinder its adoption, highlighting the importance of education campaigns (Ahmed M. Selim, 2021). Regulatory barriers and policy constraints may impede implementation efforts, calling for alignment with green initiatives. Introducing new plant species for greenery may inadvertently lead to invasive species, threatening local biodiversity (Sadaf Jan, Er Anuj Sachar, 2020). Bridging technological and innovation gaps is crucial for deploying advanced green solutions effectively (Jan et al., 2020). Public perceptions and aesthetics also play a role, with community engagement and design considerations vital for project success. Lastly, interdisciplinary collaboration among various disciplines is essential for addressing the multifaceted challenges of green infrastructure implementation, requiring concerted efforts to overcome silos and foster collaboration (Geeta Satiram et al., 2020). Integrating data-driven decision-making into green infrastructure planning also requires advanced technological solutions and effective data management practices. These challenges underscore the need for comprehensive strategies and collaborative approaches to realize the full potential of green infrastructure in building resilient cities (Jan et al., 2020) (Lin et al., 2021).

11. STRATEGIES AND SOLUTIONS FOR IMPLEMENTING GREEN INFRA-STRUCTURE

Green infrastructure solutions are pivotal components of international agreements, responding to the urgent need for sustainable development and climate resilience. Within the Paris Agreement, nations commit to limiting global warming and adapting to its impacts, recognizing the role of nature-based solutions in climate mitigation and adaptation strategies. Similarly, the Convention on Biological Diversity underscores the importance of conserving ecosystems and biodiversity, emphasizing green infrastructure as a means to achieve conservation goals while enhancing human well-being. In the context of Sustainable Development Goals (SDGs), green infrastructure contributes significantly to several targets. For SDG 11 (Sustainable Cities and Communities), green infrastructure promotes the development of liveable, inclusive cities by enhancing urban green spaces, mitigating urban heat islands, and improving air quality. SDG 13 (Climate Action) is supported through green infrastructure's ability to sequester carbon, reduce greenhouse gas emissions, and enhance climate resilience in vulnerable communities. Furthermore, for SDG 15 (Life on Land), green infrastructure initiatives foster biodiversity conservation, habitat restoration, and sustainable land use practices (Lin et al., 2021). At the national level, countries integrate green infrastructure principles into their environmental policies, urban planning frameworks, and infrastructure development strategies. Government initiatives promote the creation of green spaces, such as urban parks, green roofs, and vegetated corridors, to enhance urban resilience and ecosystem services. Public-private partnerships and climate finance mechanisms mobilize funding for green infrastructure projects, enabling the implementation of nature-based solutions across diverse landscapes. Capacity building programs and knowledge-sharing platforms facilitate the exchange of best practices and lessons learned in green infrastructure implementation. Community engagement initiatives empower local stakeholders to participate in decision-making processes and contribute to the co-creation of resilient, sustainable communities.

By embracing green infrastructure solutions, nations can address interconnected challenges related to climate change, urbanization, and biodiversity loss, fostering a harmonious relationship between nature and society while securing a sustainable future for all. One approach involves the creation and restoration of urban green spaces, including parks, community gardens, and green corridors, which provide multiple benefits such as improved air quality, enhanced biodiversity, and opportunities for recreation and social interaction. Implementation of green roofs and vertical gardens on buildings not only mitigates the urban heat island effect but also reduces energy consumption by providing natural insulation and shading. Innovative stormwater management systems, such as permeable pavements, bioswales, and rain gardens, help to capture and filter rainwater, reducing the risk of urban flooding and enhancing water quality. Incorporating natural drainage features into urban landscapes mimics natural hydrological processes, promoting groundwater recharge and reducing reliance on energy-intensive water treatment systems.

Furthermore, green infrastructure solutions integrate blue-green approaches, combining water management with green spaces to create multifunctional landscapes. Wetland restoration, riverbank stabilization, and constructed wetlands serve as effective tools for flood control, water purification, and habitat creation. These natural water retention features not only provide ecosystem services but also contribute to community resilience by reducing the vulnerability of settlements to extreme weather events. In addition to physical interventions, policy measures and regulatory frameworks play a crucial role in promoting green infrastructure adoption. Governments can incentivize green building practices, offer tax breaks for green investments, and establish zoning regulations that prioritize green space preservation and sustainable land use. Integration of green infrastructure considerations into urban planning processes ensures that nature-based solutions are systematically incorporated into development projects, fostering resilient, inclusive cities. By leveraging a combination of nature-based solutions, policy interventions, and community engagement strategies, countries can effectively harness the power of green infrastructure to address pressing environmental challenges, achieve sustainable development goals, and build resilient cities for current and future generations (Lin et al., 2021).

12. KEY FINDINGS

The study underscores the pivotal role of green infrastructure (GI) in fostering resilient cities by seamlessly integrating natural and semi-natural features into urban landscapes. It elucidates how GI, comprised of a network of natural and semi-natural features strategically integrated into urban areas, functions as a linchpin for resilience. In resilient cities, the imperative lies in not only adapting to but also withstanding and recovering from diverse environmental and socio-economic stressors. Through meticulous case studies and analyses, the study delineates the manifold contributions of GI towards enhancing urban resilience across multiple fronts. From mitigating the adverse impacts of rapid urbanization to buffering against the escalating challenges of climate change, GI emerges as a versatile and indispensable asset. Notably, the study meticulously explores the intricate components of GI, including parks, green roofs, and permeable pavements, illustrating how each element contributes to the overarching goal of urban resilience. Furthermore, it delves into the nuanced mechanisms through which GI combats urban heat island effects, fosters biodiversity, and promotes sustainable urban development practices. By emphasizing on a holistic approach, the study advocates for leveraging GI not merely as a reactive measure but as a proactive strategy to address a comprehensive spectrum of ecosystem disturbances and disasters. By embracing the environmental and ecological benefits inherent in GI, cities can not only mitigate the adverse impacts of urban sprawl but also cultivate resilient urban landscapes that thrive amidst uncertainty and change.

13. CONCLUSION

The paradigm of green infrastructure emerges as a cornerstone in the pursuit of resilient cities, providing a transformative approach that extends beyond conventional urban development. The comprehensive exploration of green infrastructure's components, benefits, and global context underscores its pivotal role in fostering sustainability, adaptability, and inclusivity within urban landscapes. The multifaceted benefits of green infrastructure, ranging from climate resilience and biodiversity conservation to enhanced public health and social cohesion, paint a compelling picture of its potential to address the complex challenges faced by cities globally. As urbanization accelerates and environmental stresses intensify, the integration of nature-based solutions becomes not just a strategic choice but an ethical imperative for responsible urban governance. The global scenario reveals a positive trend, with cities recognizing the interconnectedness between human well-being and the health of the natural environment. From innovative green roofs in densely populated urban centres to expansive urban parks designed for both recreation and ecological balance, the shift towards green infrastructure signifies a collective acknowledgment of the need for adaptive, sustainable urban development. However, challenges persist, and addressing them requires concerted efforts from policymakers, urban planners, and communities. Ensuring equitable access to green spaces, overcoming financial barriers, and fostering cross-sectoral collaboration are essential for maximizing the potential of green infrastructure in building truly resilient cities. Looking forward, the narrative of green infrastructure for resilient cities is dynamic and evolving. It necessitates ongoing research, innovation, and a commitment to integrating nature into the fabric of urban planning. The success stories and lessons learned from cities around the world provide valuable insights, guiding the way for future urban development that embraces the principles of sustainability, resilience, and environmental stewardship. Green infrastructure is not merely an addition to the urban landscape; it is a catalyst for a profound shift in how we conceive and build cities. It offers a vision of urban environments where nature and human habitats coexist synergistically, creating spaces that not only withstand the challenges of the present but also lay the foundation for a harmonious, sustainable, and resilient future. As cities continue to evolve, the legacy of green infrastructure remains a testament to the transformative power of integrating nature into the very fabric of urban life.

14. RECOMMENDATION

Embracing the principles of green infrastructure (GI) offers Indian cities a transformative pathway towards building resilience in the face of rapid urbanization and environmental pressures. Emphasizing the expansion of urban green spaces and parks can create accessible recreational areas while mitigating heat island effects and improving air quality, a strategy seen in various cities worldwide. The strategies like nature in the city, close study of biodiversity and effective government policies can implement to make city resilient. By implementing innovative GI features such as green roofs and vertical gardens can maximize land use efficiency in densely populated urban areas while providing additional greenery and biodiversity. Furthermore, investing in community engagement and capacity-building initiatives can empower residents and stakeholders to participate in the planning and maintenance of GI projects, fostering a sense of ownership and ensuring long-term sustainability. By integrating these approaches into urban planning and development processes, cities in India can harness the benefits of GI to address environmental challenges, promote public health, and enhance overall quality of life for residents.

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Assessment and Optimization of Solid Waste Disposal Practices in Srinagar, Garhwal: The Sustainable Approach for Himalayan Region

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Abstract

Rapid urbanization and rising anthropogenic activity have increased the generation of solid waste significantly, causing environmental risks. This research delves into the solid waste disposal practices within the Himalayan region of Srinagar, Garhwal, with a focus on evaluating waste generation rates and types as a primary objective. The study also aims to assess the effectiveness of waste management strategies and formulate sustainable approaches for infrastructure development in hilly terrains. The current analysis reveals that Srinagar generates a daily average of 12 to 15 metric tons of waste, with the kitchen identified as the predominant source. This contributes significantly to the heightened levels of solid waste production in Srinagar residences. Municipal solid waste management in Srinagar is deemed ineffective, marked by poor segregation and handling practices, including the disposal of collected waste in open landfills without employing scientific methods. And by analyzing the population trend and waste generation, the result obtained is that there is a substantial strong positive correlation of value 0.99 between the population and the waste generation in the study area. To address the adverse consequences of inefficient solid waste management, it is imperative for Srinagar to formulate a comprehensive waste management plan. The study recommends setting specific objectives and deadlines, defining roles and responsibilities for local government entities, non-profit organizations, and the Srinagar Municipal Authority, allocating sufficient funding, and ensuring proper transportation and disposal of municipal solid waste. These measures are crucial for mitigating the environmental impact and establishing a sustainable waste management framework in Srinagar.

1. INTRODUCTION

Solid waste gets produced in ever-increasing amounts in metropolitan areas across the world, but in comparison to wealthy nations, the organization and planning of solid waste collection services in developing countries is extremely immature (1). Municipal solid waste management (MSWM) represents one of the major environmental concerns caused by growing urbanization in developing countries such as India. The quantity and diversity of solid waste created by individuals, both at home and communally, is rising as a result of population growth, improved living standards, and technological advances. Improper garbage disposal generates substantial environmental concerns that harm human and animal health, as well as substantial economic and welfare losses. The waste management process includes gathering, transferring, treating, analyzing, and disposal of garbage from diverse sources. It is an important issue on a global basis as it contributes to water and air pollution. It depicts how it directly influences well-being, economic progress, and damage to the environment. According to a United Nations Development Programme study of 151 mayors around the world, poor solid waste disposal is the second most major problem for city dwellers behind unemployment. Choosing dump location is now something

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that many countries and organizations take very seriously. Finding a new garbage site can take a while when the existing disposal facilities are full (2). There are numerous and intricate factors involved in the development of solid waste in different nations. Finding an appropriate system of municipal solid waste management (MSWM) that takes into account every aspect of this issue is difficult because of the wide range of entities that exist. A suitable system must take into account a variety of variables, parties involved, and MSWM agents. This entails taking into account the actors' capacity in terms of their available financial, technological, and human resources as well as an MSWM system that the operators can accept (3).

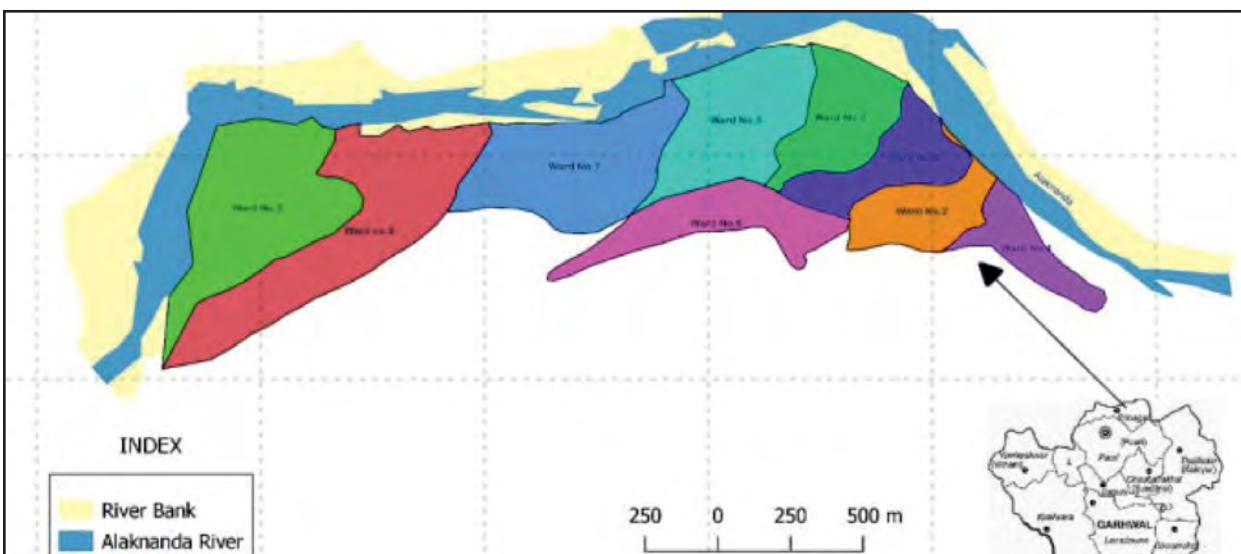
Around 29 million tons of waste is generated yearly by India's 240 million or so urban dwellers, or 0.33 kilograms per person every day. Approximately 3,000 metric tons of municipal solid trashes are produced daily in Uttarakhand, but only 40 percent of that material is treated, according to the municipal council (4). And this will creates a major problem for the local residents and the people involved in the management of solid waste. The purpose of the study is to give a comprehensive overview of the current situation of solid waste in the Uttarakhand city of Srinagar (5). Solid waste management is challenging, especially in increasingly urbanizing regions where trash output is increasing. The city of Srinagar in Uttarakhand, an Indian state situated in the Himalayas, is an example of this issue. This research study examines the solid waste management practices employed in Srinagar. It seeks to shed light on the difficulties and possibilities confronting this city. Srinagar exemplifies the issues that many hilly Indian towns encounter. This city is well-known for its breathtaking natural beauty, rich cultural diversity, and spiritual relevance. It is located in the beautiful state of Uttarakhand. However, it endures the same challenges in handling solid waste as many other expanding urban areas in India. Solid waste management is a serious issue in Srinagar Garhwal, as the population is rapidly increasing and visitors are flooding in on a regular basis. To address this issue, solid waste management must be tackled holistically and sustainably in order to preserve the region's beautiful environment, ensure public health, and maintain the place appealing to both inhabitants and tourists. We shall examine the various parts of solid waste management in Srinagar Garhwal in this introduction, looking at the situation right now, the difficulties encountered, and the potential solutions. The present research paper aims to develop a comprehensive and long-term Solid Waste Management (SWM) plan for Srinagar, taking into account the region's specific challenges and opportunities. The study focuses on merging environmental, social, and economic considerations to create a solid plan that corresponds to the principles of sustainable development. The project's goal is to provide practical insights for local governments and communities to improve waste management practices in the region using a combination of field investigations, stakeholder conversations, as well as data analysis. This region shares exceptional geology and climatic characteristics and is located in the central Himalayas. However, its techniques to waste management have evolved separately over time. Srinagar is the district's centre, serving as a hub for travellers travelling through on their way to Kedarnath, Badrinath, and other shrines. It is critical to understand the dynamics of solid waste management in these diverse but geographically adjacent communities because they present a unique opportunity to develop context-specific understanding and methods for sustainable waste management in other mountainous places across the world. As the previous house of the Garhwal Royals and the current location of the central institution Hemavati Nandan Bahuguna Garhwal institution, Srinagar lacks a robust solid waste management strategy. As a result, all of the material was dumped into the Alaknanda River, a branch of the Ganga River, and set on fire, endangering the health of citizens and producing pollution. The garbage that is burnt includes not just home waste, but also hazardous waste items such as polythene, medical waste, and computer waste. Residents are vulnerable to a variety of respiratory ailments, including asthma, chronic obstructive pulmonary disease, and potentially deadly diseases like lung cancer, as a result of the hazardous vapor produced by open trash burning.

Additionally, the likelihood that a nursery's soil may become contaminated by the ash produced by waste burning has grown due to the dumping site's proximity to the nursery. For a variety of reasons, a deeper and better understanding of solid waste management is essential. First, it outlines many difficulties that quickly urbanizing regions in ecologically fragile areas face. Second, all of this information is transferable to other Himalayan regions with comparable topographical characteristics worldwide. The capacity of comparative analysis to discover optimal procedures, potential innovations, and policy suggestions to address the particular difficulties that each area faces, such as garbage collection, disposal, recycling, and public awareness, is the third and most important component.

2. STUDY AREA

The Srinagar Garhwal region has breathtaking natural beauty. The town is located on the banks of the Alaknanda River and is surrounded by verdant hills, which contributes to its picturesque appeal. The area serves as a hub for ecological research since it provides access to some of the Garhwal Himalayas' most pristine and diversified ecosystems. A substantial number of tourists visit it every year as a gateway to numerous well-known pilgrimage locations like Badrinath, Kedarnath, and Gangotri. Srinagar's cultural vitality is visible in its historic temples and shrines. Perched atop a hill, the Shankaracharya Temple emanates spiritual importance as well as architectural splendour. With its beautiful sculptures and religious fervor, the Kamleshwar Mahadev Temple exemplifies the city's deep-rooted cultural traditions. Srinagar has embraced modernity while conserving its traditional legacy, including educational institutions, healthcare facilities, and infrastructural upgrades. The development of the city demonstrates a difficult balance between progress and the preservation of its distinct identity. Srinagar's tourist business has flourished, contributing considerably to the local economy. Nature lovers, pilgrims, and adventure seekers all flock to the city because of its accessibility and numerous attractions. The booming tourism sector also poses threats to Srinagar's delicate ecology and cultural fabric. Sustainable tourist practices and conservation activities are critical to preserving the city's natural beauty and legacy for future generations. Furthermore, all of these factors will contribute to the challenges in Srinagar. Due to the small amount of available land in the town's peculiar geographic location among hills, waste management presents particular issues. Srinagar is a municipal corporation and administrative Headquarters of Pauri Garhwal district. It is located about 33 km from Pauri town. Srinagar is situated on the left bank of the Alaknanda River at 30.22°N 78.78°E. It is on average 560 meters above sea level (6) (Singh P et al.; 2018), (Singh S. et al.; 2017). The Garhwal Hills, is the biggest town, it is accessible by the national highway NH58 from Rishikesh, which is the last city on Uttarakhand's plains and the point where the mountains begin (7). Srinagar is about 104 kilometers from Rishikesh may also be accessed via Kotdwara, which takes around 5 hours to arrive. In the Srinagar tehsil of Garhwal district, Srinagar is a Nagar Palika Parishad city. Elections are held every five years for the nine wards that make up the city of Srinagar. Srinagar has 4669 households, according to the 2011 population census. The average sex ratio in Srinagar is 871 since there are 20,115 people living there, 10,751 of them are men and 9364 of whom are women. In Srinagar city, there are 2142 children under the age of six, making up 11 percent of the total population. Between the ages of 0 and 6 years, there are 1149 male children and 993 female children. Thus, according to the census 2011, Srinagar's child sex ratio is 864, which is lower than the national average sex ratio of 871. As per the census 2011, the literacy percentage of Srinagar is 92 percent. As a result, Srinagar has a higher rate of literacy than 82 percent of the Garhwal district. In Srinagar, the literacy rates of men and women are respectively 94.22 percent and 89.51 percent. Out of entire population in Srinagar Nagar Palika Parishad, 6588 people were working. While 11.8 percent of workers engaged in marginal activity that provided a means of subsistence for less than six months, 88.2 percent of workers identified their work as main work (employment or earning longer than six months) 28 percent agricultural laborers and 29 percent were cultivators (owners or co-owners) made up the 6588 main workers (8). Srinagar, a local authority area, is comprised of 9 wards which are frequently utilized for elections (figure 1).

Figure 1: Location Map of the Study Area



Source: Municipal Council, Srinagar, (2011)

2.1 Objective

The current study's objective is

- To understand the current scenario about solid waste recovery in the study area.
- To know more about the quantification, and type of generation of waste, disposal, and recycling.

3. MATERIAL AND METHODOLOGY

The present study is based on both primary and secondary data. For the primary data collection various method like structured interview, schedule, questionnaire methods were used, which consist of both open and close ended question. In all the schedule/ questionnaire consist of 20 questions which will be covering the question related with waste generation, collection and segregation etc. (9). Municipal Corporation was given a questionnaire based on inventory on solid waste management, and they generously offered insightful responses. Primary surveys were used, particularly for the assessment. Understanding of the physical properties of waste and consultations to ascertain the communities' felt needs and priorities and the key stakeholders (10), (11), (12). The data from the municipal board provides insight into the current state of municipal solid waste management in the study area. Photographs of the dumping place, waste collecting and transportation were taken during the survey. For the collection of secondary data various government website were concerned. After the collection of data, final results were computed using MS- EXCEL software.

3.1 Interview

In Srinagar, interviews with MSWM system managers were conducted. Formal and open structured interviews were carried out. The interview provides insight into the current situation of MSWM in Srinagar city.

3.2 Direct Observation

The observation approach aids in identifying the reality on the ground. During a visit to the study area, it was seen that locals had destroyed dustbins put by the municipality. Furthermore, people have refused to cooperate with the idea to build a new landfill site, resulting in inappropriate solid waste management. There is an absence of treatment facility and scientific method of disposal of solid waste in the study area.

4. RESULTS & DISCUSSION

4.1 Major Sources of Solid Waste Generation

One of the key elements in determining the properties of trash is its source. Each day, the city produces 15 MT of solid trash. According to table 1, among the other sectors, domestic trash generation was the most significant source of solid waste. The city produces trash primarily from hotels, markets, and commercial establishments because it serves as a stopping point for many pilgrims traveling to Badrinath, Kedarnath, and several other pilgrimage and tourism destinations. According to Verma (2018) similar situation exist in Shimla and a very minute amount is generated by institutions/ offices/schools; and ceremony houses. The solid waste management in Srinagar is in the hands of the Municipal Council of Srinagar. There is a scientific landfill site in Girgaon

Table 1: A Major Source of Concrete Waste Generation in Srinagar City

No. of Holdings and Waste quantities	Waste Quantity (MT/ day)	Percentage
i) Residential	6 MT/day	40
ii) Institutions/ Office Complex/ Universities/ School Colleges etc	0.5 MT/day	3
iii) Commercial Complex	3 MT/day	20
iv) Daily Markets	2 MT/day	13
v) Wholesale vegetable/ fruit market	1 MT/day	7
vi) Hostels /Boarding House	1 MT/day	7
vii) Restaurants	1 MT/day	7
viii) Ceremony House	0.5 MT/day	3
Total Quantity of Solid Waste Generates per Day (approx.)	15 MT/day	100

Source: Municipal Council, Srinagar

which is 7 km away from Srinagar and it has an area of approximately 0.3 hectare. There are a total of 22 bins in the city and with the help of a loader all the waste gets dumped at the segregation point; this is the major method of disposal of waste. Household trash is being collected every day from every ward and there is door-to-door collection of solid waste which is being done manually. For the recycling of solid waste, there is a material Recovery Facility (MRF) which is a solid waste management plant that recycles the waste before selling it to producers as raw material. MRFs are often categorized as “clean” or “dirty”, depending on whether the facility handles materials that are mixed with other municipal garbage. The waste stream, the need for raw materials, and the pollution connected to the production of new goods are all significantly reduced by MRFs. And all these essential aspects will help in observing the cooperation between sub-urban and municipal departments, and to understand the human labor force involved in solid waste transport and disposal activity (16).

4.2 Waste Generation Quantity

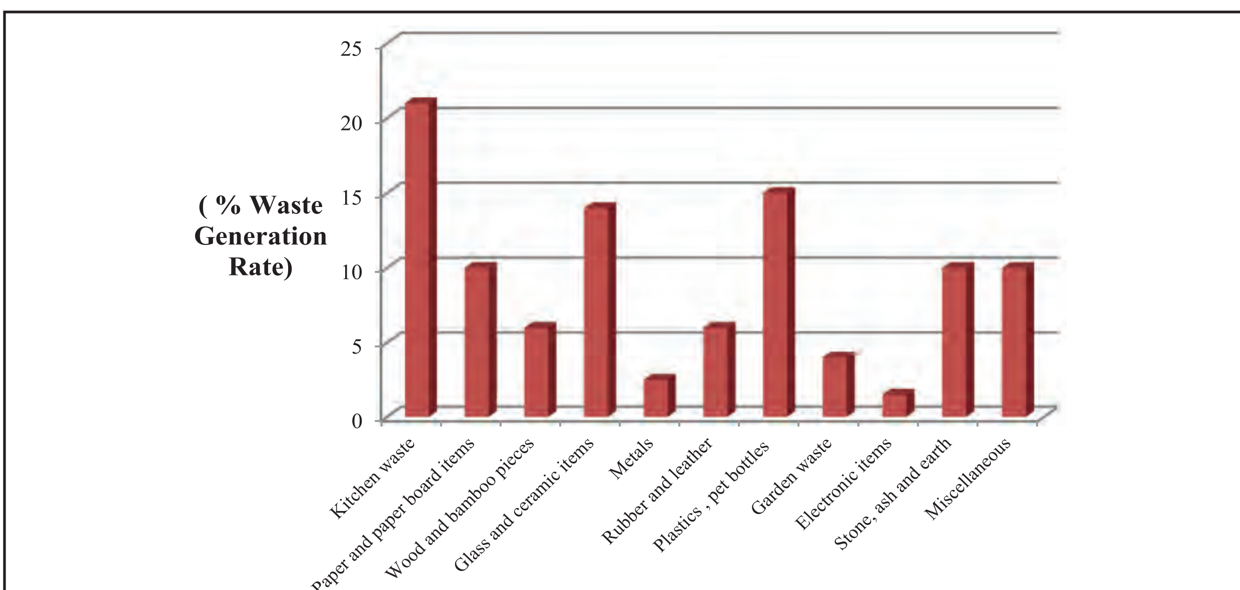
Table 2 and figure 2 compares the percentage-wise waste generation from various sources, and it shows that kitchen and food waste, which are primarily generated at homes, account for the majority of waste generation. In Srinagar Council, large waste containers have been placed at 18 places in the entire city. Apart from this, there are small dustbins in 6 places, which are emptied daily. 02 Tata Ash and 01 Cow-Grass vehicles have been

Table 2: Percentage Wise Generation of Waste Quantity from Different Sectors

S. No.	Waste Characteristics	(Percent by Weight)
1	Kitchen waste	21
2	Paper and paper board unit	10
3	Wood and bamboo pieces	6
4	Glass and ceramic items	14
5	Metals	2.5
6	Rubber and leather	6
7	Plastics, containers	15
8	Garden waste	4
9	Electronic items	1.5
10	Stone, ash, and earth	10
11	Miscellaneous	10

Source: Municipal Council, Srinagar

Figure 2: Percent of Waste Generation in Srinagar



Source: Municipal Council, Srinagar

deployed for door-to-door collection. The primary collection of waste is being carried out by 12 rag pickers. Large dustbins are pulled by the trailer and emptied daily. Apart from this, environment-friendly garbage collectors collect garbage from hand carts and take it to DP (designated plant) and fill it there. After all the garbage of the city reaches the trenching ground, it is sorted. 06 people are working for segregation. After sorting, different materials are compacted into different bundles. The compactor machine is also installed there.

4.3 Availability of Infrastructure

The types of vehicles and the number of vehicles the municipality has available to serve the area are shown in table 3. Wheelbarrows are the primary means of solid trash transportation, and there are relatively few other options, such as two manual rickshaws, 7 Hydraulic Tata and just 1 battery-operated rickshaw. The Srinagar Municipal Council's vehicle fleet requires the addition of a few additional vehicles with easy waste-lifting capabilities because the majority of the waste is still loaded manually. The number of journeys made by trash vehicles is utterly flexible. The amount of rubbish generated completely determines how frequently trips are made and which is totally dependent on the amount of waste generation rate. And as we analyzed earlier the generation of waste is maximum from the kitchen waste which is why the household waste is held responsible for the maximum generation of waste in the Srinagar city. This will ultimately call for the better infrastructural availability in the city which will further enhance the condition of managing the waste also from the different sector.

Table 3: Infrastructure Available in Srinagar Municipal Council

S. No.	Type of Vehicle	No. of Vehicle
1	Bulk waste collection trucks	3
2	Wheelbarrow	100
3	Manual rickshaw	2
4	Battery operated rickshaw	1
5	Auto 3 wheeler	Nil
6	Hydraulic Tata	07
7	JCB	Nil
8	Any other	-
	Total no. of transport	113

Source: Municipal Council, Srinagar

4.4 Population Projection

Table 4 and figure 3 depict the relationship between the population from 2011 to 2025 and annual waste generation from 2011 to 2025. And it shows how, as the population grows, so does the waste generation. To evaluate the link, we calculate the correlation coefficient between population and municipal solid waste generation in Municipal council Srinagar. As a result, it shows a strong positive correlation of the value 0.99 between the population and the Annual waste generation. In conclusion, the data reveals a more strong association between population changes and waste generation in Municipal Council Srinagar. In 2011, Srinagar city generated 300 gm/day per capita, but by 2023, the figure had risen to 367, and it is expected to rise more in the future years. This demonstrates that population pressure and economic conditions have a significant impact on waste generation.

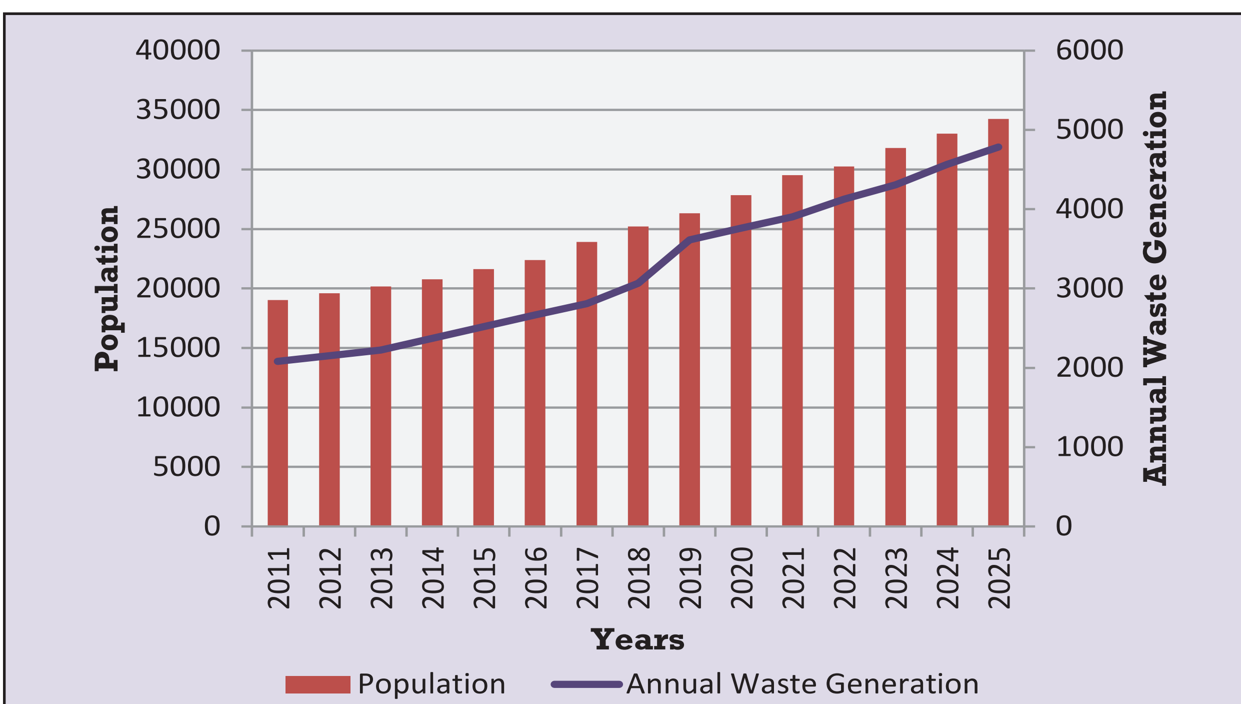
Following data gathering and processing, a calculation is made that in Srinagar, the majority of the solid waste source is residential waste and people are least bothered about that. Also, the majority of the waste is dumped close to the Alaknanda River, which causes the river to become polluted. For aquatic species, these non-biodegradable wastes, like plastic, are harmful and even lethal. The primary dumping area ought to be far away from the river bank, and if it's going to be discharged into the water, it needs to be treated beforehand. There is a room where the plastic garbage is

Table 4: Population Projection in Srinagar Municipal Council

Year	Population	Floating Population	Per Capita Gm/ day	Daily Waste Gen. (MTPD)	Annual Waste Gen. (MTPA)
2011	19019	5210	300	5.7	2080
2012	19589	5262	308	5.9	2153
2013	20176	5314	312	6.1	2226
2014	20781	5367	316	6.5	2372
2015	21612	5389	320	6.9	2518
2016	22395	5412	325	7.3	2664
2017	23910	55210	332	7.7	2810
2018	25220	55923	337	8.4	3066
2019	26335	56225	342	9.9	3613
2020	27829	57355	349	10.3	3759
2021	29520	57945	355	10.7	3905
2022	30250	58192	362	11.3	4124
2023	31820	59421	367	11.8	4307
2024	32996	60729	372	12.5	4562
2025	34250	61247	379	12.1	4781

Source: City Sanitation Plan, Srinagar

Figure 3: Changing Pattern of Population and Municipal Solid Waste Generation in Srinagar (2011-2025)



Source: City Sanitation Plan, Srinagar crushed and then transported elsewhere for recycling. The compactor machine, which is located in this chamber, is typically used to crush plastic objects and transform them into thin sheets before further processing.

Figure 4 & 5 depicts the placement of community bins, tractor garbage carrier as well as the MSW dumping site. It also shows the awful condition of community bins and an open dumping site. Stray animals such as cows, buffaloes, and donkeys eat waste food from public receptacles, further spreading it. At the disposal site, there are also stray animals. This shows that Srinagar's MSW management system is not functioning effectively. This will have an impact on the environment, individuals living near the dumping site, and Srinagar inhabitants. It will also have an impact on the health of stray animals, rag pickers, and those working in solid waste management.

According to the Waste Management Policy of the Government of India, there are no color-coded trash cans (Green & Blue) in or near the market. Instead, a big generic trash can has

Figure 4: Location of Dumping Sites

Figure 5: Tractor Garbage Carrier (Left) & Condition of Dustbins at Dumping Site (Right)

been placed in various locations. Because of this, various trash are frequently thrown into a single dumpster. Due to the lack of segregation between biodegradable and non-biodegradable wastes, as well as occasionally overflowing dustbins, various types of waste are dispersed on the ground and regrettably eaten by street animals. This is a serious problem because the animals consume both types of waste, which may cause infertility in the animals.

Table 5 is depicting the amount of total solid waste generated in Srinagar city which approx. 15 MTPD. Ward no. 1 Agency Mohalla generates the most garbage, while Ward no. 8 SSB area generates the least. Although Ward No. 3 has the most households, it generates relatively less garbage when compared to other wards in Srinagar. As a result, it is evident that the number of households and the amount of garbage generated play smaller roles in each ward. And the collection frequency is twice in ward no. 2 (Upper Bazar), ward no. 3 (Ganesh Market), ward no. 6 (Mistri Mohallah), and ward No. 7 (Kamaleshwar), and only once in ward no. 1 (Agency Mohallah), ward no. 4 (Tamta Mohallah), ward no. 5 (Niranjani Bagh), ward no. 8 (SSB Area), and ward no. 9 (Sheetla Mata Mandir Rout). Srinagar Municipal Corporation provides door-to-door waste collection and currently employs 69 people. And it is bifurcated, as there are only 9 sanitation workers in (ward no. 1) and (ward no. 2), 12 sanitation workers in (ward no. 3), 7 sanitation workers in (ward no. 4 & ward no. 6), 8 sanitation workers in (ward no. 5) & (ward no. 7), and 4 & 5 sanitation workers in (ward no. 8) & (ward no. 9), respectively. Apart from all these facilities there are some general issue like not performing source segregation, which causes numerous difficulties in the city, as discovered by the researcher through a field study and interviews with residents about the condition of solid waste management in their region. And their explanation is that there is a shortage of labour, which is why the door-to-door collecting process is not working effectively. There are fewer vehicles available for secondary storage. And, also there is availability of land for landfill site, however the local residents are opposing the notion of landfill site construction.

Table 5: Existing Situation of Solid Waste Management in Srinagar Municipal Council

Ward No.	Name	Population	No. of Household	Solid Waste Generation (MTPD)	Source Segregation	Collection Frequency
1	Agency Mohallah	3946	727	1.876	No	1
2	Upper Bazar	1640	323	1.517	No	2
3	Ganesh Market	5006	1029	1.680	No	2
4	Tamta Mohallah	1761	328	1.656	No	1
5	Niranjani Bagh	1980	437	1.625	No	1
6	Mistri Mohallah	1663	313	1.725	No	2
7	Kamaleshwar	3361	740	1.761	No	2
8	SSB Area	667	145	1.410	No	1
9	Sheetla Mata Mandir Rout	2376	372	1.750	No	1
Total		22,400	4,414	15 MTPD		

Source: City Sanitation plan, Srinagar

5. CONCLUSION

To further the conversation on sustainable waste management in Srinagar, the municipal council must manage a sizable volume of waste every day. The town's population is growing quickly, and waste production is also accelerating quickly. The communal storage, its collection, and transportation are the main problems with the entire SWM in Srinagar. Another major problem is the presence of Alaknanda River on one of its sides, the dumping location at Alkeshwar Mahadev Ghat is not suitable for the disposal of waste. It will be the cause of Alaknanda's pollution. The position of some populated areas close to the dumping site is another factor. Finding a new disposal location is therefore crucial, and efforts must be taken to limit the overall amount of garbage. Also, it is suggested that governments and NGOs should organize more education and training programs about garbage and waste management procedures, especially for municipal staff. This should be done on the basis of ground level in addition to on paper and pen. This paper mainly intends to assist the policymakers, local government, and community stakeholders in developing a more efficient and environment-friendly waste management system by identifying effective techniques and areas for development. The findings from the in-depth analysis in the municipal Council of Srinagar can ultimately be used as a guide to improve solid waste management practices in similar regions, encouraging healthier and cleaner living conditions while mitigating the adverse effect of improper disposal on the ecosystem. Further, it becomes clear that dealing with solid waste management is a global necessity rather than just a local one. The knowledge gained from the Srinagar Municipal council can be an invaluable tool for promoting sustainable waste management techniques in comparable areas around the world, ultimately helping to protect the environment and the communities that call these places home.

6. SUGGESTIONS

In the hilly regions of Srinagar Garhwal, due to difficulty of terrain and, environmental sensitivity solid waste management provide the peculiar issues. Here are some of the suggestions to deal with this problem:

- **Community Engagement and Education**

  There should be community, education programs at least twice a month to educate residents on the importance of solid waste management and its influence on the environment. Community members should involve in garbage separation, recycling, and composting.

- **Biogas Generation**

  Investigate the feasibility of building up small-scale biogas facilities to transform organic waste into electricity. Biogas may be used to cook, heat, or generate energy, which reduces reliance on fossil fuels.

- **Waste-to-Energy (WTE) Solutions**

  Investigate the sustainability of waste-to-energy technologies appropriate for steep terrains, such as small-scale incineration or gasification facilities. Ensure that such facilities follow strict environmental regulations and have little influence on air quality.

- **Territorial Zoning and Collection Routes**

  Divide the town into zones considering topography and population density. Design effective collection routes taking into account the difficult terrain to reduce transportation expenses and carbon emissions.

- **Technology Integration**

  Employ technological advancements such as IoT-equipped waste bins to enhance the monitoring and administration of waste collection. Introduce GIS (Geographic Information System) mapping to streamline collection routes and pinpoint areas prone to illegal dumping.

- **Financial Incentive**

  Launch of an initiative that provides households with a financial incentive to decrease domestic waste and adopt alternatives such as recycling and backyard composting. This might be a "waste tag" or "pay-as-you-throw" plan. And it will force people to pay a tag for each rubbish container left out (17).

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Integrating Waste Management into Urban Planning: Production of Bioethanol through Acid Hydrolysis and Fermentation Using Municipal Organic Waste of Indore City

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Abstract

Urban planning is essential for tackling the pressing issue of fossil fuel depletion and fostering sustainable energy solutions. Bioethanol production from municipal organic waste (MOW) presents a viable alternative, particularly in cities like Indore, where significant quantities of organic waste are generated. By converting MOW into bioethanol through hydrolysis and fermentation processes, urban areas can simultaneously address waste management challenges and reduce reliance on finite fossil fuels. Optimization of production parameters ensures efficient bioethanol yield while minimizing resource inputs and environmental impacts. Taguchi analysis was carried out using L9 orthogonal array approach for optimization of the parameters of hydrolysis process. The variable parameters, namely, temperature (T), acid concentration (ac), and reaction time (t) of hydrolysis process were optimized considering the amount of the hydrolysate produced and reducing sugar yield in the hydrolysate as response parameters. The optimum condition was obtained at temperature (T) 120ºC, 3% acid concentration (ac), and reaction time (t) as 20 minutes. Using hydrolysis and fermentation processes bioethanol was produced with 95% purity. Integrating bioethanol production from MOW into urban planning strategies offers multiple benefits, including improved waste management, reduced greenhouse gas emissions, enhanced energy security, and economic development. By embracing bioethanol production from MOW, urban planners can contribute to the creation of more sustainable and resilient cities, advancing towards a cleaner and greener energy future.

1. INTRODUCTION

Urbanization has led to unprecedented challenges in waste management with burgeoning cities grappling to sustainably dispose of increasing volumes of organic waste. In this context, the production of bioethanol from organic waste emerges as a promising solution that not only addresses environmental concerns but also offers opportunities for sustainable urban planning and resource management. Indore, a rapidly growing city in central India, exemplifies the pressing need for innovative waste management strategies amidst rapid urbanization and population expansion. Worldwide, the amount of municipal waste generated is around 2000 Mt/y which is estimated to increase by 70 percent by 2025 (Kowalski et al. 2022). Researchers have identified the organic fraction of municipal solid waste as a potential source of biomass (Martinez et al. 2019). It was estimated that about 20 percent of the total sold fruits and vegetables in the world contains inedible substances such as seeds, peel, and bagasse (Bibra et al. 2022). In this research Municipal Organic Waste (MOW) of Indore city was used as a feedstock for production of bioethanol. The MOW contains rotten fruits, vegetables, waste fruit pulp, peels of fruits, peels of vegetables, leftover food, bread, used tea leaves, and organic garden waste. A significant amount of organic material remains after the production of bioethanol from MOW which can be further used for production of biogas (Moreno et al. 2021).

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The MOW is perineal, easily available, almost free of cost, and available in large quantity. Generally, the MOW does not process for complete recycle. It is either land-filled or processed for incineration which causes several adverse effects on environment such as pollution of land, water, and air. Conventional and unscientific disposal of MOW imparts hazardous effects on the environment and cause of many health issues of living creatures (Pal & Bhatia 2022). In this research the waste is converted into value in terms of effective production of bioethanol by optimization of the parameters of hydrolysis process. At present, bioethanol is produced mainly form first-generation feedstocks which contain sugarcane, sugar beet, corn, wheat, rice, and other starch energy crops (Ma et al. 2016). In India availability of the crops which are rich in sugar and starch is not so adequate that they can be used for production of bioethanol (Singh & Yadav 2020). Use of first-generation feedstock to produce bioethanol creates a big conflict for use of biomass resources as a food or as a fuel (Zanivan et al. 2022). To overcome such situation research has been started to find out an effective feedstock which should not contain any food crop. This article is focused on development of an effective process of bioethanol production using a non-food feedstock.

The utilization of organic waste of Indore city for bioethanol production holds immense potential to mitigate the environmental load of waste disposal while simultaneously contributing to energy security and fostering circular economy principles. By repurposing organic waste streams, such as food scraps, garden waste, and other biodegradable materials, into bioethanol, cities like Indore can alleviate the strain on landfill capacity, reduce greenhouse gas emissions, and enhance resource efficiency. Integrating bioethanol production using organic waste into urban planning frameworks offers multifaceted benefits, ranging from enhancing energy resilience and reducing reliance on fossil fuels to promoting sustainable land use practices and fostering community engagement. Rapid depletion of fossil fuel reserves and continuously increasing cost of fossil fuels changed attention of researchers to find out other sources of fuel (Gundupalli & Bhattacharyya 2019). In search of alternative fuels, bioethanol has evolved as a potential substitute of fossil fuels (Wakamatsu et al. 2013). Bioethanol provides superior blending properties due to its higher value of octane rating than diesel (Laborde et al. 2022). Burning of bioethanol emits lower toxic emissions to the atmosphere because its molecule contains oxygen by which partial combustion of the fuel takes place in the vehicle engines (Laborde et al. 2022). Through innovative approaches to waste valorization and bioenergy production, urban planners can envision holistic waste management strategies that align with broader sustainability objectives and support the transition towards low-carbon, resource-efficient urban environments.

Singh & Yadav (2020), produced bioethanol by soyabean straw and optimized the operational parameter of the production process. Sarkar et al. (2019) used fruit pulp to produce bioethanol with the help of marine bacterialstrain Citrobacter sp. E4. For bioethanol production glycerol waste was used by Chilakamarry et al. (2022). They optimized fermentation process parameters for the bioethanol production. The effect of organic acid pretreatment was analysed on mixed vegetable waste conversion into bioethanol and biogas was modelled and experimentally investigated based on RSM and ANN techniques by Dharmalingam1et al. (2022).

This research article aims to explore the role of bioethanol production in the context of urban planning of Indore city. By examining the potential of bioethanol production from organic waste this study seeks to elucidate its potential contributions to urban resilience, energy security, and sustainable development. Incorporating urban planning considerations into bioethanol production from organic waste presents an innovative approach to address both waste management and energy security challenges in urban areas. Repurposing of organic waste streams for bioethanol production, cities can simultaneously reduce waste disposal burdens, mitigate environmental pollution, and enhance energy self-sufficiency, thus fostering sustainable urban development.

2. MATERIALS & METHODS

2.1 Preparation of MOW Samples

Waste collection vehicles of Indore city collect domestic and commercial waste from all over the city on daily basis. Organic and inorganic wastes are collected in separate containers. MOW for the research was taken randomly from the organic waste containers of these waste collection vehicles. This collected MOW was converted into fine paste and dried in an oven at 105ºC for 24 hours to remove moisture from it. Figure 1 shows paste of the MOW and figure 2 shows powder of the dry MOW. Samples for further investigations were taken randomly from the dried MOW powder.

Figure 1: Paste of the Wet MOW

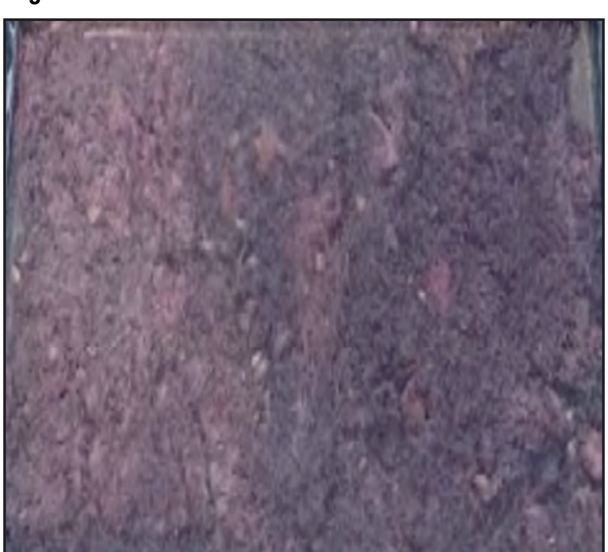


Figure 2: Powder of the dry MOW

2.2 Analysis of Composition of the MOW Sample

Analysis of the composition of the prepared MOW sample was performed using Fourier transform infrared (FT-IR) spectroscopy. The sample was scanned between the wavelengths of 4000 to 400 cm^{-1} in the transition mode. The generated FT-IR spectra of the MOW sample were analysed and compared with actual FT-IR spectra of lignin and cellulose to determine the key functional groups present in the sample.

2.3 Proximate Analysis of the MOW Sample

Proximate analysis was carried out for quantitative determination of the dried MOW sample as per the ASTM standard. Ash content (E-1755, 2015), Volatile Matter (E-872, 1998), and Fixed Carbon (E-1755, 2001 & E-872, 1998) of the prepared MOW samples were determined using a muffle furnace.

2.4 Selection of Acid for Hydrolysis

Experiments were conducted to select suitable acid for maximum extraction of reducing sugar yield from the MOW sample by hydrolysis. Three different acids, namely, sulphuric acid (H2SO4), hydrochloric acid

(HCL), and nitric acid (HNO3) in their diluted and concentrated ranges were used in the experiments. Hydrolysis of the powdered MOW sample was carried out by mixing the MOW sample with acid solution in 1:10 ratio. Three experiments were conducted using 10 gm of the prepared MOW sample with 1.5 percent acid concentration using the acids. The samples of the experiment were autoclaved at 121ºC at 1 bar pressure for 20 minutes for hydrolysate preparation. Three more experiments were conducted using 10 gm of powdered MOW sample mixed with concentrated acids of 30 percent concentration. The experiment samples were kept in the water bath at 70 ºC for 20 minutes for hydrolysate preparation. The prepared hydrolysate from all 6 experiments were cooled to room temperature and filtered using a filter cloth to remove the solid residues form it. The filtrate was collected and reducing sugar yield was estimated using dinitrosalicylic acid (DNS) method.

2.5 Acid Hydrolysis of the MOW

Sulphuric acid (H2SO4) in diluted acid concentration was used as a hydrolysis chemical. Solution of the MOW sample and H2SO4 was filled in an Erlenmeyer flask and kept in an automatic hot oil bath for hydrolysis. Uniform temperature of the hot oil was maintained by continuous stirring the oil during the process. The contents of the flask were stirred at every 10 min intervals. After completion of the hydrolysis, the prepared solution was allowed to cool down at room temperature. The solid and liquid fractions were separated by centrifugation and filtration of the prepared hydrolysate.

2.6 Experiments for Optimization of Process Parameters of Hydrolysis

Hydrolysis process parameters were optimised using Taguchi L9 orthogonal array approach with 3 level of the variable process parameters. Experiment was designed with three variable parameters, namely, temperature (*T*), acid concentration (*ac*), and reaction time (*t*) at their 3 levels. Total 9 experiments were conducted by varying these variable process parameters keeping weight of the MOW and quantity of acid solution as fixed parameters. In the present work lower values of temperature were selected to control sugars degradation in the samples. The amount of hydrolysate produced and reducing sugar yield in the hydrolysate were considered as response parameters. The details of variables and responses parameters considered in the experimentation are presented in table 1. Minitab-16 software was used for the Taguchi analysis. For maximization of the amount of hydrolysate and reducing sugar yield in it, the “larger is better” approach of the analysis of signal-to-noise ratio was used.

Table 1: Details of the Variable Hydrolysis Process Parameters and Responses Considered for Optimization

Name and symbol (unit)	Levels			Response Parameters (unit)
	I	II	III	
Temperature, “*T*” (ºC)	120	130	140	Amount of hydrolysate (ml) Reducing sugars yield (µg/ml)
Acid Concentration, “*ac*” (percent)	1	2	3	
Reaction Time, “*t*” (min)	20	30	40	

2.7 Fermentation and Distillation

For fermentation of the hydrolysate produced, a fermentation media was prepared. The fermentation media contained growth media and yeast media. The growth media was prepared for yeast to grow which contained 2 percent glucose, 2 percent peptone, and 1 percent yeast. The yeast media was prepared to provide nutritious medium for growth and propagation of yeast cultures. Yeast media solution contained 0.2 percent potassium dihydrogen phosphate (KH_2PO_4), 0.64 percent urea (CH_4N_2O), 0.1 percent magnesium sulphate heptahydrate ($MgSO_4.7H_2O$), and 2 percent glucose. After mixing of growth media and yeast media it was kept for 24 hrs for proper growth of yeast.

Yeast suspension solution was prepared by adding 15 percent yeast and 4 percent glucose in the lukewarm water. The hydrolysate was neutralized to pH 5 using NaOH solution of 1 normality to make the hydrolysate a fermentable solution. During neutralization alkali was added in the hydrolysate which facilitates detoxification of the hydrolysate which makes it a suitable medium in which yeast can survive. For fermentation of the hydrolysate, fermentation media, and yeast suspension were mixed in the ratio of 5:3:2. Fermentation was done under anaerobic conditions at 30°C for a time duration of three days.

The fermented liquid was filtered for suspended impurities. Distillation of the fermented liquid was done at a temperature of 78ºC for separation of bioethanol from the other byproducts present in the fermented liquid. To remove traces of water from the distillate, dehydration was performed with anhydrous sodium sulphate (Na_2SO_4).

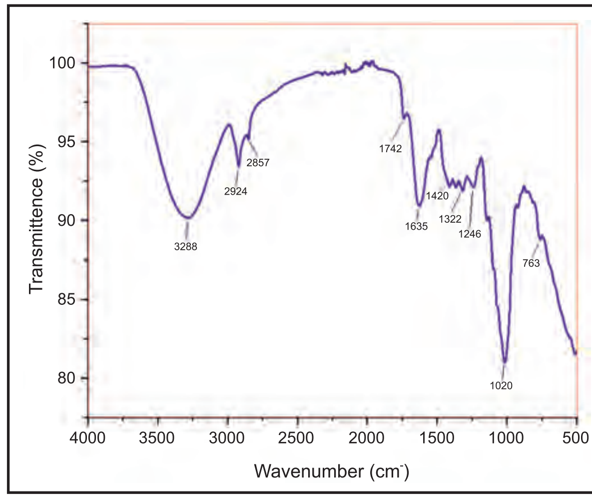
3. RESULTS AND DISCUSSION

3.1 Composition of the Prepared MOW Sample

To identify the composition of the MOW sample FT-IR spectroscopy was used. The result is shown in figure 3. The MOW sample mainly contained carbohydrates, cellulose, and hemicelluloses with functional groups like aromatic ketones, and alcohols.

FT-IR spectrum of dry MOW indicates that there are three peaks in the single bond region at 3288, 2924, and 2857 cm^{-1}. The peak at 3288 cm^{-1} shows the presence of –OH vibration from alcohol and pectic acid group in

Figure 3: FT-IR Spectra of the MOW Sample



the composition of biomass. The peak at 2924 cm^{-1} corresponds to the C–H asymmetrical stretching vibrations of aliphatic structures, and the peak at 2857 cm^{-1} represents methylene C–H symmetrical Stretch. In the double bond region peaks identified at 1742 cm^{-1} represent the presence of hemicelluloses structure in sample composition and the peak at 1635 cm^{-1} represents aryl-substituted C=C stretching. The vibrations of aliphatic chains of basic cellulosic materials are seen at 1420 cm^{-1}. C–O stretching of lignin has been seen due to Peaks at 1246. A peak at 763 cm^{-1} represents an aromatic C–H band.

3.2 Results of the Proximate Analysis

Results of the proximate analysis of wet MOW shows that the sample contained 76.79 percent moisture. Proximate analysis of the dry MOW sample shows that it contained ash content 5.98 percent, volatile matter 70.15 percent, and fixed carbon 23.87 percent.

3.3 Results of the Experiments of Acid Selection

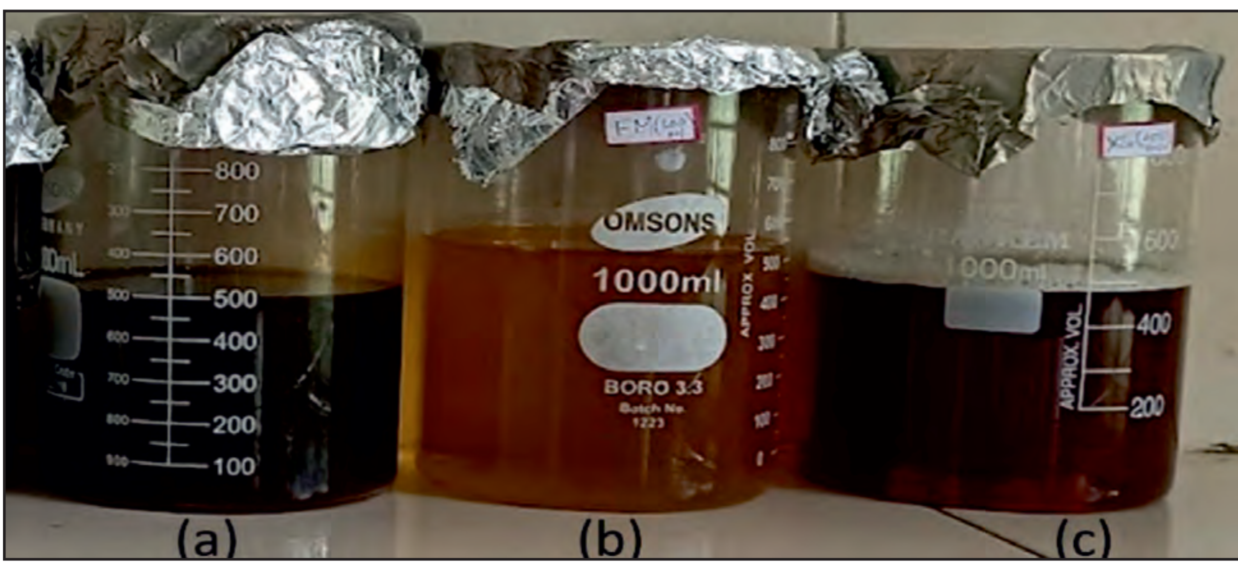
The prepared MOW sample was mixed with H_2SO_4, HCL, and HNO_3 on their concentrated and dilute ranges. After hydrolysis, hydrolysate was produced which was tested for reducing sugar yield using DNS Method. The results obtained are represented in table 2.

Table 2: Results of the Experiments Conducted for Acid Selection

Experiment Number	Name of the Acid	Concentration (Percent wt)	Temperature (ºC)	Reaction Time (Minutes)	Reducing Sugar Yield (μg/ml)
1	H2SO4	1.5	121	20	999.18
2	H2SO4	30	70	20	178.16
3	HCL	1.5	121	20	238.23
4	HCL	30	70	20	133.82
5	HNO3	1.5	121	20	515.14
6	HNO3	30	70	20	Not found suitable

Concentrated range of HNO3 was found not suitable in the experiments with the MOW sample because its chemical reaction produces hazardous fumes of orange colour causing nose and eye irritations. Experiment was conducted to estimate the reducing sugar yield present in the MOW sample without acid treatment. In this the MOW sample was mixed in distilled water in 1:10 ratio and kept in the water bath for 20 minutes at 70 ºC. Reducing sugar yield in this untreated MOW solution were found 148.07 μg/ml. After the treatment of the MOW samples with different acids in different concentrations, the maximum sugar yield was obtained at 1.5 percent concentration of sulphuric acid (H2SO4). Results shows that sulphuric acid (H2SO4) of diluted concentration was producing maximum sugar yield and so it was found suitable for hydrolysis of the MOW samples. Figure 4 shows the prepared hydrolysate, fermentation media and yeast suspension.

Figure 4: (a) Hydrolysate, (b) Fermentation Media, (c) Yeast Suspension



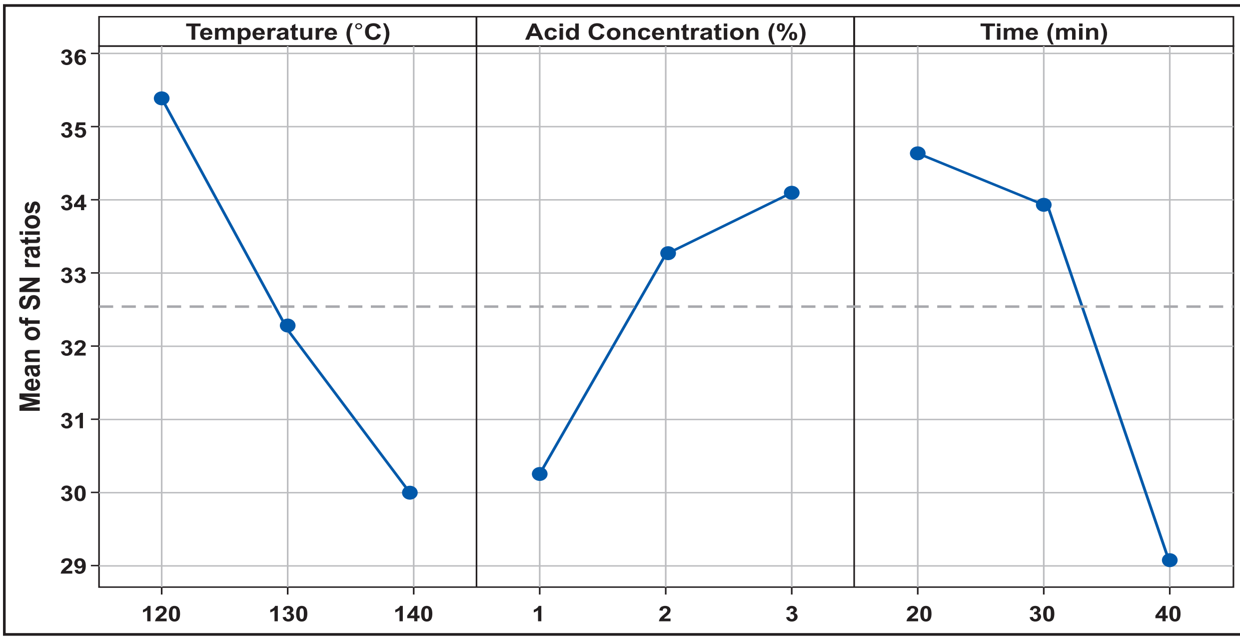
3.4 Optimization of Process Parameters of Hydrolysis

Taguchi method was used for optimization of the parameters of hydrolysis process. As shown in table 3, total 9 experiments at designed combinations of the process parameters were conducted and results obtained.

3.4.1 Analysis of Signal-to-Noise Ratio for Amount of Hydrolysate Produced

For maximum conversion of the MOW sample into hydrolysate by hydrolysis process, variable process parameters, namely, temperature (*T*), acid concentration (*ac*), and reaction time (*t*) were optimized by Taguchi method

Figure 5: Plot for Signal-to-Noise Ratio for the Hydrolysate Produced



considering the "larger is better" approach using Minitab-16 software. Main effect plot of signal-to-noise ration are shown in figure 5.

The optimum conditions of the process parameters were achieved at temperature (*T*) of 120 ºC, 3 percent acid concentration (*ac*), and 20 minutes reaction time (*t*). As shown in table 4, the reaction time (*t*) is the most significant parameter of the hydrolysis process followed by temperature (*T*), and acid concentration (*ac*).

Table 4: Response Table for Signal-to-Noise Ratio for the Hydrolysate Produced

Level	Temperature (*T*)	Acid Concentration (*ac*)	Reaction Time (*t*)
1	35.40	30.26	34.62
2	32.26	33.26	33.91
3	29.94	34.08	29.07
Delta	5.47	3.82	5.55
Rank	2	3	1

3.4.2 Analysis of Signal-to-Noise Ratio for Reducing Sugar Yield

Taguchi analysis was carried out to obtain optimal conditions of the hydrolysis process parameters for the maximum reducing sugar yield in the hydrolysate produced considering the "larger is better" approach of the analysis. Optimum values of the process parameters were obtained at 130 ºC temperature (*T*), 2 percent acid concentration (*ac*), and 20 minutes of reaction time (*t*), as shown in figure 6. Acid concentration (*ac*) is found the most significant parameter followed by reaction time (*t*), and temperature (*T*) as shown in table 5.

3.4.3 Analysis of Combined Signal-to-Noise Ratio for Hydrolysate Produced and Reducing Sugar Yield

To maximize the values of both, the amount of hydrolysate produced and reducing sugar yield in the hydrolysate simultaneously, the

Figure 6: Plot for Signal-to-Noise Ratio for the Reducing Sugar Yield

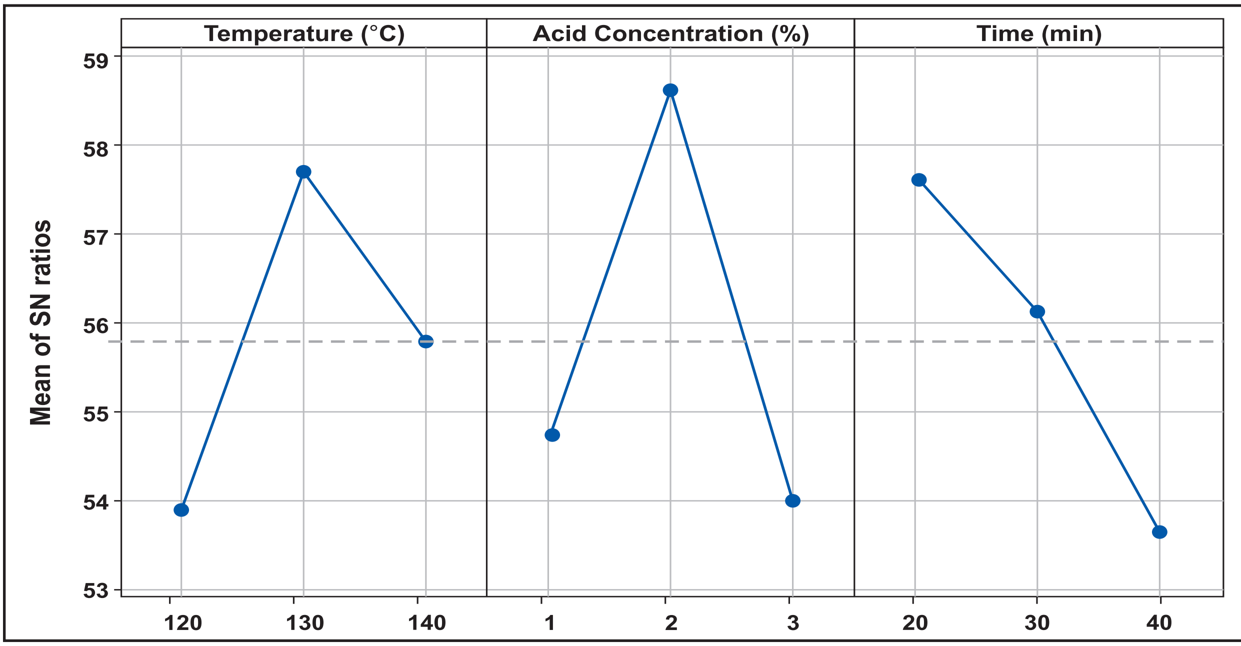


Table 5: Response Table for Signal-to-Noise Ratio for the Reducing Sugar Yield

Level	Temperature (*T*)	Acid Concentration (*ac*)	Reaction Time (*t*)
1	53.87	54.74	57.63
2	57.72	58.64	56.11
3	55.79	54.00	53.64
Delta	3.84	4.63	3.99
Rank	3	1	2

optimum values of the process parameters obtained are shown in figure 7.

The "Larger is better" approach is used for the analysis for maximization of both the response parameters.

The optimum values of temperature (*T*), acid concentration (*ac*), and reaction time (*t*) were 120ºC, 3 percent, and 20 minutes, respectively. As shown in table 6, reaction time (*t*) has found the most significant process parameter followed by temperature (*T*), and acid concertation (*ac*).

3.4.4 Result of Confirmation Experiment

Experiments were conducted at the obtained optimized hydrolysis process parameter by Taguchi analysis. Hydrolysate was produced at the optimized values of the process parameters, namely, temperature (*T*) at 120 ºC, 3 percent acid concentration (ac), and reaction time (*t*) 20 minutes. At optimised parameter setting 75.34 ml hydrolysate was produced with 1124 µg/ml reducing sugar yield. Summary of the experiments are presented in table 7.

3.5 Result of Fermentation Experiments

After conversion of MOW sample into hydrolysate, bioethanol was extracted from the hydrolysate by fermentation. Fermentation media and yeast suspension were added in the hydrolysate for fermentation. The produced fermented liquid was filtered, distilled, and dehydrated. From 100 ml sample of mixture of the hydrolysate, fermentation media, and yeast suspension, 62.75 ml bioethanol with 95 percent purity was produced.

Figure 7: Plot for Combined Signal-to-Noise Ratio for the Hydrolysate Produced and Reducing Sugar Yield

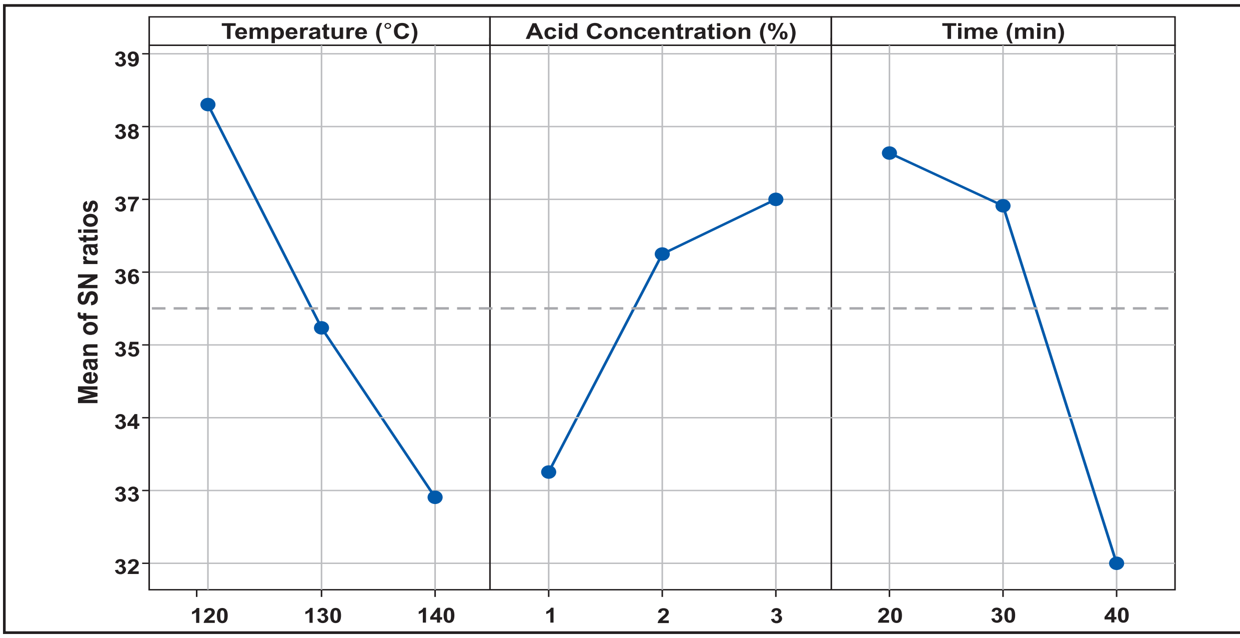


Table 6: Response Table for Combined Signal-to-Noise Ratio for the Hydrolysate Produced and Reducing Sugar Yield

Level	Temperature (*T*)	Acid Concentration (*ac*)	Reaction Time (*t*)
1	38.30	33.24	37.61
2	35.25	36.25	36.89
3	32.93	36.99	31.99
Delta	5.37	3.75	5.62
Rank	2	3	1

Table 7: Summary of the Hydrolysate Produced on Different Process Parameters

Parameter Setting	Variable Process Parameters			Responses	
	Temperature (ºC)	Reaction Time (minutes)	Acid Concentration (percent)	Amount of Hydrolysate (ml)	Reducing Sugar Yield (µg/ml)
On general parameter setting (Without optimization)	70	30	0.5	48.000	148.074
On optimized parameter setting for amount of hydrolysate	120	20	3	72.567	-
On optimized parameter setting for reducing sugar yield	130	20	2	-	1098.265
On optimized parameter setting for amount of hydrolysate and reducing sugar yield	120	20	3	75.340	1124.800

4. CONCLUSION

Utilization of Municipal Organic Waste (MOW) from cities like Indore as a feedstock for bioethanol production holds significant implications for urban planning and sustainability. By repurposing organic waste generated within urban areas, this research contributes to waste management strategies, reducing the burden on landfills and incineration facilities. In search of alternate feedstock, MOW has found a perennial, easily available, and almost free of cost feedstock to produce bioethanol. In this research MOW of Indore city was used as an effective feedstock for production of bioethanol. For conversion of the MOW into bioethanol, hydrolysis and fermentation processes were performed. Experiments were conducted for optimization of the parameters of hydrolysis process. Taguchi method with L9 orthogonal array approach was used for the analysis. Furthermore, the optimization of hydrolysis processes using Taguchi method underscores the importance of technological innovation in urban sustainability initiatives. By improving the efficiency and yield of bioethanol production from MOW, this research contributes to the development of sustainable energy solutions tailored to the needs of urban environments. The utilization of MOW for bioethanol production not only addresses waste management challenges but also fosters sustainable urban development by promoting resource efficiency, energy independence, and environmental resilience. This interdisciplinary approach underscores the interconnectedness of waste management, energy production, and urban planning in building more sustainable and resilient cities. A considerable amount of bioethanol was produced after the optimization of the process parameters. Following are the conclusions of the research:

- MOW was found a potential feedstock for bioethanol production due to its abundance availability and cost effectiveness.
- Sulphuric acid (H_2SO_4) was found most effective chemical for acid hydrolysis of the MOW.
- Optimization of the parameters of hydrolysis process was done for maximum conversion of MOW into hydrolysate. The optimum condition was obtained at temperature (*T*) 120 ºC, 3 percent acid concentration (*ac*), and reaction time (*t*) of 20 minutes.
- Optimum condition of the process parameters was achieved at temperature (*T*) 130 ºC, 2 percent acid concentration (*ac*), and reaction time (*t*) 20 minutes for maximum reducing sugar yield in hydrolysate produced from the MOW.
- To achieve maximum conversion of MOW into hydrolysate and to get maximum reducing sugar yield in the hydrolysate produced simultaneously, the optimum condition was achieved at temperature of (*T*) 120 ºC, 3 percent acid concentration (*ac*), and reaction time (*t*) of 20 minutes.
- The reaction time (*t*) was found most significant parameter of hydrolysis for maximum production of hydrolysate from the MOW.
- Acid concentration (*ac*) was found most significant parameter to achieve maximum reducing sugar yield in the hydrolysate.
- For maximum production of hydrolysate with maximum reducing sugar yield simultaneously, reaction time (*t*) was found most significant parameter.
- Hydrolysis and fermentation processes have found suitable for production of bioethanol from MOW. Using the processes bioethanol was produced with 95 percent purity.

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Developing Blue-Green Infrastructure in Megacities of India: Case of Delhi & Mumbai

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Abstract

Urbanization has caused enormous environmental issues, such as air and water pollution, soil deterioration, and the loss of natural ecosystems. Blue-Green Infrastructure (BGI) are natural or engineered systems that integrate water management with green spaces to promote eco-balance and societal benefits. It can offer significant benefits to urban areas, including improved water quality, lessened heat island effects, diversified life, and more recreational spaces. This research paper examines the BGI of four major cities, national and international respectively id est, Mumbai and Copenhagen, Delhi, and New York City- to evaluate their efforts in promoting sustainable urban development. These four major cities have been selected carefully based on certain factors such as geographical, climatic, social, and economic conditions. Copenhagen, a city situated in northern Europe, boasts a robust BGI network comprising parks, vegetated rooftops, and water-responsive landscapes, all aimed at alleviating the impacts of climate change. Mumbai, a city with high population density and susceptibility to flooding, has made significant investments in BGI to improve water management and reduce flood risks. New York City, after Hurricane Sandy, has adopted a resilient approach, combining BGI with hard infrastructure, to mitigate future natural disasters. Delhi, a rapidly urbanizing city with water scarcity issues, is implementing BGI strategies to enhance water security and create green spaces. The research attempts to identify common themes in BGI development across the cities, such as community engagement, multi-stakeholder collaboration, and institutional support. However, it also highlights the unique challenges faced by each city in implementing BGI, such as financing, land-use regulations, and governance issues. This research emphasizes the importance of contextualizing BGI interventions to local conditions and integrating them into urban planning policies for long-term sustainability. Overall, the study contributes to the emerging literature on urban resilience and sustainable development, providing insights into the design, implementation, and management of BGI in diverse urban contexts.

1. LITERATURE REVIEW

Rapid urbanization has led to a slew of issues. One such major issue is climate change which is making our cities more vulnerable. The need to combat these issues has made it imperative to adopt more nature-based solutions that will not only be sustainable but will also help in striking a balance between the man-made and natural environment. Earlier grey infrastructure was employed exclusively for the collection and channelling of storm-water runoff from major cities. The term grey infrastructure is used to describe wastewater treatment which is human-engineered and includes drainage plants, reservoirs, and cemented pipelines. Reliance on grey infrastructure, however, had several unintended negative effects that affected the quantity and quality of water and were caused by the higher-than-expected peak flows and discharge from storms and torrential downpours. Therefore, urban waterways got greater quantities of nutrients and toxins accumulated which in turn degraded aquatic habitat. Moreover, combined sewer overflows in moist conditions became bacterial and toxin spawning grounds. The population, which depended on the water bodies for food, was at risk from these pathogens. As a result, Blue-Green Infrastructure (BGI) became necessary as a reliable and effective response to the serious threats posed by outdated and old Grey Infrastructure (Chen et al., 2021). BGI management is seen as a

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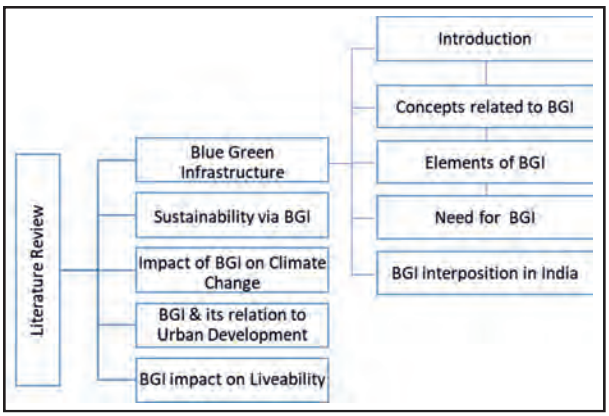
sustainable method of mitigating the negative impact of urbanization, such as lowering flood risks, managing stormwater, reducing the heat island effect, climate adaptation and resilience, enhancing biodiversity, etc. (Drosou et al., 2019).

This research's literature review encompasses an exploration of BGI and its influence on sustainability, liveability, urban development, and climate change (figure 1). Additionally, it delves into its current status in India, incorporating international case studies such as Copenhagen and New York City, while also drawing comparisons with two major Indian megacities, namely Mumbai and Delhi.

Figure 1: Literature Review Process



Source: Author (2023:3)

1.1 Introduction to Blue-Green Infrastructure (BGI)

BGI explains the natural or engineered system that provides a range of ecosystem services that address both social and environmental challenges. It refers to an approach to urban planning and design that attempts to integrate natural systems into the built environment. It involves the use of natural and built-in features of the environment such as green roofs, wetlands, and other types of vegetation to manage water, air quality, and urban heat islands, among other things. BGI has become increasingly popular to address the environmental, social, and economic challenges faced by cities around the world due to increasing urbanization (Ghofrani, Sposito & Faggian, 2017).

India's fast urbanization has been fuelled by the nation's growing economic growth as well as commercialization and industrialization, as people migrate from rural to urban areas in quest of better employment prospects and higher standards of living. It is predicted that by the year 2050, approximately 68 percent of the world's population will be residing in cities (Stadler, 2021). By then, it is anticipated that two out of every three Indians will reside in a city. Most Indian cities are hampered by problems with traffic, pollution, and unequal resource availability. Rapid urbanization has put an excessive amount of pressure on public health, sewerage, and freshwater supplies (Stadler, 2021).

Given these facts, it is time to move beyond the conventional grey infrastructure when it comes to urban planning. The above issues can be solved in large part by implementing sustainable infrastructure. A core component of it is blue-green Infrastructure.

The concept of BGI is based on the idea that natural systems can provide many of the same benefits as traditional "Grey" infrastructure (e.g., pipes, pumps, and tanks), but more sustainably and cost-effectively. For example, green roofs and urban forests can help reduce the storm-water runoff that flows into sewers and rivers, which can help prevent flooding and lessen the amount of pollution that enters waterways. Wetlands and other types of vegetation can help purify water, absorb carbon dioxide, and provide a habitat for wildlife (Bozovic & consultancy, n.d.).

1.2 Concepts Related to BGI

Blue-green infrastructure encourages resource-saving and sustainable lifestyles. Using a straightforward illustration, effective and efficient water treatment plans enable the use of wastewater for multiple purposes in industries and agriculture, reducing excessive water waste and depletion. Blue-green infrastructure has numerous advantages and produces results that cut across the economic, social, and environmental sectors. This kind of infrastructure is especially regarded as a powerful source of climate mitigation measures, and it plays a significant role in environmental protection. Initiatives in this segment work to control regional ecosystems, lower urban temperatures, and reduce pollution. These in turn have a significant economic impact, for instance, terrace gardens encourage lower building surface temperatures, which reduces the need for cooling and, consequently, the demand for energy(Ghofrani, Sposito & Faggian, 2017).

Blue-green technologies emphasize:

- Rainwater harvesting and capture is becoming an increasingly important tool in areas with limited water resources.
- Allowing a sizable amount of yearly rainfall to enter and evaporate is crucial for maintaining natural catchment hydrology, replenishing groundwater, improving soil and ecosystem health, and lowering contributions to combined sewer discharges.
- By delaying and storing flows, it is possible to minimize the morphological and biological impact on urban watercourses and reduce the risk of flooding downstream in both natural and separated catchments.
- Urban pollutants carried by runoff are naturally filtered and cleaned before it reaches our natural environments.

BGI also has important social and economic benefits. For example, green spaces and other types of natural features can improve public health by providing opportunities for exercise and recreation, and by reducing the amount of air pollution in cities. They also have the potential to increase property values and generate new economic prospects, such as through the establishment of green roofs and various other forms of green infrastructure (Wescoat & Rawoot, 2021).

The term "blue-green infrastructure" reflects the fact that water management is a key part of BGI. By integrating natural structures with the built environment, cities can better manage water resources and reduce the risk of flooding and other water-related disasters. For example, wetlands and green roofs can help retain and absorb rainwater, while permeable pavement and bioswales landscaping techniques can help in filtering and managing stormwater runoff.

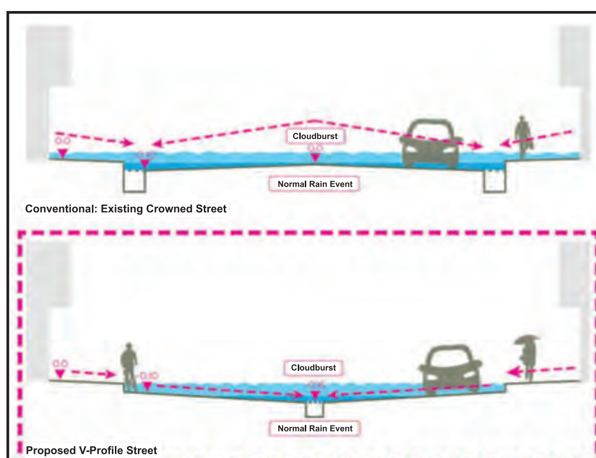
1.3 Elements of BGI

Various elements of blue-green infrastructure can help with issues caused by rapid urbanization. Some elements of successful Blue Green Infrastructure are mentioned below:

- **Cloudburst Roads**

  Cloudburst roads are used to direct and channel cloudburst water (figure 2). These roadways can be designed with a V-shaped profile and elevated curbs to direct water away from houses and toward the center of the road. Moreover, canals and swales can be built beside roads so that water

Figure 2: Section Showing Cloudburst Roads

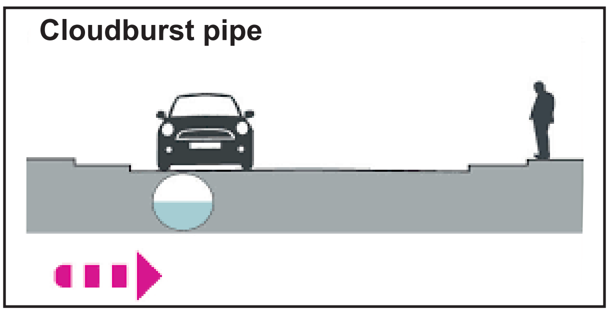


Source: (Ghofrani, Sposito & Faggian (2017:5) flows into urban rivers or green strips (Ghofrani, Sposito & Faggian, 2017).

- **Cloudburst Pipes**

  A cloudburst pipe, like a cloudburst road, collects rainwater (figure 3). This is installed slightly below street level to ensure connectivity with other surface systems. This technique is employed when there is little room for above-ground transportation(Ghofrani, Sposito & Faggian, 2017).

Figure 3: Section Showing Cloudburst Pipes



Source: (Ghofrani, Sposito & Faggian (2017:5)

- **Wet Plazas**

  Wet plazas or floodable public places are other elements that have excellent potential for high retention capacity in densely populated metropolitan areas. These places, which are often hardscaped with some potential plants, collect, hold, and retain rainfall to minimize floods. They can also include drainage connections to allow the plaza, courtyard, and other places to return to normal usage as soon as possible (Munir Shah, Suhane & Gajjar, 2021).

- **Retention Boulevards**

  Retention boulevards are similar to cloudburst roads in scale, but they include large, green, depressed medians that can detain and retain stormwater while allowing regular traffic to use the street. They necessitate the removal of roads, but they can be very effective along larger urban arteries that are underutilized (Munir Shah, Suhane & Gajjar, 2021).

- **Green Rooftops**

  Green rooftops, decorated with greenery, aid in soaking up rainwater to mitigate the urban heat island effect and improve air quality. To filter storm-water runoff and minimize its impact, shallow depressions in the ground called rain gardens are utilized (Munir Shah, Suhane & Gajjar, 2021).

- **Wetlands**

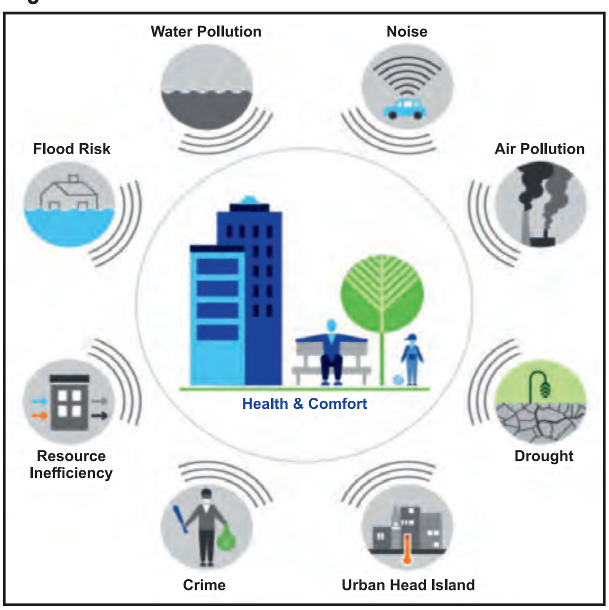
  Wetlands are permanent or seasonal areas of land saturated with water that have a wide range of plants and wildlife; they help store water during floods and improve water quality by removing pollutants. Urban environments face numerous challenges such as limited space and increased human activity which give rise to environmental issues like pollution, high temperatures, and dryness- all adding up these problems expose city dwellers to unfavourable living conditions which may consequently affect their health status significantly (Klein Rosenthal & Crauderueff Virginia Keesler, n.d.).

Implementing sustainable solutions such as groundwork designs focused on green infrastructure like tree canopies have become increasingly popular; they not only provide beautiful backgrounds but deliver services ranging from absorption and storage of runoff water among other roles vital towards healthy surroundings. Natural or man-made blue corridors are instrumental in enhancing water quality while providing a habitat for aquatic fauna. These narrow strips of greenery along the sides of bodies of water can significantly improve the diversity and abundance of native species, hence retaining ecological balance. Additionally, these riparian habitats provide several ecosystem services such as mitigating pollution levels, excessive flooding, and soil erosion. The number of BGI projects that have been completed or are currently being developed is limited, but this number will grow in the future. Despite its immense potential, several barriers are preventing the BGI concept from being widely adopted. While implementing BGI is expensive, the cost is soon repaid via reduced damage that occurs during any of the above-mentioned issues and is readily justified by the other advantages that occur (Afata, Derib & Nemo, 2022).

1.4 Need for BGI

Blue-Green Infrastructure is a multipurpose method in urban development that serves people, the environment, and the economy. Some of the key needs of BGI (figure 4) include (Perini & Sabbion, 2016):

Figure 4: Need For BGI



Source: Wescoat Jr. et al (2016:7)

- **Managing Stormwater**: BGI can be beneficial in minimizing the risk of floods and can help in managing stormwater runoff. Green rooftops, rain gardens, and bioswales are examples of BGI that absorb and filter stormwater.
- **Improving Water Quality**: BGI can improve water quality by filtering runoff water from the pollutants present in it and decreasing the amount of untreated water that enters streams and rivers.
- **Minimizing the Urban Heat-Island Effect:** BGI can mitigate the effects of increased temperatures in urban areas by incorporating green shades and decreasing the prevalence of heat-absorbing surfaces within urban environments.
- **Promoting Climate Adaptation and Resilience**: BGI also helps communities to adapt to climate change and increase resilience by lowering floods and improving water quality.
- **Supporting Human Health and Well-being**: BGI can have positive impacts on human health and well-being by reducing air pollution, providing opportunities for physical activities, and better mental health by providing green areas for relaxation and stress relief.
- **Enhanced Biodiversity**: BGI facilitates the habitat for wildlife and helps biodiversity in urban areas. Green roofs, street trees, and urban wetlands are examples of BGI that can provide habitat for plants and animals.
- **Providing Recreational Opportunities**: BGI can provide recreational opportunities and improve the aesthetic value of urban areas. Parks, greenways, and bike trails are examples of BGI that can provide recreational opportunities.

2. BGI AS A TOOL TO ACHIEVE "SUSTAINABLE DEVELOPMENT GOALS"

In pursuit of sustainable development, a set of 17 interconnected global goals was adopted by the United Nations in 2015 known as the Sustainable Development Goals (SDGs). These goals, which range from combating climate change to eliminating poverty and inequality, served as worldwide endeavours. BGI can act as an approach to sustainable urban development which involves the use of natural structures and processes to manage water and other environmental resources in cities. It involves implementing strategies such as the creation of green rooftops, rain gardens, and wetlands, which serve to absorb and filter stormwater, mitigate flooding and erosion, and offer habitats for wildlife. BGI is closely related to sustainability because it helps to promote a more resilient and liveable urban environment. By managing water and other resources more sustainably, BGI can reduce the environmental impact on urban development and facilitate the resident's quality of life.

Some of the key benefits of BGI include:

- Improved water quality: BGI features like wetlands and green roofs aid in purifying stormwater pollutants, thereby enhancing water quality in streams, rivers, and other aquatic ecosystems.
- Reduced floods: BGI helps to absorb and store rainfall water reducing the risk of flooding and erosion.
- Improved air quality: BGI elements like trees and green roofs play a role in absorbing air pollutants, thereby enhancing air quality in urban areas.
- Increased biodiversity: BGI has the potential to offer habitats for diverse plant and animal species, thus promoting biodiversity within urban environments.

Overall, BGI supports sustainability through efficient water management, climate change adaptation, biodiversity, preservation, resource efficiency promotion, social and economic benefits, community engagement, innovation, and resilience enhancement. BGI is an important tool for promoting sustainability in urban development by integrating natural systems and processes into the built environment (Sønderup & Roy, 2016).

2.1 The Impact of Blue-Green Infrastructure on Climate Change

Urban areas face growing vulnerability to climate change along with risks to environmental sustainability and human well-being. BGI emerges as a natural and semi-natural solution that can offer numerous environmental advantages, notably in mitigating the effects of climate change. BGI brings several advantages in addressing climate change, such as:

Reduced Urban Heat Island Effect: BGI mitigates the urban heat island phenomenon by offering shading and evaporative cooling, effectively lowering temperatures within urban areas. Consequently, this can decrease the demand for cooling energy, thereby contributing to the reduction of greenhouse gas emissions.

Carbon Sequestration: BGI helps in lessening the carbon dioxide from the atmosphere through photosynthesis. Trees, plants, and other vegetation absorb carbon dioxide during photosynthesis and store it as carbon in their tissues.

Flood and Erosion Control: BGI mitigates the effects of flooding and soil erosion by offering natural buffers that absorb and decelerate stormwater runoff. This serves to minimize the likelihood of property damage and safeguard infrastructure.

Biodiversity Protection: BGI provides habitat for a range of plant and animal species to promote biodiversity and ecosystem health. This can help to maintain the resilience of ecosystems.

BGI helps alleviate the urban heat island effect, cools the atmosphere, and offers shade, thereby diminishing heat-related health hazards for communities. Moreover, it provides cities with green areas, urban forests, and wetlands, which can function as natural buffer zones (Tubridy, 2021).

3. BGI'S RELATION TO URBAN DEVELOPMENT

The use of BGI has a significant impact on urban development in several ways. It helps in managing stormwater, reducing flooding, and improving the quality of water. By using natural systems to capture, store, and filter rainwater, BGI reduces the need for expensive and energy-intensive infrastructure, such as pipes and pumps. It also creates green spaces that provide habitats to wildlife including birds, insects, and small mammals. This improves the overall ecological health of cities and enhances the aesthetic appeal of urban landscapes. By mitigating the impacts of climate change, such as extreme weather events and increasing temperatures, BGI also aids in the development of more resilient cities. By enhancing the natural systems that regulate the urban environment, BGI mitigates the effect of climate change and improves the overall health and well-being of urban populations. Also, it provides a range of health benefits to urban populations. Green areas and parks, for instance, have demonstrated the ability to alleviate stress, enhance mental well-being, and encourage physical activity (Doost Mohammadian & Rezaie, 2020). BGI also reduces air pollution improves the air quality and reduces the risk of heat-related illness. Overall, the use of blue-green infrastructure has the potential to transform urban development by creating more sustainable, resilient, and liveable cities.

3.1 BGI and its Impact on Liveability

The implementation of BGI in cities, towns, and metro areas can have a significant impact on liveability by improving environmental quality, social well-being, and economic vitality. The primary benefit of BGI is the ability to manage storm-water runoff, which can reduce flooding and water pollution, and enhance the quality of urban water bodies. This can lead to improved public health outcomes, reduced infrastructure costs associated with traditional grey infrastructure, and increased recreational opportunities. BGI can also improve social well-being by enhancing green spaces and increasing access to nature, which can promote physical activity, mental health, and social cohesion (Wescoat & Rawoot, 2021). BGI projects often involve community engagement and participation, which can lead to increased social capital and stronger social networks. BGI can also benefit economically by enhancing property values, creating new job opportunities, and attracting new businesses and tourism. BGI projects can also provide opportunities for education, research, and innovation in fields such as environmental science, engineering, and design.

4. BGI IN INDIA

The 4th Five Year Plan (1964–1969), which outlined India's environmental policy and explained environmental protection as a crucial ideology of an active existence and noted how environmental issues affected nations worldwide and was the first to highlight the importance of environmental protection in the country which led to the development of green infrastructure. However, throughout time, various concerns have gained attention, including the preservation of wetlands, mangroves, and natural resources, as well as the management of air and water pollution (Venkatesham, 2015).

India has taken a few initiatives that, contribute to the success of the BGI. The inception of the National Action Plan on Climate Change (NAPCC) in 2008, prompted by the UN Framework Convention on Climate Change (UNFCC) and the UN "Green Economy Initiative," was one such endeavour. Alongside outlining the macroeconomic, environmental, and poverty-alleviating implications of green investments across different sectors, the initiative proposed strategies to enhance investment in areas such as sustainable agriculture and renewable energy. The NAPCC encompasses 12 sub-missions, each playing a role, directly or indirectly, in advancing BGI. Among these are:

- National Mission of Green India
- National Mission of Solar
- National Mission of Water
- National Mission of Sustainable Agriculture
- National Mission of Sustainable Habitat
- National Mission of Enhanced Energy Efficiency
- National Mission of Himalayan Ecosystem
- National Mission of Strategic Knowledge on Climate Change
- National Mission of Wind
- Mission of Health (to address how human health is impacted by climate change)
- National Coastal Mission; and the Waste-to-Energy Mission

These cross-departmental initiatives aim to address sustainable habitat, water management, agriculture, and forestry.

In addition to the NAPCC, India has two national programs aimed at enhancing urban living while incorporating blue and green components: the Smart Cities Mission and the Atal Mission for Rejuvenation and Urban Transformation (AMRUT). The Smart Cities Mission plays a crucial role in fostering sustainable urban development by prioritizing sanitation, water provision, conservation of open spaces, and enhancing the quality of life for citizens, while AMRUT focuses on improving water supply, sanitation, and green spaces. For example, the Udaipur Smart City initiative includes actions for the revitalization of lakes, such as decreasing sewage discharge, removing weeds from lakes, and prohibiting idol immersion. Primarily, the program's focus is to clean up the water and create more liveable waterfronts and places because the city's economy is strongly reliant on tourism, which accounts for a sizable amount of its lake-based revenue. Likewise, the Nashik Smart City initiative aims to clean the Godavari River and establish parks, gardens, and green areas in adjacent regions, alongside water cleaning efforts. The achievements of both cities, along with those of other smart cities, will guide the incorporation and designing of BGI (Munir Shah, Suhane & Gajjar, 2021).

Despite being an innovative idea, Indian cities like Delhi, Bhopal, Madurai, and Bangalore are integrating blue-green elements into their initiatives to improve existing natural water systems within the city and its surrounding public areas through planning.

However, these cities are already densely constructed and have a few concerns, including mixed land use, duplication of power among numerous authorities, asymmetrical growth patterns, technological obstacles, and a lack of socio-political will. Because of the limited space available for blue-green installations in these densely populated locations, urban blue-green infrastructure development must be very efficient and adaptable.

5. CASE STUDY REVIEW

To gain a better understanding of the BGI in major cities across the globe, two international and two national case examples were reviewed and compared based on certain similarities. The cities for the case study review are Copenhagen and Mumbai, New York City, and Delhi. These cities face diverse environmental challenges that require different solutions. Copenhagen and Mumbai are coastal cities that face issues of flooding and sea-level rise, while New York City and Delhi come under the same climate zone i.e., the humid subtropical climate zone, and are facing the consequences of urbanization and climate change.

5.1 Blue-Green Infrastructure in Copenhagen and Mumbai

Copenhagen, a northern European city, has a well-established BGI network to offset the consequences of climate change, including parks, green roofs, and water-sensitive urban architecture. Mumbai, a densely populated and flood-prone city, has invested heavily in BGI to enhance water management and mitigate flood hazards. To mitigate the impacts of these challenges, both cities have implemented BGI strategies.

In Copenhagen, the city has a strong tradition of green infrastructure, and its BGI strategy is based on a comprehensive approach that combines hard infrastructure (e.g., dams and dikes) with soft measures (e.g., green roofs, permeable pavements, and rain gardens). The city has also created new wetlands and restored existing ones to improve water quality, biodiversity, and recreational opportunities. The city's efforts have been successful, as it has reduced the risk of flooding and improved the quality of life for its citizens. The plan involves establishing parks and green spaces that can also serve the purpose of temporary flood retention zones during severe weather occurrences. Another example is the green roof of the Bella Sky Hotel, recognized as one of the largest in Northern Europe. The green roof helps to regulate temperature, absorb rainwater, and provide a habitat for birds and insects. The example projects in Copenhagen prioritize flood management over the utilization of stormwater. Landscape features such as rain gardens, swales, and vegetated or paved recreational areas acting as detention basins form integral parts of these relatively recent Storm Water Management (SWM) systems (Ghofrani, Sposito & Faggian, 2017). These features are often combined with engineering elements like water storage tanks and soakaways primarily for flood control purposes, with minimal attention to stormwater utilization. Due to significant concerns regarding water quality for recreational activities involving human contact, the initial proposal of reusing runoff from rooftops and highways collected in an underground basin to supply the square fountain was abandoned in the Lindevang Park concept. Instead, the collected water is gradually discharged into the sewer system. While Taasinge Square and Lindevang Park incorporate both retention and detention measures, enhancing water balance and flood control, their impact on flood control is limited due to the relatively small scale of the connected Environmental Impact Assessments (EIAs) and their positioning upstream within the catchments. Sct. Annie Square primarily focuses on flood prevention, with minimal enhancements to water balance, achieved through retention measures and some consideration for utilizing runoff for plant irrigation (O'Donnell et al., 2021). The landscape features in Copenhagen's case studies were holistically planned for both SWM and to deliver various advantages. Water features were used in Taasinge Square and Lindevang Park projects for beauty, amusement, and environmental education during modest rain occurrences. Initial designs proposing visible water features in playgrounds and pedestrian areas at Sct. Annie Plaza was abandoned to preserve the site's historical architectural integrity. The instances observed in Copenhagen ensure that stormwater runoff discharged into the environment meets acceptable quality standards, primarily by allowing runoff from rooftops, non-motorized traffic, and non-paved surfaces to undergo treatment before infiltration and discharge into public water bodies. Bio-filtration using filter soil is a common treatment method. UV treatment is occasionally utilized, particularly when rainwater is reused for recreational reasons. Storm-water quality is not being checked systematically. To some degree, biodiversity and ecological functionality were considered by carefully introducing native plants, as well as water- and drought-tolerant species, along with fruit trees and shrubs. Because research, technological innovation, and technical performance monitoring were not carried out, there is minimal technical performance documentation, even if the primary pieces and the entire project have been seen to operate in general. Factors such as areas not connected to sewers, the permeability of vegetated or porous surfaces, residents' and businesses' utilization and appreciation of urban spaces, and construction costs relative to conventional technical solutions are all considered in evaluating performance. The Copenhagen example projects serve as illustrations of integrated solutions that merge Storm Water Management (SWM) with the delivery of various benefits in urban environments (O'Donnell et al., 2021). They continue to be extensively employed for global communication and municipal branding, playing a significant role in Copenhagen's esteemed reputation for employing BGI methods for cloudburst management, even though the city's Cloudburst Management Plan (2012) primarily focuses on detention (Sønderup & Roy, 2016). The absence of research and documentation in Copenhagen's case studies poses challenges in disseminating solutions, approaches, and lessons learned to municipal administrators and practitioners for scaling up.

In Mumbai, BGI is becoming increasingly important due to the city's rapid urbanization and the associated challenges of flooding, pollution, and the urban heat island effect. The BGI strategy in Mumbai has been more focused on traditional hard engineering solutions, such as seawalls and stormwater drain. However, the city has also recognized the importance of BGI in addressing environmental challenges (Wescoat & Rawoot, 2021). One example is the city's efforts to revive the Mithi River, which had become a dumping ground for industrial waste and sewage. The city has also created new wetlands and green spaces to improve water quality and biodiversity. While Mumbai's BGI efforts are still in their early stages, they show promise in addressing the city's environmental challenges. Another notable project is the Mumbai Coastal Road, which aims to create a more resilient shoreline by combining road infrastructure with a series of parks, promenades, and waterfront amenities. The project also includes the construction of several seawater desalination plants to provide a sustainable source of fresh water for the city. Additionally, the Brihanmumbai Municipal Corporation (BMC) has implemented several BGI measures in its Open Spaces policy, which mandates that all new development projects in the city must include a minimum of 15 percent open space, with a focus on creating parks and green spaces(Stadler, 2021).

5.2 Blue-Green Infrastructure in New York City and Delhi

New York City ranks among the most densely populated cities globally and faces unique environmental challenges due to its urbanization. New York City, with a rising population of 30,000 by the end of the 18th century, required a supply of fresh water (Klein Rosenthal & Crauderueff Virginia Keesler, n.d.). The city lacked a sewage infrastructure, and the majority of its wells were filthy. Cholera, typhoid, and yellow fever outbreaks were prevalent. Firefighting water supplies were insufficient, and flames burned unabated, damaging entire city blocks (Klein Rosenthal & Crauderueff Virginia Keesler, n.d.). The city has implemented a range of BGI strategies to address these challenges, such as green roofs, bioswales, and rain gardens. The Croton Reservoir, a backup source of water supply, was built into the park's design and was actively used until 1993 (Perini & Sabbion, 2016). The reservoir's southern parts were drained and turned into the Great Lawn, one of the city's most popular public places; the Great Lawn is regularly utilized for plays and concerts. The northern reservoir is likewise a public asset, with a popular jogging path and stunning vistas surrounding its perimeter (Perini & Sabbion, 2016). In the mid-nineteenth century, the creation of Central Park around the Croton Reservoir revealed an early usage of blue-green infrastructure. However, while

Central Park benefited many with public health advantages, it also displaced a strong and dynamic African American neighbourhood with an abnormally high incidence of homeownership in an area of generally low property value - an early example of 'blight removal' or urban renewal. BGI's early growth in New York City was not motivated by equity considerations. The city has also established parks and green areas to enhance air quality, mitigate the heat island effect, and provide more recreational opportunities. One of the city's most significant BGI projects is the $1.5 billion Green Infrastructure Plan, which aims to capture and manage storm-water runoff through green infrastructure. The plan includes the installation of 2,000 bioswales and the planting of 10,000 additional trees (Perini & Sabbion, 2016). The plan has effectively minimized the likelihood of flooding and enhanced water quality in the city's waterbodies. Other BGI projects in New York City include the Living Shoreline at Sunset Cove in Brooklyn, which uses oyster reefs and other natural features to protect the shoreline from erosion and storm surges, and the High Line Park, a converted elevated rail line on the west side of Manhattan that includes a variety of green spaces and storm-water management features.

Delhi, one of the fastest-growing cities globally, grapples with considerable environmental hurdles stemming from rapid urbanization and climate change. In its 2041 master plan, Delhi emerges as one of India's pioneering cities to emphasize a blue-green policy approach. While the details of the policy are still under development through public consultations, the primary objective is to ensure that water bodies and green spaces are planned in synchronously and interconnectedly (Stadler, 2021). With the expiration of the Delhi master plan 2021, the Delhi Development Authority (DDA) is obligated to inform the public once the new plan is finalized. The city's BGI policy is geared towards enhancing air quality, mitigating the impacts of heat islands, and effectively managing water resources. To this end, the city has implemented various BGI initiatives, such as green roofs, rainwater harvesting systems, and the expansion of parks and green spaces. The Yamuna Revitalization Project is one of the city's major BGI initiatives, to improve the Yamuna River's water quality and ecological health. The project calls for the development of new wetlands, the rehabilitation of existing ones, and the building of sewage treatment plants. While the initiative is still in its early phases, it shows potential for resolving the city's environmental issues. The DDA has taken a pragmatic approach, devising a multifaceted method to guarantee that the policy is included in the design. Presently, efforts are underway to create a comprehensive 60-layer computerized map of the city, encompassing various entities responsible for managing diverse water and land bodies. Subsequently, the focus will shift towards cleaning the 50 major drains (nullahs) currently overseen by different agencies. This cleanup operation will involve treating pollutants and prohibiting both treated and untreated waste dumping into water sources. Given that Delhi produces approximately 3,800 million litres of sewage daily, these measures are imperative for safeguarding water quality and environmental health (Anon, n.d.). Given that half of this sewage directly enters water bodies without undergoing treatment, the cleaning of drains becomes imperative. After the cleaning process, the areas surrounding the drains will be designated as buffer zones and green corridors. Additionally, walking and cycling pathways will be integrated into gardens within these zones. Furthermore, low-impact infrastructure will be developed, comprising exercise areas, yoga gardens, open-air theatres, museums, boating facilities, eco-friendly residences, and community food gardens. A slew of government organizations has resulted in the city's rules and decisions being inadequately implemented. The Delhi Development Authority (DDA) is partnering with multiple entities to establish a standardized rulebook for the integrated development of BGI in Delhi. Moreover, ensuring efficient coordination and collaboration among the city's various municipal bodies, the DDA, the state government, and development agencies will be crucial for the successful implementation of the blue-green strategy and the overall master plan (Munir Shah, Suhane & Gajjar, 2021).

6. FINDINGS/RESULTS

6.1 Copenhagen & Mumbai Case

Copenhagen is known for its sustainable urban planning and design. The city has an extensive network of parks, green spaces, and waterways, which provide many environmental and social benefits. The city's BGI includes green roofs, rain gardens, green walls, and urban wetlands. These components aid in stormwater management, air quality improvement, reduction of the urban heat island effect, and enhancement of biodiversity (Liao, Deng & Tan, 2017). Conversely, as per the World Population Review, Mumbai is identified as one of the rapidly expanding cities globally, boasting a population exceeding 20 million individuals as of 2022. The city's BGI includes mangroves, wetlands, and natural lakes, which provide many environmental benefits, such as flood control, carbon sequestration, and biodiversity conservation. However, the city's BGI is under threat from rapid urbanization, pollution, and climate change.

Mumbai's approach to blue-green infrastructure focuses on flood management and mitigation, whereas Copenhagen's approach focuses on improving water quality, biodiversity, and recreational opportunities. However, Mumbai encounters notable hurdles in implementing BGI attributed to inadequate funding, coordination issues, and a lack of political determination. In contrast, Copenhagen has a more favourable environment for blue-green infrastructure due to strong political support and public engagement (Sønderup & Roy, 2016).

As a highly populated city with water management concerns, Mumbai may benefit from Copenhagen's well-established BGI network to encourage sustainable urban development. Following are some BGI practices that Mumbai may learn from Copenhagen:

- **Rain Gardens**: A rain garden is a landscaping feature designed to capture and absorb storm runoff, reduce flood risk, filter pollutants, create wildlife habitats, and promote biodiversity. This type of green infrastructure also has potential benefits in terms of improved air quality. In Copenhagen, these gardens are typically constructed on public property or along waterways and they use plants that will thrive in wet conditions (Sønderup & Roy, 2016)
- **Green Roofs**: Like rain gardens, green roofs are an effective way for cities to manage storm-water run-off by providing additional surface area for precipitation infiltration into soils beneath the roof or drainage system below it (Doost Mohammadian & Rezaie, 2020). Furthermore, this form of green infrastructure not only helps control flooding but provides cooling effects during summer due to increased insulation values and reduced urban heat island effect caused by dark asphalt surfaces commonly found on traditional rooftops. In Copenhagen, there exist several large-scale research centers dedicated solely to advancing our understanding of how such technologies work best given specific regional climate types as well as the materials used in their construction (Doost Mohammadian & Rezaie, 2020).
- **Street Bioswales**: Another way cities like Copenhagen have successfully managed

rainfall is through the installation of bioswales alongside streetscapes which allow excess water to enter sewer systems during times when heavy rains occur thus reducing any potential impacts downstream from flooding events which may otherwise happen (O'Donnell et al., 2021). Additionally, these bioswales act similarly to natural wetlands ecosystems creating habitat for soil organisms, and native vegetation species whilst doing their job filtering out pollutants thereby creating aesthetically pleasing streetscapes. Since many Indian cities already possess wide street networks installing such features could help provide much-needed relief against monsoon season floods at lower costs than constructing massive underground tunnels or even rerouting entire rivers - both solutions having proved expensive elsewhere under stringent timelines (Ghofrani, Sposito & Faggian, 2017).

6.2 New York City & Delhi Case

New York City has an extensive BGI network, which includes parks, greenways, and waterfront parks. The city's BGI also includes green roofs, green walls, and rain gardens, which help to manage stormwater, improve air quality, and reduce the urban heat island effect. The BGI has been successful in improving the liveability and resilience of the city, especially after Hurricane Sandy in 2012. Delhi ranks among the most polluted cities globally, characterized by poor air quality and insufficient availability of green spaces. The city's BGI includes parks, green spaces, and wetlands, but these elements are under threat from rapid urbanization, encroachment, and pollution. The city's BGI needs to be improved to address the environmental and social challenges facing the city (Munk & Cohn, 2017).

New York City and Delhi face similar environmental challenges that can be addressed through BGI. Both cities have implemented BGI interventions such as green roofs and rain gardens. However, New York City has focused more on the social benefits of BGI, while Delhi has focused more on the environmental benefits. Both cities face challenges in the implementation of BGI, such as limited funding and maintenance. However, Delhi also faces challenges related to political will and bureaucracy.

New York City has made great strides in promoting the development of green infrastructure practices both within its city limits and beyond. The following are a few of the practices that Delhi can benefit from:

- **Storm-water Capture and Management** – Under Mayor Michael Bloomberg's leadership, New York City invested $2 billion to better manage storm-water runoff through green roofs, rain gardens, permeable pavement, bioswales (narrow channels designed to capture and filter water) along street medians as well as retrofitting traditional drainage systems with "green infrastructure components like oversize catch basins or underground storage tanks to hold excess runoff during wet weather" (Perini & Sabbion, 2016). This investment has led to improved air quality across the city by reducing energy expenditure on pumping wastewater into bodies of water located outside NYC; reduced flooding risks from heavy storms thanks largely in part to natural soil absorption; increased ecological diversity via expanded aquatic habitats for birds and butterflies - more healthy soils below ground serve not just plants above it but also microbes living beneath them; healthier communities overall because aging sewer pipes were prevented from overflowing too often leading citizens exposed hazardous chemicals when overflows occurred.

- **Increased Green Spaces**– New Yorkers currently have access to 1 million acres of parkland throughout five boroughs which is managed directly by the Parks Department. A large proportion of this acreage comes as a result off open spaces created by reusing former industrial sites such as Fresh Kills Park which was once an illegal landfill site since 1948 before transforming into one largest parks being developed currently adding 2200 additional acres while at same time improving local habitat conditions, increasing recreation opportunities reduce risk exposure nearby areas all flood protection efforts implemented there place far-reaching benefits entire region many other new recreational locations been established around NYC considering potential value they could bring addressing climate change taking account fact sea level rise projected occur future mayor Bill de Blasio continued commitment towards developing parks thus making more accessible public including various low income majority neighbourhoods remain cornerstone current administration whereas Bloomberg plan focused mainly providing physical amenities use these newly open spots leveraging latest trends green technologies also help increase resilience (Perini & Sabbion, 2016).

The case study review showed that the BGI of Copenhagen and New York City are well-established and have been successful in improving ecological sustainability, liveability, and resilience. Mumbai and Delhi have extensive BGI networks, but these elements are under threat from urbanization, pollution, and climate change. These cities need to invest in their BGI to address the environmental and social challenges facing them. Adopting such approaches, especially in megacities, can help India achieve the 2030 targets of sustainable development goals (SDGs) which makes it more important to explore the possibilities and invest in BGI.

7. CONCLUSION

Numerous urban planning regulations in India are outdated, characterized by a rigid approach to land use planning and development management. To accommodate the evolving nature of elements like BGI, Indian cities need to embrace dynamic urban planning that considers changes in their environments. The public sector should establish more robust and transparent digital platforms, including GIS mapping and live tracking, to enable real-time monitoring and evaluation of blue-green benefits. This is essential to align with contemporary urban planning trends, such as real-time environmental GIS mapping and the integration of artificial intelligence for fostering sustainable urban development. Installing BGI components in Indian cities has the potential to greatly enhance storm-water management, water quality, and urban green spaces. Rain gardens, permeable pavement, green roofs, constructed wetlands, and so on.

In conclusion, Developing Blue-Green Infrastructure (BGI) in megacities of India, such as Delhi and Mumbai, is a major challenge. Nevertheless, it can be addressed through the adoption of various strategies that emphasize multiple objectives including water resource protection/management approaches and overall urban design considerations which will result in adaptation to climate change impacts while simultaneously enhancing economic development opportunities. These strategies need to include involvement from all stakeholders—from governmental agencies at different levels down to civil society organizations—for long-term successful implementation within these cities with high population densities. In addition, proper planning should take place before the actual deployment of BGI measures; this includes a detailed assessment of feasibility based on existing infrastructure constraints or potential land use conflicts due to comprehensive outreach initiatives involving everyone involved must also accompany any attempt at developing blue-green infrastructures in Indian megacities like Delhi & Mumbai. Finally, adequate funding needs to be provided by governments if BGI projects are going to see success within these important Indian city centers along with continued research into new innovative best practices for their application locally and globally.

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Uncovering the Impacts of Land Use Change: A Case Study of Open/Green Areas Converted to Commercial Areas in Bathinda City, Punjab

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Abstract

Due to rapid urbanization in cities, the expansion of the urban environment is progressing at an exceptional pace in order to accommodate the needs of the growing population and to support economic growth. The expansion of various activities has put increased pressure on cities to build more spaces. This paper assessed the spatio-temporal variations in land use and their impact along one of the major commercial streets of Bathinda, Punjab, between 2002 and 2022. Land-use maps along the mall road were analyzed using satellite images, followed by quantification of land use change in the last two decades. The results showed that the commercial areas along the mall road have increased at the expense of shrinking green and open areas. These alterations in land use have increased impervious surface coverage, resulting in water logging issues, putting more pressure on the existing road capacity, and causing a loss of sense. This study intends to uncover the impacts of such land use changes on urban design and to further offer insights into ways of mitigating the adverse consequences of this trend.

1. INTRODUCTION

The relationship between urbanization and economic growth has been perplexing. (Chen, 2014) Urbanization leads to economic progress but is also associated with many serious issues. Rapid population growth in urban areas is one of the prominent reasons for urbanization. It is the primary driver of changes in land use and land cover patterns and the most prevalent form of irreversible land transformation (Jain, 2016). According to a United Nations report, the world's urban population surpassed its rural population in 2007 and became predominantly urban (United Nations, 2013). By 2050, through urbanization and the natural increase in urban population, another 2.5 billion people are expected to increase the global urban population (United Nations, 2014). Nearly 90 percent of this increase in population is expected to be concentrated in African and Asian countries (Jain, 2016). As per Census of India (2011), 31.2 percent of people live in urban areas, equivalent to 11 percent of the global urban population. Moreover, it has been estimated that by 2050, India's urban population will be around 52.8 percent. Such a rapid increase in urban population is impacting the growing cities of Punjab, Bathinda being one of them. It, with its population of 2,85,788 (Census of India, 2011), is the fifth largest city in Punjab state. Due to significant industrial advancements in the past two decades, the growth impulses emanating from them have resulted in expansion beyond the limits of Bathinda Municipal Corporation. (Master Plan, Bathinda 2009-2031).

In recent decades, Bathinda has experienced significant changes in its land use pattern. The primary factor in such a transformation is urbanization. Bathinda had an urban population of 2,17,256 in 2001, which increased to 2,85,788 in 2011 (Census of India, 2011). The projected population of Bathinda city for 2021 is 3,71,000. An increase in urban population increases the need for land to

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carry out various activities. Due to this, the open/green patches in the core of the city are converted to commercial activities to fulfill the growing economic needs of the area. It has an adverse effect on the land use pattern, transportation, and sewage system and leads to inadequate parking spaces, water logging due to an increase in impervious spaces, traffic congestion, etc.

2. GREEN OR OPEN SPACES

Green or open areas are important for human well-being and environment. They offer various advantages, such as better air quality, increased biodiversity, and the chance for recreation and relaxation (Revich, 2023; Perdigones, 2023). Green areas such as parks and trails are often used by local residents as a place to recreation, spend time with family and friends, and enjoy nature. Also, they play a notable role in decreasing the bad consequences of the rapid rate of urbanization. (Li L., 2017). As a result of urbanization, the loss of urban green spaces has been found in both developed and developing countries, and is based on the rate of urban growth, often impacted by socio-economic factors (Gairola, 2010).

Rapidly increasing populations, resulting in increased urban needs, have put huge pressure on green areas and transformed them into impervious landscapes. A lot of studies have documented this loss of urban green/open spaces due to urban growth (Odindi, 2012). This has led to a decline in the availability of green areas in numerous regions across the globe. The conversion of open/green areas to commercial spaces has become a common trend in urban areas, with significant impacts on urban design. The impact of land use change from open/green areas to commercial is a complex issue with wide-ranging implications for communities and the environment (Leite, 2023). While commercial development may bring economic benefits through job creation and tax revenue, it can also have negative impacts, such as increased traffic congestion and emissions, poor air quality, noise pollution, etc., which may have negative health effects on the local residents, particularly vulnerable populations such as children and the elderly. This study investigates the impacts of this trend on various urban design aspects, including social, economic, and environmental factors.

3. STUDY AREA

Bathinda city is situated in the northern Indian state of Punjab (figure 1). It is one of the oldest cities in Punjab, with a rich cultural and historical heritage. The city is located in the Malwa region, and is known for its agricultural productivity and industrial growth. Over the years, Bathinda has undergone substantial land use changes, driven by the growing demand for urban infrastructure, housing, and commercial development. This beautiful city of lakes is home to a large commercial hub.

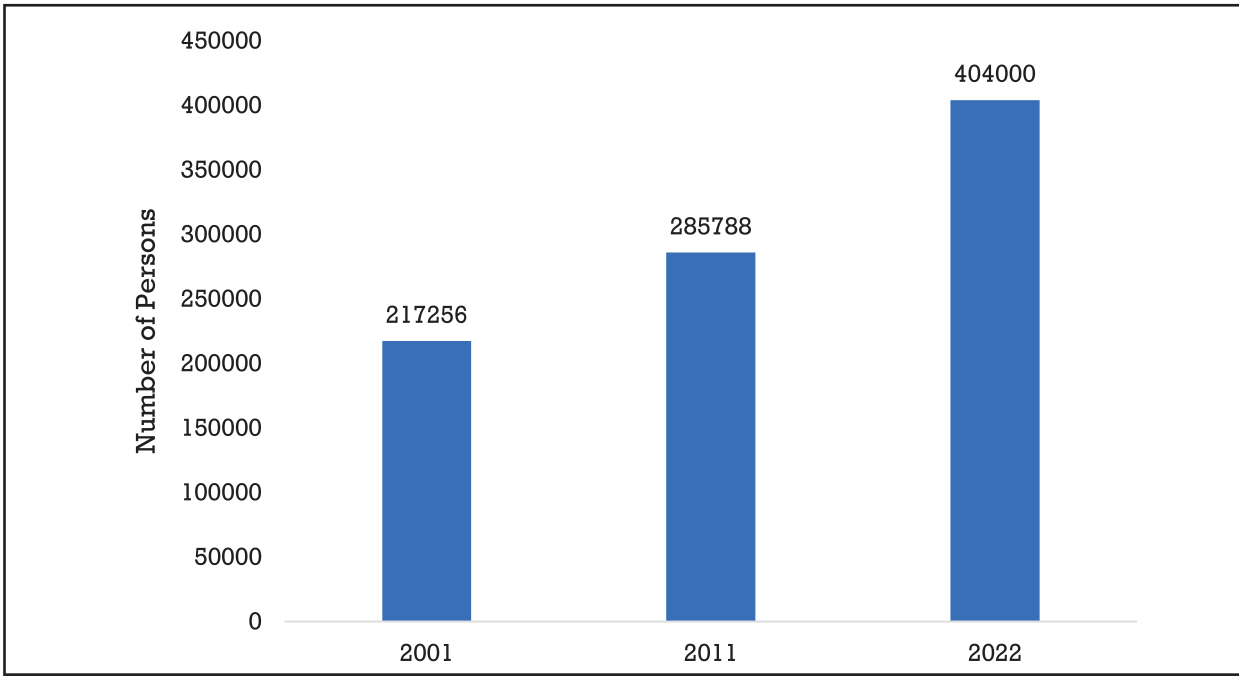
Figure 1: Location of Bathinda City in Punjab State

Source: Google Image

4. DEMOGRAPHIC PROFILE OF BATHINDA

The population of Bathinda city exhibited a steady upward trend from 2001 to 2022 (figure 2). The growth rate of the population in the year 2001, 2011, 2022 was 1.36 percent, 1.31 percent and 1.41 percent respectively (BTD Report, 2011).

Figure 2: Population Growth of Bathinda City (2001-2022)



Source: BTD Report 2011, Govt. of Punjab

5. RELATION BETWEEN POPULATION GROWTH AND EXPANSION OF BUILT-UP AREA

A significant correlation is found between population growth and the expansion of built-up areas, as indicated by the research conducted on urban sprawl in Bathinda city. (Guite, 2019; Bhat, 2017). The study suggests that the extent of built-up area is a dependent variable on population; therefore, with the rise in population, there is also an increase in built-up areas.

Spatial expansion is an unavoidable occurrence within the evolving demographic characteristics of Bathinda. The phenomenon of human settlement and spatial reorganization has been thoroughly recorded, consequently leading to land use changes. It is undisputed that the expansion of urban land is imperative to cater to the growing population and economic growth. The effects of these changes in land use on the development of Bathinda have been significant, leading to variations in the physical and social landscape of the city.

6. HISTORY OF MALL ROAD, BATHINDA

During the early 1900s, Mall Road, originally named Upper Bazaar Road, was developed. Bathinda, under British rule, served as a significant hub for trade and commerce. The construction of Upper Bazaar Road aimed to cater to the growing population's needs and establish a central marketplace within the city. A multitude of shops and markets adorned the road, transforming it into a favorite spot for the residents and tourists.

Over the years, Mall Road has experienced continual growth and transformation, with the emergence of new shops and businesses alongside the expansion of the existing ones.

Presently, it stands as one of the most bustling and popular areas in the city, offering a vibrant mix of retail, entertainment, and dining options. Additionally, it boasts a number of significant cultural and religious landmarks, including temples and gurudwaras, which contribute to its distinctive character and appeal. The road has played a crucial role in the growth and development of Bathinda, with its rich history serving as a source of inspiration and attracting people from various parts of the globe.

7. METHODOLOGY

The study of a 1-kilometer-long stretch of mall road starting from Hanuman Chowk till Gol Diggi has been conducted. The location coordinates of the selected stretch of mall road are from 21°12'44.19"N, 74°56'44.33"E to 30°12'46.77"N, 74°56'10.32"E. The location of Mall Road, Bathinda, is shown in Figure 3. The study uses a mixed-methods approach, including analysis of land use/land change (LULC) for the last two decades, site observations, and interviews. The percentage of various land uses within a radius of 500 m along the mall road has been studied for the years 2004, 2012, and 2022 by raster satellite images of Google Earth on AutoCAD software.

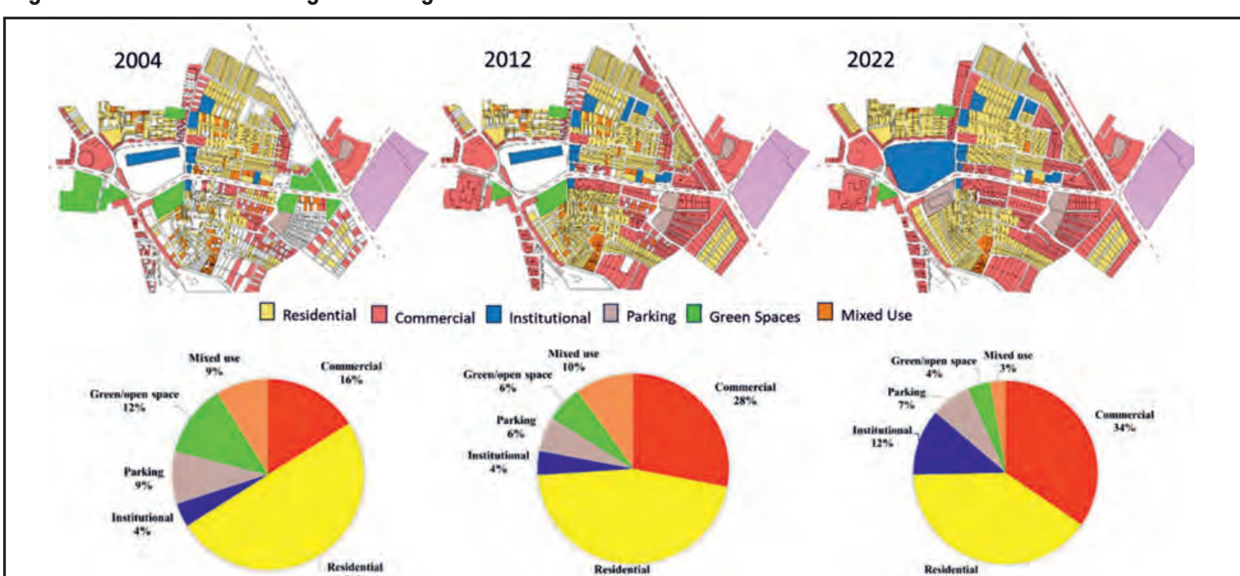
Figure 3: Location of Mall Road

Source: Google Earth Pro

8. DATA COLLECTION AND ANALYSIS

The land use/land change (LULC) plans were prepared with the help of satellite images from Google Earth for the below mentioned years. The percentages of various land uses were calculated and analyzed for a distance of 500 m on both sides of the mall road. Figures 4 shows the changes in the percentages of various land uses along the stretch.

Figure 4: Land use Changes during 2004-2022



The figure clearly shows that the commercial use has grown tremendously along the Mall Road. It has risen from 16 percent in 2004 to 34.6 percent in 2022. However, the decline in the percentage of green areas/open spaces from 12 percent to 4 percent is very prominent and noticeable. Residential land use has remained more or less the same. Mixed use increased during 2001-2011, but fell in 2022.

9. ISSUES

The results of this study reveal that land use change has significant impacts on the city landscape. The following issues have emerged due to the change of green/open areas into commercial areas:

- **Reduction of Open/Green Areas**

  Shrinking of green/open spaces (12 percent to 3.8 percent) along the mall road area resulted in the inaccessibility of the citizens to these recreational spaces. It also caused a loss of social interaction and a sense of space for the inhabitants of this city.

- **Issue of Water Logging**

  The reduction in the percentage of green/open spaces, from 12 percent in the year 2004 to 3.8 percent in the year 2022 respectively, has resulted in more impervious areas along mall road, which eventually caused the problem of water logging (figure 5) in monsoon season, creating inconvenience to the citizens of the city.

Figure 5: Water Logging on the Mall Road

Source: author

- **Traffic Congestion**

  It is clearly seen that the land use percentage of commercial areas along the mall road has increased more than twice (16 percent to 34.6 percent) in the last two decades. These changes have put immense pressure on mall road through increased traffic volume, exceeding road capacity, and a and a lack of parking space, which has resulted in traffic congestion on this major commercial road (figure 6).

Figure 6: Traffic Congestion on the Mall Road

- Encroachment

  The increase in land use percentage of commercial areas due to the high demand and also the reduction in the percentage of parking space (from 9 percent to 7.1 percent has resulted in the encroachment of road space by unauthorized parking and by street vendors, which caused inconvenience and difficulty, especially for the pedestrians on this road.

10. RESULTS AND DISCUSSION

The study underscores the necessity for efficient urban planning approaches to alleviate the adverse effects of land use alterations. The research concludes by scrutinizing the implications of the outcomes for urban planners and designers, providing insights into ways of developing more sustainable and effective urban planning approaches in the context of land use change.

In tackling these challenges, urban planners and policymakers need to prioritize sustainable development practices that achieve a balance between the economic aspects of commercial development and the social and environmental costs. This can include strategies such as green infrastructure, which seeks to integrate natural and built environments to maximize the benefits of open/green areas while accommodating commercial development.

The findings suggest that the conversion of open/green areas to commercial areas can have negative impacts on urban planning, including loss of biodiversity, increased traffic congestion, and reduced access to public spaces. However, the study also identifies opportunities to mitigate these negative impacts, such as incorporating green spaces into commercial developments and promoting mixed-use development. The research concludes with recommendations for urban planners and designers to develop more sustainable and effective urban development strategies that can balance the needs of commercial development with the preservation of open/green spaces and public amenities.

11. CONCLUSIONS AND RECOMMENDATIONS

In conclusion, the repercussions of transforming open or green spaces into commercial areas constitute an intricate matter, demanding a thoughtful examination of the social, environmental, and economic consequences. While commercial development may bring economic benefits, it may also result in notable adverse effects on the natural environment, public health, and the well-being of local residents. Careful planning and management of land use can help to mitigate these impacts and ensure that development is sustainable and benefits all members of the community.

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