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The Spatio-Temporal Dynamics of Green Spaces and their impact on the Urban Environment of Bhopal Region, Madhya Pradesh, India

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Abstract: Green spaces are an integral part of urban landscape and offer numerous benefits related to quality of urban life. As the world's population continues to urbanize, population density increases and people endure the ever-increasing speed of the urban environment. Urban green space plays an essential role in the urban ecosystem and highly contributes to the welfare of urban residents. Understanding the dynamics of green space is crucial for its planning and management. The role of urban green space (UGS) in urban sustainability is attracting increasing attention from researchers. However, due to various factors, the distribution of green spaces among city neighbourhoods is often skewed. Urban growth is occurring at an unprecedented rate worldwide with 65% of the population expected to reside in urban areas by 2025. The extensive study of literature reveals that most of the environmental impacts of urbanization are associated with green space. Having realized the importance of green space in urban ecosystems, considerable work has been devoted to improving the urban environment and enhancing citizens' quality of life through urban green space planning. Hence, urban planners require effective tools to routinely map and monitor the greening/ un-greening phenomena among the neighbourhoods. This research study caters to the need by adopting a geospatial green space distribution assessment approach that encompasses green space quantity, quality, and accessibility aspects.

Keeping the aforesaid knowledge in mind, Bhopal City has been chosen for further detailed investigation. In this study, we investigate the spatio-temporal variation of UGS and its relationship with urban growth based on an empirical analysis in the Bhopal study region during rapid urban development decadal phases between 2001–2021.The remote sensing data reveals that changing UGS pattern declined notably in the first decade and has increased slightly since 2001, with the green areas mainly clustered in the urban centres. In this study, FRAGSTATS software has been employed to quantify spatial patterns in land cover through landscape metrics and their changes over time in the study region. This study attempt has been made to quantify the cooling effect of green spaces and its spatial variation, using Landsat 9 USGS Earth explorer by employing ArcGIS. It reveals that urban green spaces have a significant impact in reducing land surface temperatures (LST), contributing to a more pronounced cooling effect in the surrounding neighbourhoods. In this research, an attempt has been made to explore the causal relationship between green spaces and land values, by employing multiple regression analysis. The findings shed light on the significant impact of park size and location in relation to other parks on the average temperature of the neighbourhood. Furthermore, it indicates that development of parks can contribute to better land prices in the surrounding areas, potentially leading to increased revenue for urban local bodies. This is clearly evident that the economic benefits associated with the strategic allocation and preservation of green spaces within the urban environment. Based on the findings, the study evolve a comprehensive operational framework and suggested guidelines for determining the optimal size and spacing of parks within neighbourhoods to enhance the potential of urban green spaces navigating towards sustainable urban growth

Keywords: Urban Green Space; LST; Cooling Effect; Compactness Index; Urban Growth; Sustainable Development.

Introduction

The rapid pace of global urbanization is dramatically reshaping our world, with projections indicating that 70% of the global population will reside in urban areas by 2050. This unprecedented urban growth brings to the forefront the critical need for sustainable urban development, as outlined in the United Nations' Sustainable Development Goal 11. At the heart of this sustainability challenge lies the complex interplay between urban densification and the preservation of green spaces, often referred to as the "compact city paradox." Urban green spaces (UGS), particularly public parks, play a vital role in mitigating the negative impacts of urbanization by offering a multitude of environmental, economic, and social benefits. These include pollution control, biodiversity conservation, energy savings, property value enhancement, and improvements in public health and well-being. However, the spatio-temporal dynamics of these green spaces within the evolving urban fabric present both challenges and opportunities for city planners and policymakers.

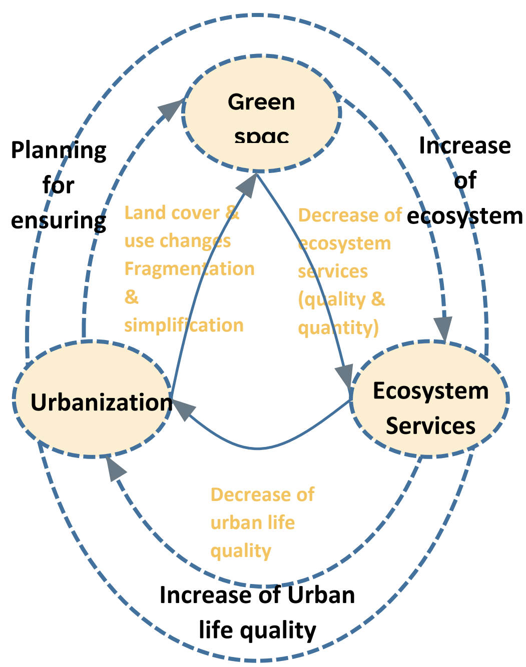


Figure 1 Urbanization and its casual relationship with Urban Green Spaces.
Source: Generated by the Authors, 2024

This research paper aims to explore the intricate relationship between the spatial and temporal changes in urban green spaces and their multifaceted impacts on the urban environment, providing insights crucial for creating resilient, sustainable, and livable cities of the future.

This research addresses significant gaps in understanding the complex interactions between UGS and urban development in Bhopal's unique historical, cultural, and environmental context. Despite growing recognition of UGS importance, there is limited empirical evidence on how these spaces interact with urban growth dynamics and contribute to sustainable development in Bhopal.

Green Space and Urban Growth Dynamics

Urban green space (UGS) is although play a vital role in the mitigation of negative impacts of urbanization, but it often abominably affected by the process of land-use land-cover (LULC) changes in an urban area. Thus, the present study aims to examine the loss in urban green space (UGS) in relation to LULC change by using a multi-temporal land-use transition scenario and to predict the loss of UGS in the future in the city Bhopal. Urban green spaces are fundamental components of biodiversity that play a crucial role in balancing the environment within urban ecosystems. However, rapid urbanization, particularly in developing nations, has led to a decline in urban green areas, compromising environmental services for local populations. These verdant havens, including parks, trees, and green belts, serve multiple functions beyond mere aesthetics. They act as environmental guardians, regulating land surface temperature, mitigating the urban heat island effect, and providing recreational spaces that enhance residents' quality of life. The dynamics of urban growth, driven by factors such as population increase, economic development, and land use policies, often conflict with the preservation and expansion of green spaces. This tension creates a complex interplay between urban development and green infrastructure, shaping the spatial form, ecological integrity, and socio-economic dynamics of cities. Understanding this relationship is crucial for urban planners and policymakers in developing sustainable strategies that balance the needs of urban growth with the preservation and enhancement of green spaces, ultimately contributing to the creation of more livable, resilient, and environmentally conscious urban environments.

Study Area Profile

Bhopal, the capital city of the central Indian state of Madhya Pradesh, stands as a testament to a historical legacy, cultural vibrancy, and a unique blend of tradition and modernity. Bhopal's green spaces play a crucial role in the city's ecosystem and quality of life. Situated between the Malwa Plateau in the north and the Vindhyachal ranges in the south, Bhopal's topography is characterized by hillocks and lakes, creating a unique setting for its green spaces. As of 2021, the city's green cover assessment revealed a diverse landscape with 975 sq km of agricultural land, 294 sq km of other green spaces, 36 sq km of fallow land, 35 sq km of evergreen forest, and 20 sq km of wasteland.

Figure 2 Geographical location of Bhopal Study Region.
Source: Compiled by the Authors, 2024

The evergreen forests are primarily located in the southern part of the city, while other forests are concentrated in the west and south. Agricultural lands are predominantly found along the periphery of the Bhopal Municipal Corporation boundary, spreading radially throughout the area. Patches of wasteland are visible mainly towards the north, east, and south, with current fallow land located in the southwest. A notable feature is the presence of a National Park near the Upper Lake, situated in the city center.However, the city has experienced a dramatic decline in green cover over the decades, dropping from 92% in 1977 to 18% in 2014, with projections indicating a further reduction to 4% by 2030 without intervention. This decline is particularly concerning given Bhopal's geographical context and its reputation as the 'City of Lakes'.The city maintains 116 parks of varying sizes, categorized as Housing Area Parks, Neighborhood Parks, Community Parks, District Parks, and Sub-city Parks. These green spaces provide essential ecosystem services, including cultural and regulating services, recreation, and microclimate regulation. Despite these efforts, the per capita green space in Bhopal is 7-8 m², falling short of the URDPFI guidelines recommendation of 10-12 m² for cities in geographically plain areas.

Bhopal's parks are unevenly distributed, with more concentrated near the city center and fewer towards the periphery. The city's administration is proposing more parks in the southeast to accommodate urban expansion, aligning with the city's growth pattern. The challenge for Bhopal lies in balancing urban development with the preservation and enhancement of its green spaces to ensure a sustainable and livable urban environment, particularly in the context of its unique geographical setting between plateaus and ranges.

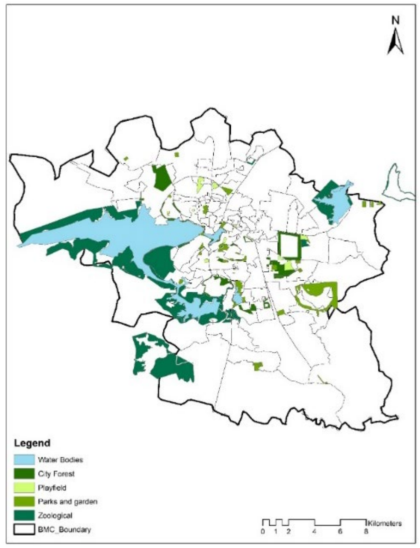


Figure 3 Urban Green Space Map of Bhopal Region
Source: Compiled by the Authors, 2024

Urban Growth Dynamics And Green Space Development Planning.

Identifying urban environmental issues requires various data sets. To pinpoint heat island hotspots, researchers use satellite imagery to analyse land use, vegetation density, land surface temperature, and water presence. They also consider air temperature, humidity, and wind data. For air pollution hotspots, data on specific pollutants like PM2.5 and SO2 is crucial. Social vulnerability assessments involve socioeconomic data, healthcare facility access, and green space availability. This data helps target interventions for a healthier city.

Table 1 Urban Growth and Green Space Spatial Dynamics.

Dynamics of Urban Growth and Green Spaces		
INDICATORS	**DATA REQUIREMENT**	**UNIT OF MEASUREMENT**
Patch size	Land cover map	Area: hectares (ha)
Patch shape		Dimensionless
Edge density		meters per square meter (m/m²)
Fragmentation	Boundaries	meters (m)
Diversity		Dimensionless
Urban Growth	Land use Map	square kilo meters (km²)
	Green cover	NDVI
	Roads	kilometres (km)
	Building Height	No of Floors
	Building Footprint	hectares (ha)
	Population	(people/m² or people/ha)
Cooling Effect of Urban Green Space Spatial Patterns		
Thermal load	Spectral radiance	Degree Celsius
	Brightness temperature	
	NDVI	
	Emissivity	
Impact of UGS on the Property Values		
Economic Benefits Assessment	Land Value	Price per unit area
	Infrastructure	Distance in m

Source: Generated by the Authors, 2024

Land use Land Cover Scenario of Bhopal Region.

As of 2021, Bhopal city covers an area of 812.05 sq km. The land use distribution is as follows: agriculture (49%, 395.51 sq km), built-up areas (19%, 151.33 sq km), other green spaces (17%, 140.45 sq km), water bodies (6%, 46.23 sq km), current fallow (4%, 32.05 sq km), forests (3%, 26.75 sq km), and wasteland (2%, 19.73 sq km). The city is home to six major lakes, with Upper Lake being the largest at 3,100 ha.

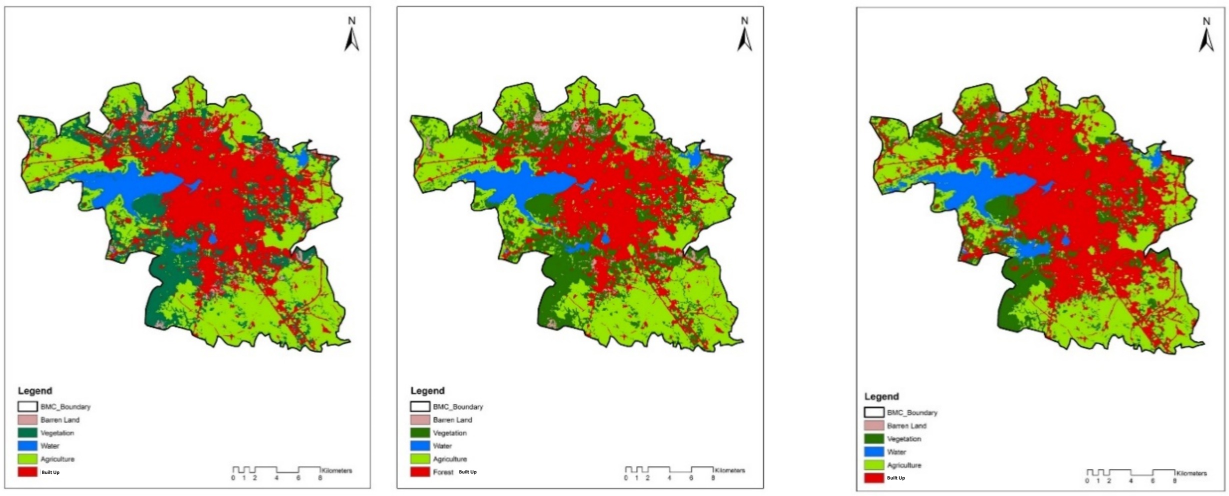


Figure 4 a) LULC 2001 **b)** LULC 2011**c)** LULC 2021

Source: Generated by the Authors, 2024

The spatial dynamics of Bhopal city over the past two decades reveal a striking contrast between urban expansion and environmental preservation. From 2001 to 2021, the city experienced a substantial increase in built-up areas, reflecting rapid urbanization and population growth. This urban expansion came at a significant cost to the city's green cover, as evidenced by the dramatic decrease in vegetation. The vegetation cover plummeted from 37.25% in 2001 to a mere 18.77% in 2021, representing a substantial 18.48% decline. This inverse relationship between built-up area growth and vegetation loss highlights the ongoing challenge of balancing urban development with environmental conservation, a critical issue for sustainable urban planning in rapidly growing cities like Bhopal

Fragmentation Anaysis of Study Region

Fragmentation analysis is a crucial aspect of landscape ecology, and Fragstats is a software tool used to analyze landscape structure and fragmentation by processing satellite imagery or thematic maps.

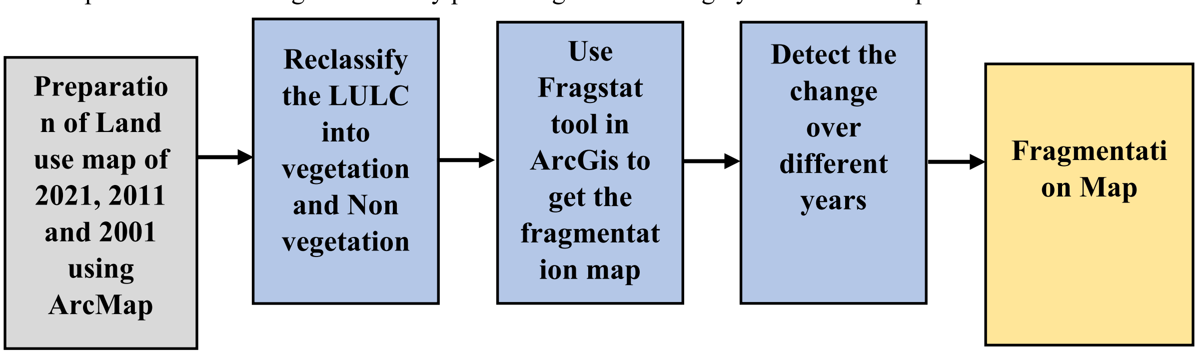


Figure 5 Methodology adopted for generating fragmentation Map
Source: Generated by the Authors, 2024

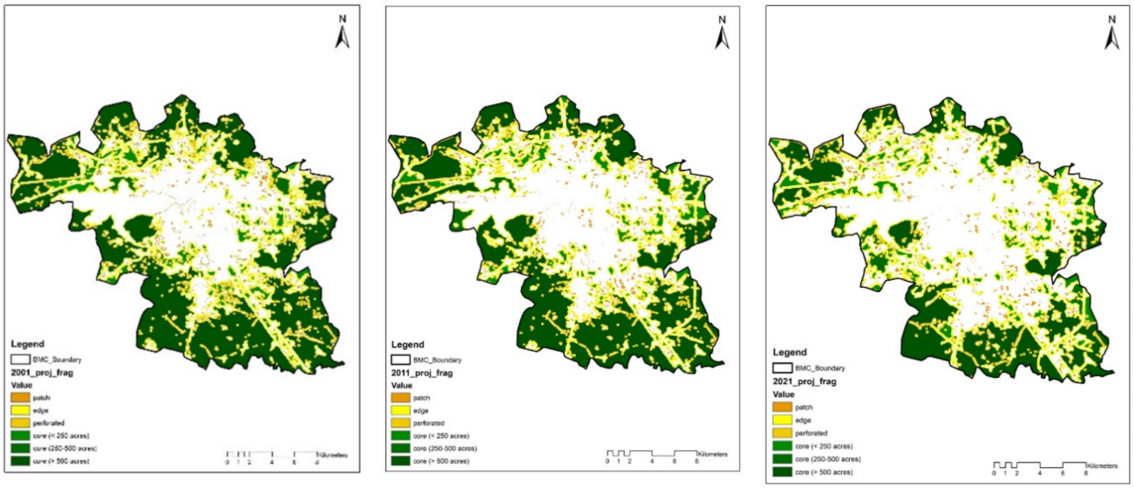
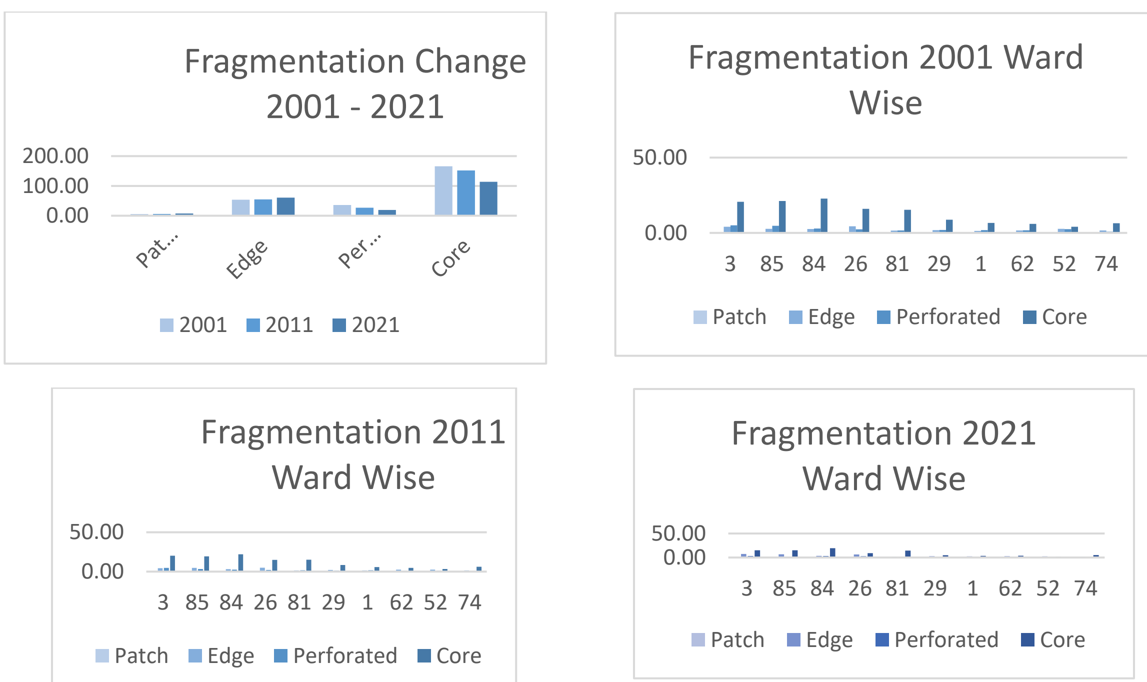


Figure 6 a) Fragmentation Map of 2001**b)** Fragmentation Map of 2011**c)** Fragmentation Map of 2021
Source: Generated by the Authors, 2024

The fragmentation map of Bhopal city reveals a complex evolution of green spaces over time. A notable trend is the increase in patch size, suggesting a shift towards larger but potentially less interconnected vegetated areas. This could result from urban development isolating larger green patches or the merger of smaller fragmented areas through natural processes. Simultaneously, the map indicates a continuous decrease in core size, signifying a decline in high-quality, interior habitat within these vegetated patches. This reduction in core areas is concerning, as these spaces typically offer critical ecological benefits. The parallel trends of increasing patch size and decreasing core areas highlight the challenges Bhopal faces in maintaining ecological connectivity and habitat quality amidst ongoing urbanization.

Table 2 a) Fragmentation Change 2001- 2021 **b)** Fragmentation Map of 2001 Ward Wise **c)** Fragmentation Map of 2011 Ward Wise **d)** Fragmentation Map of 2021 Ward Wise

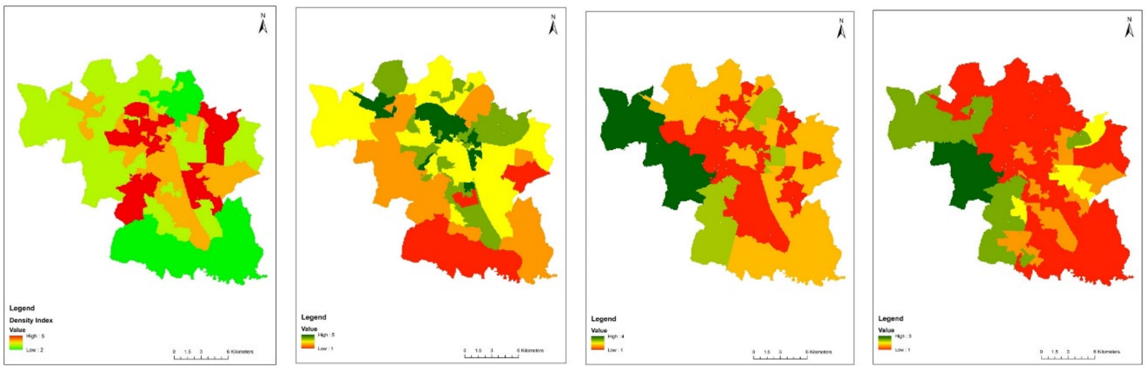


Source: Generated by the Authors, 2024

Urban Compactness Index (UCI)

In the context of rapidly urbanizing cities like Bhopal, understanding the dynamics of urban form and its relationship to green spaces is crucial for sustainable development. This study employs a comprehensive Urban Compactness Index to analyze the spatial and temporal changes in Bhopal's urban structure and its impact on green spaces. The index incorporates four key components: Density (D), Land Use Mix (LUM), Street Connectivity (SC), and Urban Green Accessibility (UGA). By examining these factors, we aim to quantify the city's urban compactness and its evolution over time, with a particular focus on how these changes affect the distribution, accessibility, and quality of urban green spaces. This analysis provides valuable insights into the challenges and opportunities for integrating green infrastructure within Bhopal's urban fabric, offering a foundation for evidence-based urban planning and policy-making aimed at creating a more sustainable and livable city.

Methodology for Social Vulnerability Index has been adopted for this investigation of study region.



Urban Compactness Index UCI = ¼ DI + ¼ SCI + ¼ LUMI+ ¼ UGI

Figure 7 a) Density Index Ward Wise **b)** Landuse Mix Index Ward Wise **c**) Street Connectivity Index Ward Wise **d)** Urban Green Accessibility Index
Source: Generated by the Authors, 2024

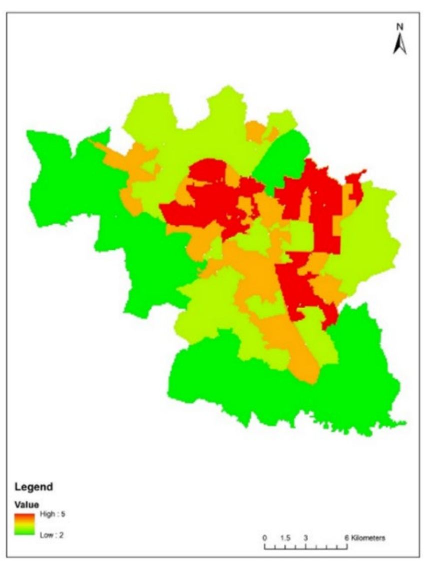


Figure 8 Urban Compactness Index Map of Bhopal Region.
Source: Generated by the Authors, 2024

Density Mapping

Bhopal's recent growth exhibits a fascinating duality. The city has seen a penetrating expansion in its northwest and southeast zones, suggesting targeted development or the presence of resources attracting population and infrastructure in those specific directions. At the same time, Bhopal's overall growth pattern can be described as radial, indicating a densification radiating outward from the city center. This implies that urbanization is not just concentrated in specific zones, but is also intensifying throughout the city, gradually reaching the periphery. In essence, Bhopal is experiencing a focused surge in certain areas while simultaneously expanding outwards, creating a comprehensive urban sprawl.

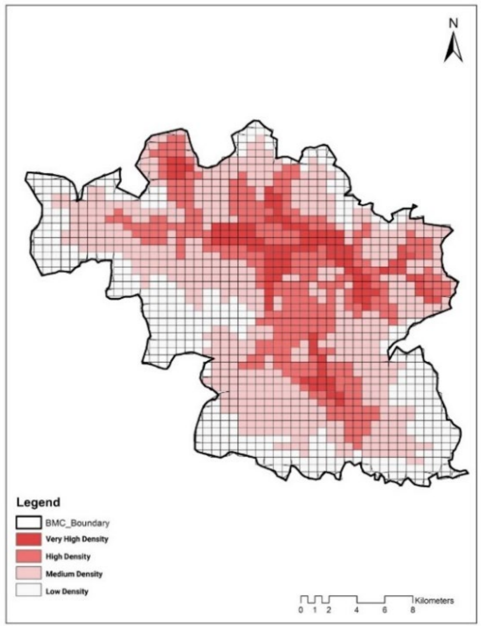


Figure 8 Density Map of Bhopal Region.
Source: Generated by the Authors, 2024

Strategic Zoning Approach for selection of Zones

To comprehensively analyze the spatio-temporal dynamics of green spaces and their impact on Bhopal's urban environment, this study employs a strategic zoning approach based on urban density patterns. Utilizing both urban compactness index and density maps, we have identified three distinct zones within Bhopal, each represented by a carefully selected park: a high-density zone characterized by intense urban development and limited green space, a medium-density zone balancing built infrastructure with green areas, and a low-density zone featuring more dispersed development and abundant green cover. This zoning framework allows for a nuanced examination of how green spaces function and evolve within varying urban contexts. By comparing these zones, we aim to uncover the complex relationships between urban density, green space accessibility, and environmental quality across Bhopal's diverse urban landscape.

Quantification of Cooling Impact Of Selected Zones In Study Region

Cooling effects of urban parks was assessed through a process that uses Land Surface Temperature It was observed that in year 2011, only 10.2% of the area in the municipal corporation boundary of Bhopal has the lowest land surface temperature whereas 53.5% of the area has the maximum surface temperature in the city. And it was found that in year only 3.7% area in the city has the lowest land surface temperature of 29.5 deg c whereas 76% of the total area has a lst of 43.6 deg c and about 2.7% area has the highest temperature of 48.3 deg c. In 2021 55% of the land has the temperature range in the Urban Heat Island intensity range.

Table 3 a) Area of Park b) Average Park Temperature

Area of Park	
Bada Bagh	12.4 Ha
Arera Colony Park	1.56 Ha
Shahpura Park	2.3 Ha

Average Park Temp			
Year	Site 1	Site 2	Site 3
2001	31.76	31.05	29.47
2011	32.49	31.84	30.18
2021	33.41	32.28	30.96

Source: Generated by the Authors, 2024, (Garden Dept - Bhopal Municipal Corporation), 2024

Table 4 Average Surrounding Temperature

Average Surrounding Temperature									
	Site - 01			Site - 02			Site - 03		
Year	**2001**	**2011**	**2021**	**2001**	**2011**	**2021**	**2001**	**2011**	**2021**
Min Temp	**24.94**	**25.97**	**26.54**	**23.85**	**24.58**	**25.23**	**23.16**	**24.09**	**26.05**
Max Temp	**36.49**	**39.20**	**41.03**	**36.05**	**37.15**	**39.45**	**35.12**	**36.49**	**36.14**
Avg Temp	**30.71**	**32.85**	**33.78**	**29.95**	**30.86**	**32.34**	**29.74**	**30.29**	**31.09**

Source: Generated by the Authors, 2024

Determining Cooling Impact of Sites

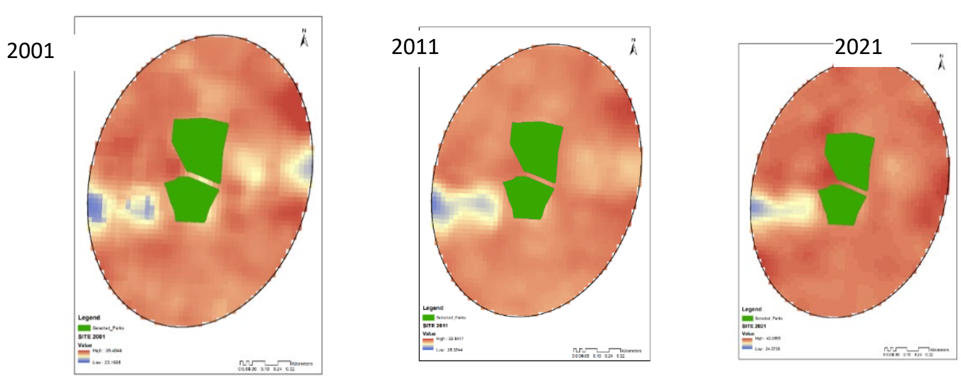


Figure 9 Land Surface Temperature Variation of Site 1

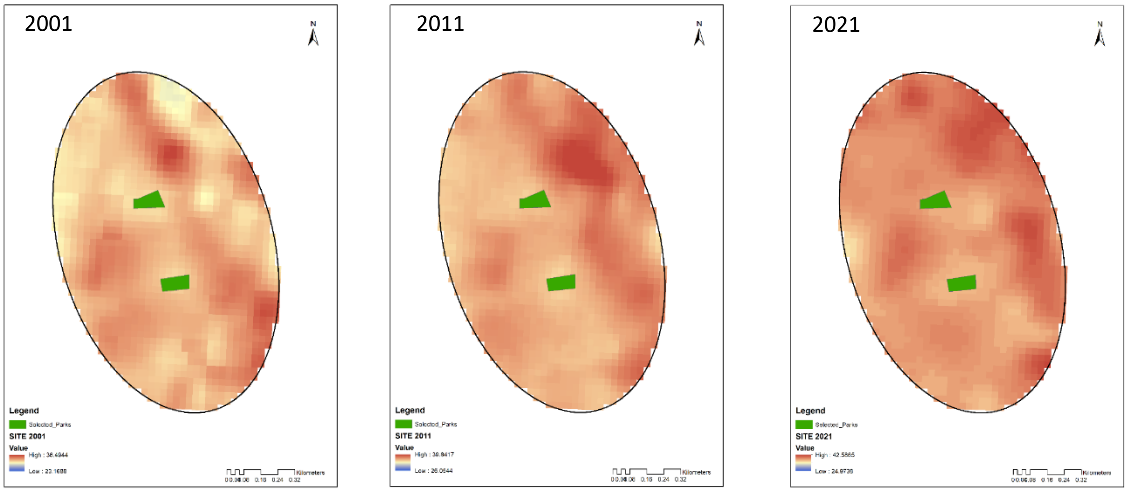


Figure 10 Land Surface Temperature Variation of Site 2

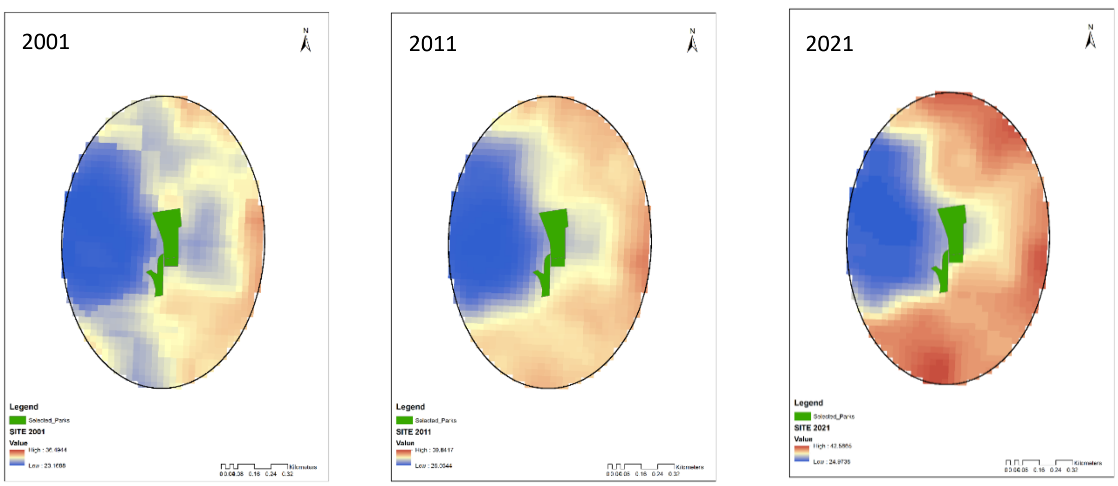


Figure 11 Land Surface Temperature Variation of Site 3

Source: Generated by the Authors, 2024

Maximum Cooling Distance

The maximum cooling distance is the distance from the green space boundary to the buffer with the first turning point increased by 0.1 °C. It was observed that the MCD has been decreased from 2001 to 2021

Table 5 Maximum Cooling Distance

Maximum Cooling Distance			
	2001	2011	2021
Site 1	200	80	50
Site 2	300	150	80
Site 3	450	300	150

Source: Generated by the Authors, 2024

Park Cooling Area

Park Cooling Area is the buffer area with the Maximum Cooling Distance from the Park boundary'. It defines the cooling coverage of the park, it was observed that the cooling coverage has decreased from 2001 to 2021

Table 6 Park Cooling Area

Park cooling area (PCA)			
	2001	2011	2021
Site 1	406080	109500	291260
Site 2	321800	266300	158100
Site 3	626100	350000	258000

Source: Generated by the Authors, 2024

Park Cooling Intensity

"Park cooling intensity is the amplitude of lowering temperature of surrounding impervious surface". It is obtained by the difference between the impervious surface temperature at Maximum cooling distance and the average LST of the Park. From the observation the PCI in site has decrease continuously from 2001 to 2021 by 0.58 °C for site 1, 0.2 °C for site 2 and 0.54 °C for site 3

Table 7 Park Cooling Intensity (PCI)

Park Cooling Intensity (PCI)									
	Site - 01			Site - 02			Site - 03		
Year	2001	2011	2021	2001	2011	2021	2001	2011	2021
T(S)	31.71	32.85	33.78	31.85	31.86	32.34	30.74	30.89	31.09
T(P)	30.76	32.49	33.41	31.05	30.84	32.28	29.47	30.18	30.96
T	0.95	0.36	0.37	0.8	1.02	0.6	1.27	0.71	0.73

Source: Generated by the Authors, 2024

Park Cooling Efficiency (PCE)

It is the ratio of Park Cooling Area and Park area that gives the Area cooled per unit area of park." It is observed that the efficiency of the park has decreased from 2001 to 2021 continuously

Table 8 Park Cooling Efficiency (PCE)

Park Cooling Efficiency (PCE)									
	Site - 01			Site - 02			Site - 03		
Year	2001	2011	2021	2001	2011	2021	2001	2011	2021
MCA	406080	109500	291260	321800	266300	158100	626100	350000	258000
PA	124000	124000	124000	15600	15600	15600	23000	23000	23000
MCA/PA	3.27	0.88	2.35	20.63	17.07	10.13	27.22	15.22	11.22

Source: Generated by the Authors, 2024

It is the ration of Park Cooling Intensity and Maximum cooling distance which gives, temperature cooled per unit distance of park cooling effect. The temperature cooled per unit area of park has increased to 0.0019 in 2021 for site 1 and 0.0014 for site 3 , decreased for site 2 by 0.003

Table 9 Park Cooling Gradient

Park Cooling Gradient (PCG)									
	Site - 01			Site - 02			Site - 03		
Year	2001	2011	2021	2001	2011	2021	2001	2011	2021
PCI	0.95	0.36	0.37	0.8	1.02	0.6	1.27	0.71	0.73
MCD	200	80	50	300	150	80	450	300	150
PCI/MCD	0.0048	0.005	0.007	0.003	0.007	0.008	0.003	0.002	0.005

Source: Generated by the Authors , 2024

The cooling effect provided by the bigger park in Site 1 is less, The cooling effect provided by the smaller parks in Site 2 and Site 3 is comparatively observed more in the system,

Assessing the Nexus Between Urban Green Space and Land Value

To further understand the impact of green spaces on Bhopal's urban environment, this study examines the relationship between park accessibility and property values. Using a log-linear Ordinary Least Squares (OLS) model, we analyze how various factors, including distance to parks, influence property values across the identified density zones. The model is expressed as:

$LnYi = \beta 0 + \beta 1Xi + \beta 2Zi + Ui$

Where Y is the log of property value, X and Z represent location and housing characteristics respectively, and Ui is the error term.

This approach allows us to quantify the impact of green space proximity on land values while controlling for other property and neighborhood characteristics. The analysis employs IBM SPSS Statistics 26 to assess data normality and perform both linear and bivariate regression analyses.

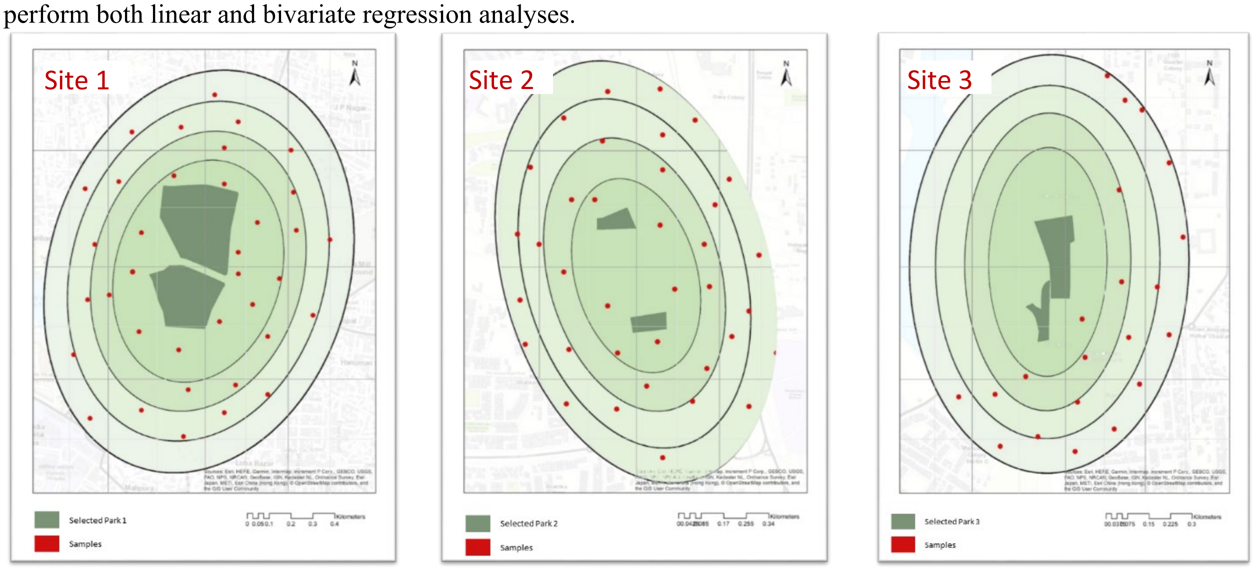


Figure 12 Samples from each grid and each zone in Sites

Source: Generated by the Authors, 2024

Table 10 Correlation Results

	Land Value	Road Quality	Distance from Bus	Cultural amenities	Distance from Hospital	Distance from School	Distance from Park	Quality of Park	Distance from CBD
Land Value	1								
Road Quality	0.7371	1							
Distance from Bus stop	0.4617	0.5534	1						
Cultural amenities	0.6121	0.1022	0.1574	1					
Distance from Hospital	-0.3568	0.2556	0.5052	-0.0331	1				
Distance from School	-0.3213	0.0365	0.2344	-0.1268	0.1918	1			
Distance from Park	0.5568	0.4263	0.4244	0.2358	0.0490	0.3553	1		
Quality of Park	0.4262	-0.2341	-0.4854	-0.2466	-0.1253	-0.0820	0.3139	1	
Distance from CBD	0.1034	-0.4283	-0.6392	-0.0694	-0.1877	-0.2679	-0.5893	0.2272	1

Source: Generated by the Authors, 2024

Preliminary correlation results suggest a positive influence of most location and housing characteristics on property values, with distance to parks and park quality showing notable positive correlations. Interestingly, proximity to hospitals and schools demonstrated weaker or negative correlations with land value in the study area.

This economic valuation of green spaces provides crucial insights into their perceived value within Bhopal's urban fabric. Understanding these relationships can inform urban planning strategies, highlighting the economic benefits of preserving and developing green spaces in different urban density contexts. Moreover, it underscores the multifaceted role of urban green spaces in shaping not only the environmental quality but also the economic landscape of Bhopal.

To further quantify the impact of green spaces on Bhopal's urban environment, we employed multiple linear regression analysis across the three identified density zones. This method allowed us to isolate the effect of parks on land value while controlling for other influential factors. The regression models provided statistically validated insights into the strength and direction of the relationship between park proximity and property values.

Table 11 Details of Indicators and Variables

Variable	Indicator		Unit	Minimum	Maximum
Land Value	Land Value	Y	Rs/sqft	6300	14980
Mobility and accessibility	Road Quality	X1	Scale	1	5
	Distance from Bus stop	X2	metre	80	1450
Socioeconomic	Cultural amenities	X3	metre	300	4580
	Distance from Hospital	X4	metre	250	5600
	Distance from School	X5	metre	650	1680
Green Infrastructure	Distance from Park	X6	metre	150	3400
	Quality of Park	X7	Scale	1	5
Mobility and accessibility	Distance from CBD	X8	km	5	9

Source: Generated by the Authors, 2024

Log-linear Ordinary Least Squares (OLS) Regression Model Results and Discussion.

A combined model using data from all three sites was developed:

Y= 0.21+ 0.2211 (X1)+ 0.3960 (X2)+0.1043(X3)-0.288(X4)-0.1067(X5)+**0.2057(X6)+0.0987(X7)**-0.0476(X8)

Table 12 Regression Table for site 1

Variable	Indicator	R Square	Coefficient	Significance factor	P value
Mobility and accessibilty	Road Quality	0.647964778	0.192205158	.00233015	0.02672053
	Distance from Bus stop		0.990086392		0.03049766
Socioeconomic	Cultural amenities		0.034378923		0.00631128
	Distance from Hospital		-0.122870981		0.04869331
	Distance from School		-0.007857981		0.07137712
Green Infrastructure	Distance from Park		0.198756321		0.01586331
	Quality of Park		0.048540998		0.06458792
Mobility and accessibilty	Distance from CBD		-0.158569070		0.05426879

Y= 0.03+0.1922(X1)+ 0.9900(X2) + 0.0343(X3)-0.1228(X4) 0.0078(X5)+**0.1987(X6)+0.0485(X7)**-0.1585(X8)

Table 13 Regression Table for site 2

Variable	Indicator	R Square	Coefficient	Significance factor	P value
Mobility and accessibilty	Road Quality	0.647964778	0.192205158	.00233015	0.02672053
	Distance from Bus stop		0.990086392		0.03049766
Socioeconomic	Cultural amenities		0.034378923		0.00631128
	Distance from Hospital		-0.122870981		0.04869331
	Distance from School		-0.007857981		0.07137712
Green Infrastructure	Distance from Park		0.198756321		0.01586331
	Quality of Park		0.048540998		0.06458792
Mobility and accessibilty	Distance from CBD		-0.158569070		0.05426879

Y= 0.03+0.2206(X1)+0.3531(X2)+0.0437(X3)-0.0985 (X4)+0.1882(X5)+**0.1978(X6)+0.0492(X7)**-0.0054(X8)

Table 14 Regression Table for site 3

Variable	Indicator	R Square	Coefficient	Significance factor	P value
Mobility and accessibilty	Road Quality	0.857954913	0.349767236	.00435041	0.005197
	Distance from Bus stop		0.430933713		0.024618
Socioeconomic	Cultural amenities		0.054343923		0.483476
	Distance from Hospital		-0.065989721		0.403150
	Distance from School		-0.135648361		0.201230
Green Infrastructure	Distance from Park		0.248165261		0.198917
	Quality of Park		0.036492654		0.413428
Mobility and accessibilty	Distance from CBD		-0.041509900		0.393402

Source: Generated by the Authors, 2024

Y= 0.19 + 0.3497 (X1) + 0.4309 (X2)+0.0543 (X3)-0.0659 (X4) - 0.1356 (X5) + **0.2481 (X6) + 0.0364 (X7)** - 0.0415 (X8)

The model reveals that park proximity (X6) and park quality (X7) have significant positive impacts on property values across all density zones in Bhopal. Interestingly, the influence of these factors varies across the different density zones, with the high-density zone showing the strongest positive correlation between park proximity and property values.

Willingness to Pay

To further understand the value of green spaces in Bhopal's urban context, we conducted a Willingness to Pay (WTP) analysis across the three identified density zones. This approach aimed to quantify both the economic and societal impact of green spaces by measuring residents' willingness to pay extra for their property values in relation to park improvements and increased park size.

Figure 13 WTP for Sites

Source: Generated by the Authors, 2024

The analysis revealed a clear pattern across all three sites: WTP decreased as distance from the park increased. In Site 1, WTP ranged from 5% to 15% of property value. Site 2 showed a higher range of 10% to 15%, while Site 3 demonstrated the highest WTP.

Table 15 WTP in value for site 1

Willingness to pay extra for the presence of Park						
Zone	WTP IN %	Market Value	Plot Area	Plot Value	WTP for Plot	WTP for MV
A	1	1085	85	92225	922.25	10
B	0.5	1320	120	158880	794.4	7
C	0.25	1270	90	115020	287.55	3
D	0.25	1450	110	160160	400.4	4

Table 16 WTP in value for site 2

Willingness to pay extra for the presence of Park						
Zone	WTP IN %	Market Value	Plot Area	Plot Value	WTP for Plot	WTP for MV
A	1	2800	150	434250	4343	28
B	1	2700	120	327600	1638	16
C	0.5	2200	200	454000	2270	11
D	0.5	2500	110	281820	1409	7

Table 17 WTP in value for site 3

Willingness to pay extra for the presence of Park						
Zone	WTP IN %	Market Value	Plot Area	Plot Value	WTP for Plot	WTP for MV
A	1	3100	180	558000	5580	31
B	1	2800	150	420000	4200	28
C	0.5	2600	120	312000	1560	13
D	0.5	2400	100	240000	1200	12

When quantified in monetary terms, the results showed:

- Site 1: Rs. 10 per unit area of park in Zone A, decreasing to Rs. 4 in Zone D.
- Site 2: Rs. 28 per unit area in Zone A, decreasing to Rs. 7 in Zone D.
- Site 3: Rs. 31 per unit area in Zone A, decreasing to Rs. 12 in Zone D.

Table 18 Difference in WTP between site 1 and site 2

Willingness to pay extra for the presence of Park							
	Max WTP	Max WTP	Min WTP	Difference 1	Difference 2	Difference 1 in %	Difference 2 in %
Site 1	10	10	3	0	7	0%	70%
Site 2	28	11	7	17	4	60.7%	36.3%
Difference	64.28%		57.14%			60.70%	33.70%

Table 19 Difference in WTP between site 1 and site 3

Willingness to pay extra for the presence of Park							
	Max WTP	Max WTP	Min WTP	Difference 1	Difference 2	Difference 1 in %	Difference 2 in %
Site 1	10	10	3	0	7	0%	70%
Site 3	31	13	12	19	1	58%	7.6%
Difference	67.74%		75%			58.00%	62.40%

Table 20 Difference in WTP between site 2 and site 3

Willingness to pay extra for the presence of Park							
	Max WTP	Max WTP	Min WTP	Difference 1	Difference 2	Difference 1 in %	Difference 2 in %
Site 2	28	11	7	17	4	60.7%	36.3%
Site 3	31	13	12	19	1	58%	7.6%
Difference	9.67%		41.66%			2.70%	28.70%

Notably, the value of parks in Zone A of Site 2 was 64.28% greater than in Site 1, while Zone A in Site 3 was 9.6% greater than Site 2. As distance from the park increased, the perceived value decreased by 70% in Site 1, 36.3% in Site 2, and 7.6% in Site 3.

These findings underscore the significant economic value residents place on proximity to green spaces, particularly in higher-density urban areas. The variation in WTP across sites and zones highlights the complex relationship between urban density, green space accessibility, and perceived value.

This analysis provides crucial insights for urban planners and policymakers in Bhopal. It demonstrates that investments in park quality and accessibility can yield tangible economic benefits, particularly in densely populated areas. Moreover, the higher WTP in zones closer to parks suggests that strategic placement and improvement of green spaces could significantly enhance property values and, by extension, the city's tax base.

This WTP analysis, combined with our earlier regression results, provides a comprehensive picture of the multifaceted value of green spaces in Bhopal's urban landscape. It underscores the importance of preserving and enhancing green spaces as a key strategy for sustainable urban development, balancing economic growth with environmental and social well-being.

Results and Key Findings

Over the past two decades, the urban environment in Bhopal has experienced a concerning deterioration. This degradation has impacted the city and its residents across various sectors. The primary driver behind the destruction of the urban environment is the decline in green spaces within the city, which have been converted into impervious land areas. This conversion has led to an increase in microclimatic temperatures, resulting in the formation of Urban Heat Islands (UHIs). The presence of UHIs contributes to higher daytime temperatures, reduced evening cooling, and elevated levels of air pollution. Consequently, there is a pressing need for the strategic distribution of green spaces to regulate the urban microclimate and provide better environmental conditions in urban areas.

Bhopal, the capital city of Madhya Pradesh, is one of the rapidly growing urban centers in India. As a city attracting people from across the country, there is a significant demand for land, which is a scarce amenity in urban areas. The research findings indicate that when land prices are higher, the surrounding facilities and accessibility tend to be better. Furthermore, the study has revealed that green spaces are one such amenity that can enhance land prices. Green spaces not only provide recreational areas but also contribute to creating pleasant microclimatic conditions in the surrounding areas. Additionally, the inclusion of green spaces presents an opportunity to increase land taxation, which serves as a source of finance for the municipal authorities within the region.

Figure 14 Interconnectivity between the variables

Source: Generated by the researcher, 2024

Recommendation and The Way Forward

Based on our research findings, we propose a set of guidelines for the optimal distribution of open spaces in Bhopal, aimed at maximizing cooling impacts and enhancing urban livability. These recommendations focus on strategic placement and sizing of parks to effectively mitigate urban heat island effects.

Size of the Green space

We suggest a tiered approach to park sizes, categorizing them into small (0.5 hectares), medium (1 hectare), and large (2 hectares) parks. Each category has recommended minimum distances between parks and specific buffer zones to ensure optimal cooling effects and accessibility.

Table 21 Size of Green Space

Size of Green Space			
Size	Large	Medium	Small
Area	2 ha	200	100
Temperature	2 – 1.9°C	0.42 – 0.32°C	0.2 – 0.1°C

Table 22 Guideline for Park Allocation

Guideline for Park Allocation				
S. No.	Size of the Park in sq. m (ha)	Distance Between Park in m	Cooling Impact in m	Population Served
1	5000 (0.5)	200	100	7000
2	10000 (1)	400	300	15000
3	20000 (2)	500	400	30000

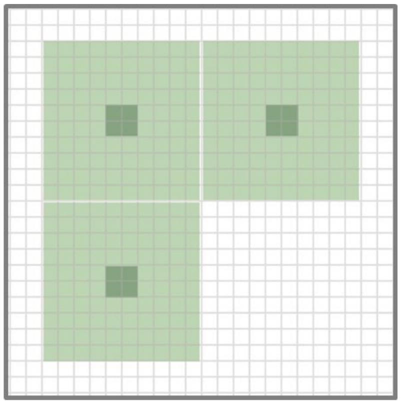
Table 23 Park Size Distance Matrix

Park Size and Buffer Matrix			
Park Size	0.5	1	2
0.5	100	150	250
1	150	200	300
2	250	300	400

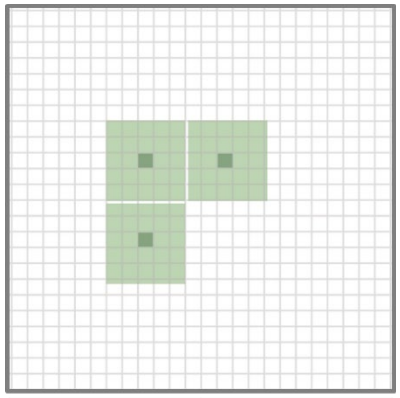
Table 24 Park Size and Buffer Matrix

Park Size Distance Matrix			
Park Size	0.5	1	2
0.5	200	300	500
1	300	400	600
2	500	600	800

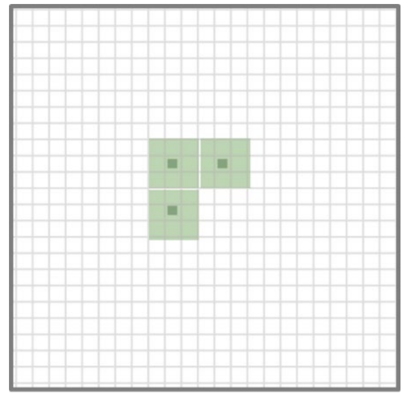
Parks Models - Based on Cooling Impact



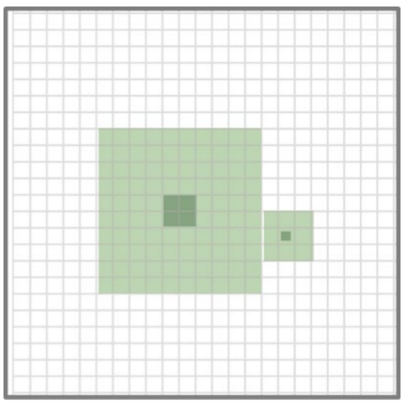
Size of Park	2 Ha
Distance	800 m



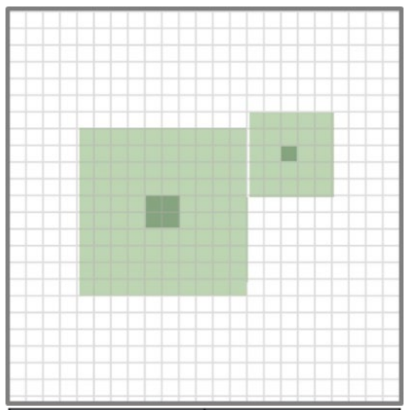
Size of Park	1 Ha
Distance	400 m



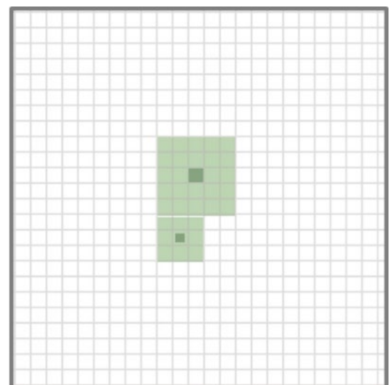
Size of Park	0.5 Ha
Distance	200 m



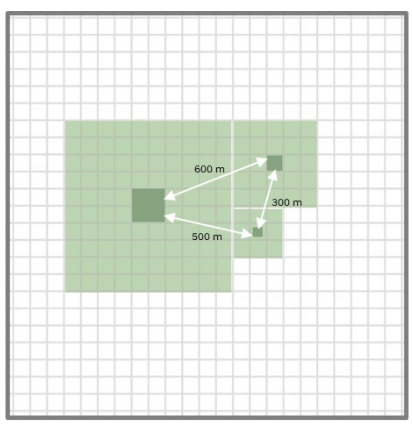
Size of Park	2 & 0.5 Ha
Distance	500 m



Size of Park	2 & 1 Ha
Distance	600 m



Size of Park	1 & 0.5 Ha
Distance	300 m



Size of Park	2, 1 & 0.5 Ha

Figure 15 Park Models
Source: Generated by the Authors, 2024

Our proposed park models include various combinations of these park sizes, strategically placed to create a comprehensive network of green spaces throughout the city. These models account for the cooling impact of different park sizes and their spatial relationships.

The guidelines also specify the required percentage of green cover within each park size category, recognizing that larger green spaces generally offer greater cooling benefits due to increased vegetation cover, enhanced biodiversity, and improved air circulation.

For implementing these guidelines, we recommend focusing on areas within Bhopal that currently have high land surface temperatures, lower land values, and are predominantly residential with available public land. Priority should be given to areas lacking existing green spaces.

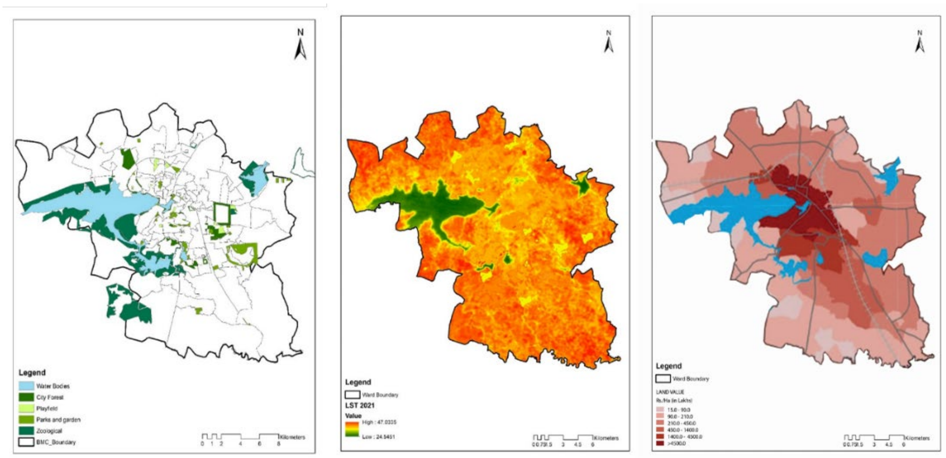


Figure 16 Identification of BMC lacking green Space overlaying LST and Land Value

Source: Generated by the Authors, 2024

These recommendations aim to create a balanced and effective network of parks and green spaces across Bhopal. By following these guidelines, urban planners and policymakers can work towards developing a more sustainable and livable urban environment that effectively combats the urban heat island effect while providing numerous environmental, social, and economic benefits to the city's residents.

Strategies for enhancement of UGS

Understanding the availability and shortage of UGS in the city of Bhopal, suggesting a systematic procedure for assessing and indexing wards for available UGS, correlating the extent, population density, and available UGS of the wards, and recommending a conceptual framework for decision-makers to achieve an ecologically sustainable urban neighbourhood with optimal grey-green coverage.

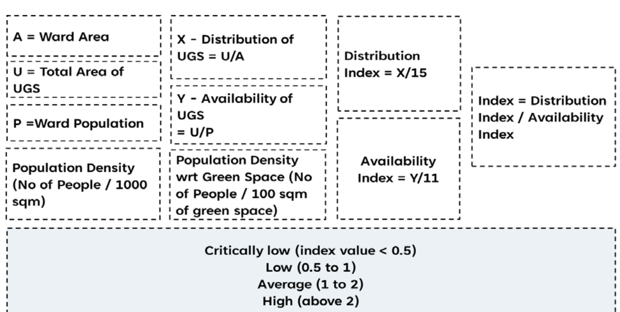


Figure 17 Methodology for Strategies for enhancement of UGS

Source: Generated by the Authors, 2024

Table 25 Recommended strategies for quantitative and qualitative enhancement of UGS

Recommended strategies for quantitative and qualitative enhancement of UGS			
Categorisation of ward	Principle	Area of application	Strategies recommended
Critically Low (Index Value: 0 to 0.5)	Integration of green infrastructure into grey infrastructure	Existing buildings	Green roofs and green walls
		Developing buildings	Making strict norms for mandatory open spaces and offering incentives for tax reduction or additional floor area benefits to implement any façade-based and ground-based green infrastructure and rainwater harvesting options.
		Joint use of institutional amenities – shared spaces	Gardens or playgrounds in educational institutions can be shared with the local people after regular academic hours
		Street scaping	Roadside plantation, permeable paving material, vegetated swales
Low (Index Value: 0.5 to 1)	Integration of green grey infrastructure	Interstitial vacant spaces	Organized planting and management of vacant lands, parking areas, rail tracks, and corridors between buildings
		Neighborhood parks, playgrounds, gardens, and cemeteries	Proper maintenance of these parks and converting them into multifunctional areas to cater to all sections of people
		Local water bodies	Proper maintenance of local water bodies to raise their cultural and ecological value
		Gardens around the historical or important building	A revival of these gardens or making them open to public
Average to High (Index Value: Above 1)	Preservation of already existing green infrastructure	urban parks, and lakefronts	Preserving the existing natural assets and protecting the eco-sensitive zones
			Creating a continuous "ecological corridor" to bring nature into the congested wards

Comprehensive Three-Phase Operational Framework

To address the spatio-temporal dynamics of green spaces and their impact on Bhopal's urban environment, we propose a comprehensive three-phase operational framework. The first phase, Planning and Assessment, involves conducting a thorough inventory of existing green spaces, analyzing built density, and mapping Land Surface Temperature (LST) using remote sensing data. This phase also prioritizes areas based on factors such as low green space access, high population density, and high LST. The second phase, Implementation Strategies, focuses on developing diverse green space typologies including large urban parks, pocket parks, green streets, urban forestry, and green roofs. This phase emphasizes functional design, use of native plant species, and explores land value optimization strategies such as taxation on increased land value and inclusionary zoning. The final phase, Monitoring and Maintenance, involves tracking progress through key metrics, developing long-term maintenance plans, and encouraging community stewardship. This framework aims to combat urban heat island effects, improve microclimatic conditions, enhance land values, and create a more sustainable and livable urban environment in Bhopal.

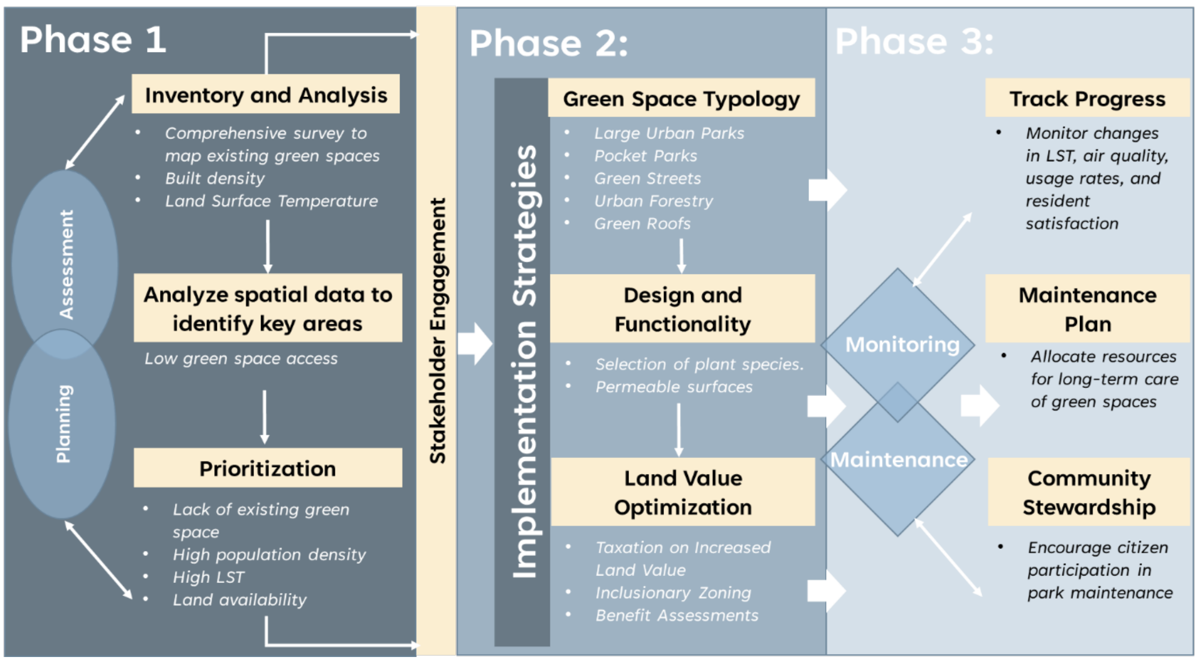


Figure 18 Comprehensive Three-Phase Operational Framework

Source: Generated by the Authors, 2024

Conclusion

In the context of rapid urbanization and climate change, urban green spaces significantly contribute to mitigate the s ubsequent increasing urban heat island (UHI), particularly to reduce the increasing land surface temperature (LST), aridity and intensity of heat waves through their cooling effects in the surrounding areas. Increase in population has adversely affected the green cover in urban India.

The gradual depletion of urban green spaces, largely due to increasing population pressure and urban expansion, has resulted in the land use land cover change (LULC) and has altered the microclimate of the urban ecosystem. In this c ontext, the present study has analysed and assessed the changing scale and spatial layout of the urban green spaces.

Urban green spaces are one of the most significant elements of any urban ecosystem, both due to its ecosystem dynamics and its essential contribution in well being of human race. However, it is ironic that despite of its immense significance, vegetation is undergoing destruction and degradation in the modern times due to rapid and haphazard urbanization in developing countries, making urban settlements major source of GHG emissions and at the same time making them more vulnerable to global environmental change impacts. Hence, landuse/landcoverand green cover changes monitoring becomes very crucial in decision making and conserving green spaces in cities and at this stage significant contributions can be provided by remote sensing technologies.

Presently Bhopal Region is experiencing large number of immigration from other regions of state and nation insearch of economic opportunities, which is leading up to leapfrog increase in the city population onsequently escalating demand for allocation of residential sector in developmental plans and increasedallocation of land and funds for associated infrastructure to facilitate such a large population.This scenario is leading into increased need for vacant land for both residential purpose and infrastructural services (roads etc). This urgent and growing need is taking its toll on the other habitats of the city, like urban green spaces, barren and fallow lands, agricultural lands are being converted into residential complexes and shopping malls, also encroachment of hill slopes and riverbeds by slums haveled to degradation of both these habitats.Green cover is also being depleted not in forest only but also on other fronts, like, artificial plantations of exotic species etc this is leading not only degradation of local habitat but also disturbing the local biodiversity. Thus, clearly highlighting the issue of rapid urbanization due to exponential increase of population in urban centres leading to various environmental issues both at regional and collectively at global level.Lastly it can be concluded from this study that, urbanization and urban sprawl is one of the most important and urgent issue which all developing countries like India are facing, and it needs to tackled holistically involving all stakeholders like general public, corporate sector and NGO’s, not just the decision makers of any urban ecosystem. And to facilitate these conservative measurers remote sensing can play a vital role in both monitoring the landuse changes and sustainable urban planning.

References

1. Crompton, J. L. (2001) 'The impact of parks on property values: A review of the empirical evidence, Joural of Leisure Research, 33(1), Pp. 1-31. doi: 10.1080/00222216.2001.11949928.
2. EnyinnAadiele, C. and lyenemiibiminaKakulu, P. (2021) the impact of infrastructure development on land values in selected neighbourhoods in greater port Harcourt city Chika EnyinnaAdiele and Prof lyenemilbiminaKakulu', American Journal of Humanities and Social Sciences Research (AJHSSR), 5(9), pp. 53-59.
3. Eswar, M. and Roy, A. K. (2018) 'Urbanisation in Karnataka: Trend and Spatial Pattern', Journal of Regional Development and Planning, 7(1), pp. 61-69. Available at: http://www.jrdp.in/currentissue/7_1_5.pdf.
4. Fallis, A.. (2013) Vision Document RMP 2031', Journal of Chemical Information and Modeling, 53(9), pp. 1689-1699. Available at:https://opencity.in/documents/bda-revised-master-plan-2031-vision-document.
5. Fernandez, L., Mukherjee, M. and Scott, T. (2018) 'The effect of conservation policy and varied open space on residential property values: A dynamic hedonic analysis', Land Use Policy, 73(December 2017), pp. 480-487. doi: 10.1016/j.landusepol.2017.12.058.
6. Herrice, C. (1939) The Effect of Parks Upon Land and Real Estate Values', Joumal of the American Planning Association, 5(4), pp. 89-94. doi:10.1080/01944363908978834.
7. Huang, H., Yang, H., Chen, Y., Chen, T., Bai, L., and Peng, Z.-R. (2021). Urban green space optimization based on a climate health risk appraisal—A case study of Beijing city China. Urban For. Urban Green. 62:127154. doi: 10.1016/j.ufug.2021.127154.
8. Kong, X., Sun, Y. and Xu, C. (2021) 'Effects of urbanization on the dynamics and equity of access to urban parks from 2000 to 2015 in beijing, china', Forests, 12(12), doi: 10.3390/f12121796.
9. Kumar, A. and Dixit, G. (2018) 'Sustainable Production and Consumption An analysis of barriers affecting the implementation of e-waste management practices in India: A novel ISM-DEMATEL approach', Sustainable Production and Consumption, 14, pp. 36-52. doi: 10.1016/ spc.2018.01.002.
10. Latini, G., Cocci Grifoni, R. and Tascini, S. (2010) Thermal comfort and microclimates in open spaces', Thermal Performance of the Exterior Envelopes of Whole Buildings - 11th International Conference, (Vdi 1998).
11. Li, F. et al. (no date) 'Forests-10-00333-V3.Pdf.
12. Multiscale spatiotemporal dynamics analysis of urban green space: Implications for green space planning in the rapid urbanizing Hefei City, China
13. Nikolaos, K., Dimitra, V. and Agapi, X. (2011) 'Real Estate Values and Environment: A Case Study on the Effect of the Environment on Residential Real Estate Values', International Journal of Academic Research, 3(1), pp. 861-868. Available at www.ijar.lit.az
14. Pearson, L. J., Tisdell, C. and Lisle, A. T. (2002) the impact of noosa national park on surrounding property values: An application of the hedonic price method, Economic Analysis and Policy, 32(2), pp. 155-171. doi: 10.1016/S0313-5926(02)50023-0.
15. Sharma, A. S. and Lovely, M. A. (2021) 'Urban Open Spaces Sustainability, 8(1), pp. 65-70.

16. Sturiale, L. and Scuderi, A. (2019) 'The role of green infrastructures in urban planning for climate change adaptation', Climate, 7(10). doi: 10.3390/cli7100119.
17. UN-Habitat (2022) Envisaging the Future of Cities, World City Report 2022.
18. Wu, C. et al. (2021) 'Estimating the Cooling Effect of Pocket Green Space in High Density Urban Areas in Shanghai, China', Frontiers in Environmental Science, 9(May), pp. 1-14. doi: 10.3389/fenvs.2021.657969.