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Spatiotemporal Dynamics of Navi Mumbai Municipal Corporation's Urban Expansion (2001-2021): A Geospatial Analysis

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Abstract

Over the past two decades, Navi Mumbai has undergone significant urban transformations, marking its evolution as one of India's prominent urban centers. This study meticulously examines the spatiotemporal dynamics of urban growth within the Navi Mumbai Municipal Corporation (NMMC) from 2001 to 2021 using Geographic Information Systems (GIS) and Remote Sensing (RS) technologies. By deploying a series of satellite datasets—Landsat-5 and 7 (ETM+), and Landsat-8 (OLI/TIRS), the research captures the nuanced changes in land-use and land-cover. Our analysis reveals intricate patterns of urbanization, emphasizing the areas of rapid growth, land conversion, and potential environmental challenges. The juxtaposition of these Landsat datasets offers a comprehensive temporal view, highlighting the interplay between planned urban initiatives and spontaneous expansion. This investigation underscores the significance of geospatial technologies in decoding urban growth trajectories, providing valuable insights for urban planners, policymakers, and environmentalists keen on steering the sustainable future of the NMMC region.

Keywords: Urban expansion, GIS & RS, Land Use & Land Cover.

1. Introduction

Urban evolution, in all its layers and complexities, is not just a phenomenon but a tapestry of socio-economic, environmental, and infrastructural changes. As urban spaces become the central hubs of human activity, they echo the societal shifts, technological advancements, and even the broader environmental changes happening globally. This centrality of urban regions underscores their role not just in geography but in the broader scopes of urban planning, societal studies, and environmental discourse. Understanding these urban expansions — their causes, patterns, and implications — goes beyond academic interest. It becomes imperative to not only plan for the present but also to forecast the future, ensuring that urban spaces remain sustainable, livable, and adaptable to future challenges. This urgency to comprehend the spatial spread and the temporal pace of urban sprawl is thus not just for scholars but for policymakers, urban planners, environmentalists, and even for the ordinary urban dweller. As noted by scholars like Deng et al. (2016), Seto et al. (2017), and Angel et al.

(2015), urban sprawl isn't just a pattern on a map; it's a narrative of human adaptation, aspiration, and sometimes, challenges that need immediate attention.

Urbanization is not a singular tale but a compilation of multifaceted narratives. These narratives span the gamut from the challenges of infrastructural augmentation, required to accommodate ever-growing urban populations, to the intricate dance of ecological balance and socio-economic equitability (Zhou et al., 2018; Gamba & Herold, 2019). Each urban center, with its unique history and context, faces a specific set of challenges, often requiring bespoke solutions. In this intricate web of urbanization challenges, technological advancements have emerged as invaluable allies. The integration of Geographic Information Systems (GIS) and Remote Sensing (RS) has revolutionized our understanding of urban dynamics. Especially when powered by sophisticated datasets like those offered by the Landsat series, these tools provide unparalleled insights, illuminating the complexities of urban sprawl, land use changes, and infrastructural development with previously unattainable granularity (Liu et al., 2020; Pesaresi et al., 2016). For policymakers, city planners, and urban strategists, the significance of GIS and RS transcends beyond their capacities as mere data visualization or analytical platforms. They are not just instruments that chart the course of urban development. Instead, they have matured into foundational pillars upon which the edifice of sustainable urban planning stands (Anderson & Hardy, 2019). In the quest for crafting urban spaces that harmonize human aspiration with ecological sustainability, these tools provide the precision, foresight, and strategic depth, guiding decisions towards a more sustainable, equitable, and prosperous urban future (Potere et al., 2017).

Urban landscapes continue to evolve rapidly, influenced by a multitude of socio-economic, environmental, and infrastructural factors. In their 2017 study, Angel et al. elaborated on the complex patterns of urban expansion, underscore ing the roles of policy measures, demographic changes, and socio-economic determinants. This growth is inextricably linked to environmental consequences. Oke (2019) emphasized the significance of urban microclimates, particularly the rising prominence of the urban heat island effect2. As Ewing and Chen (2018) highlighted, the sprawling nature of modern cities leaves a distinct ecological footprint, necessitating sustainable urban designs.

Integrating advanced technological tools into urban studies, Seto et al. (2016) utilized remote sensing to correlate socio-economic data with urban land-use transitions, providing a granular insight into urban evolution. Davis (2020) delved into the complexities of informal settlements, exploring their origins, trajectories, and challenges for urban governance. Notably, as urban territories expand, so does the criticality of connectivity. Cervero and Sandoval's (2015) research showcased the intertwined nature of urban growth and transportation, emphasizing the importance of sustainable transit planning for future urban trajectories.

2. Study Area

The Navi Mumbai Municipal Corporation (NMMC) is spread over a total area of 162.5 sq. km. defined by 19°05'3.1"N to 19°15'44.2"N latitude and 73°05'22.12"E to 73°55'13.9"E longitude, with an average elevation of 11 meters. According to census figures from 1991, the city's population was 3, 97, 000, but by 2011 it had risen to 1120547.

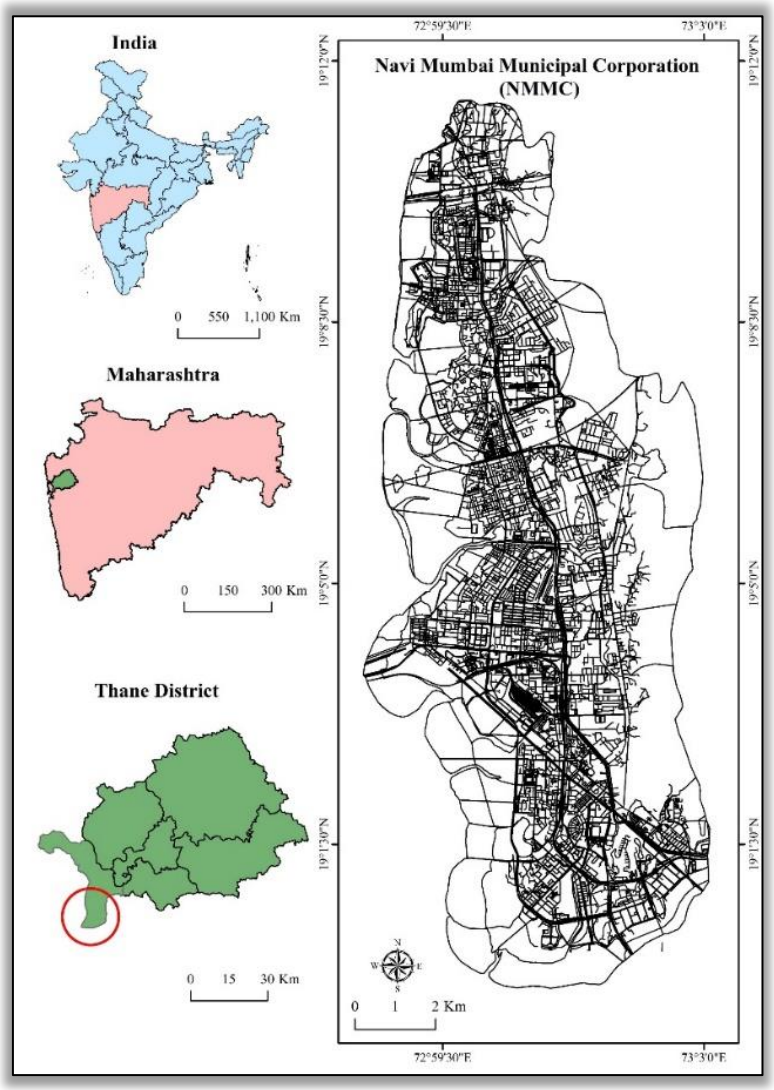

Figure 1: Location Map of Study Area.

3. Material and Methods

Our research approach commenced with the acquisition of satellite imagery from the Landsat ETM+ for the years 2001 and 2011 and the Landsat 8 OLI/TIRS for 2021. These images underwent rigorous pre-processing, which included the rectification of scan line errors, atmospheric and geometric corrections, image enhancement, and layer stacking to ensure optimal quality. Spectral signature training was initiated to discern distinct land cover classes by developing unique spectral profiles from select 'training areas'. Subsequent image

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classification was achieved via the Maximum Likelihood and Hybrid Classification algorithms. Upon classification, the accuracy of the images was stringently assessed against ground-truth data to ensure reliability. With the refined data, Land Use and Land Cover (LULC) maps for 2001, 2011, and 2021 were developed, providing a visual representation of six categories namely build up, open land, vegetation, mangroves, wetland/swamp, waterbodies over the 20-year span. Parallelly, urban growth maps for the same periods were generated, spotlighting the specific urban dynamics and transitions across the two decades.

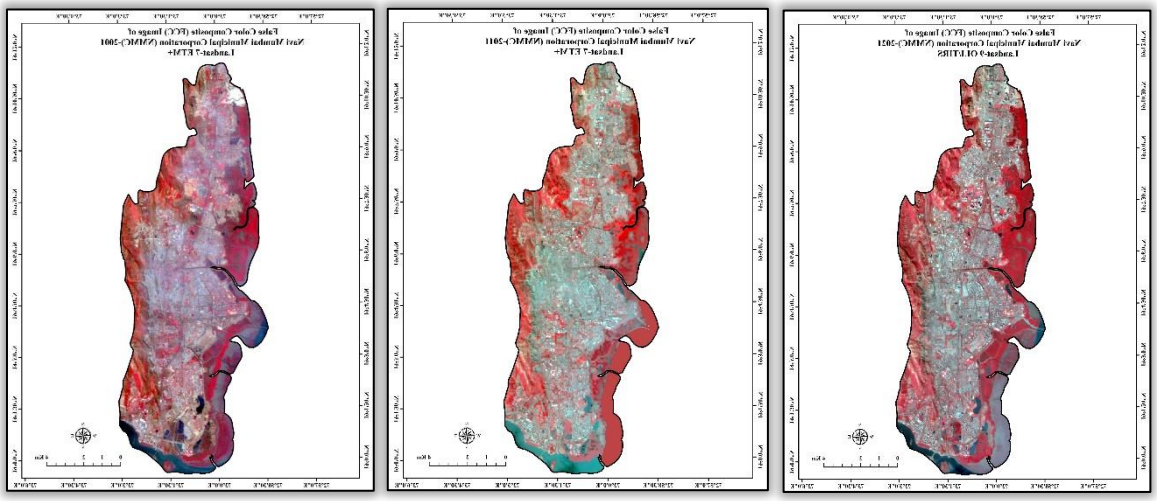

Figure 2: False Color Composite (FCC) Image 2001, 2011 & 2021

Table 1: Land Use and Land Cover Analysis of the NMMC 2001-2021

Sr.No.	LULC	2001		2011		2021	
		Area (Km^2)	%	Area (Km^2)	%	Area (Km^2)	%
1	Built-Up	52.81	32.5	72.14	44.39	92.14	56.7
2	Open land	40.28	24.79	23.88	14.7	7.46	4.59
3	Vegetation	26.59	16.36	21.52	13.24	19.67	12.1
4	Mangrove	19.92	12.26	17.98	11.06	16.76	10.31
5	Wetland/Swamp	14.97	9.21	17.85	10.98	17.86	10.99
6	Water body	7.93	4.88	9.13	5.62	8.61	5.3

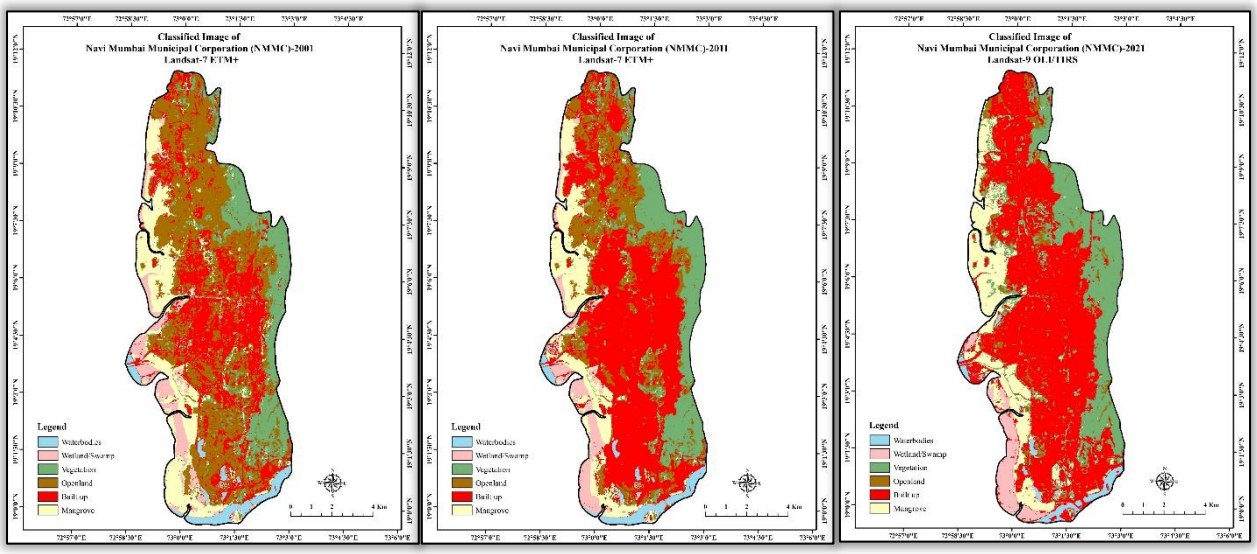

Figure 3: Land Use and Land Cover Analysis of NMMC for the Year 2001, 2011 & 2021

4. Result and Discussion

- **Land Use and Land Cover Analysis**

The data in Table 1 provides a lucid account of the land use and land cover (LULC) changes in the NMMC region over a span of two decades (2001-2021). Commencing with the built-up areas, there's a clear trend of increasing urbanization over the years. Starting from 32.5% of the total area in 2001, it has seen a steady ascent, reaching 44.39% in 2011 and further surging to 56.7% by 2021. This rise underscores the profound urban developmental activities and infrastructural expansions in the region during this period. Contrarily, open lands have shown a significant decline. Occupying nearly a quarter of the region in 2001 at 24.79%, it dwindled drastically to 14.7% in 2011, and further contracted to a mere 4.59% by 2021. This decline can be interpreted as a consequence of the urban sprawl, with previously undeveloped lands being appropriated for construction and infrastructure projects.

The vegetative cover, too, witnessed a diminishing trend, albeit at a less pronounced rate than open lands. From 16.36% in 2001, it declined to 13.24% in 2011 and marginally decreased to 12.1% by 2021. Such a decrease in vegetation over the years emphasizes potential anthropogenic interventions and perhaps changes in land management practices.

Mangroves, often termed the sentinels of the coast, experienced a steady decline from 12.26% in 2001 to 10.31% in 2021. While the decrease is not as stark as in some other categories, it is vital to note such changes given the ecological significance of mangroves in coastal stabilization and as biodiverse habitats. Interestingly, the wetland and swamp category exhibited resilience and even a slight increment. From 9.21% in 2001, they expanded to 10.98% in 2011 and maintained roughly the same proportion (10.99%) by 2021. This trend could indicate successful conservation measures, natural hydrological changes, or both.

Water bodies remained relatively stable over the two decades. They occupied 4.88% of the area in 2001, increased slightly to 5.62% in 2011, but saw a minor reduction to 5.3% by

2021. Being a tidally influence waterbody the dynamics of this class can be consider as rhythmic phenomena This stability, in the midst of significant LULC shifts, is noteworthy.

Table 2: Land Use and Land Cover Dynamics 2001-2021

LULC	2001-2011		2011-2021		2001-2021	
	Area	Growth Rate	Area	Growth Rate	Area	Growth Rate
Built-Up	19.33	36.60	20	27.72	39.33	74.47
Open land	-16.4	-40.71	-16.42	-68.76	-32.82	-81.48
Vegetation	-5.07	-19.07	-1.85	-8.60	-6.92	-26.02
Mangrove	-1.94	-9.74	-1.22	-6.79	-3.16	-15.86
Wetland/Swamp	2.88	19.24	0.01	0.06	2.89	19.31
Water body	1.2	15.13	-0.52	-5.70	0.68	8.58

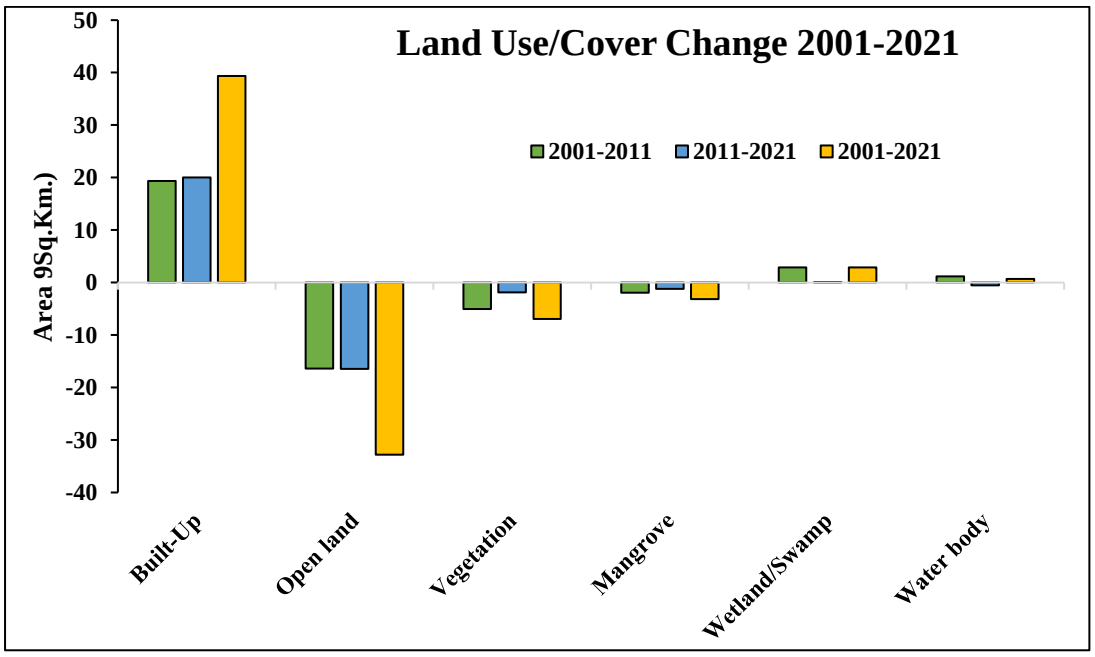

Figure 4: Land Use and Land Cover Dynamics of NMMC for the Year 2001, 2011 & 2021

- **Land Use and Land Cover Dynamics**

The land use and cover changes over two pivotal decades: 2001-2011 and 2011-2021. Notably, urbanization emerges as a prominent theme, with built-up areas expanding by 39.33 sq.km, reflecting a cumulative growth rate of 74.47%. This expansion mirrors regional development and urban clustering. Amidst this urban trajectory, ecological consequences

emerge. The considerable 81.48% decline in open lands echoes urban growth, prompting a need to assess urban expansion in the context of sustainability. Evidently, vegetation and mangroves have undergone shifts, declining by 26.02% and 15.86% respectively, raising questions on human interventions and environmental changes, necessitating conservation discourse. Notably, resilient wetlands and swamps witnessed a 19.31% increase, possibly due to conservation success or natural shifts. In contrast, water bodies exhibit nuanced dynamics with an 8.58% growth yet punctuated decline, prompting to tidal influences. In synthesis, the region showcases an intricate interplay of urban evolution and ecological shifts, advocating a balanced approach harmonizing urban progress with ecological sensitivity.

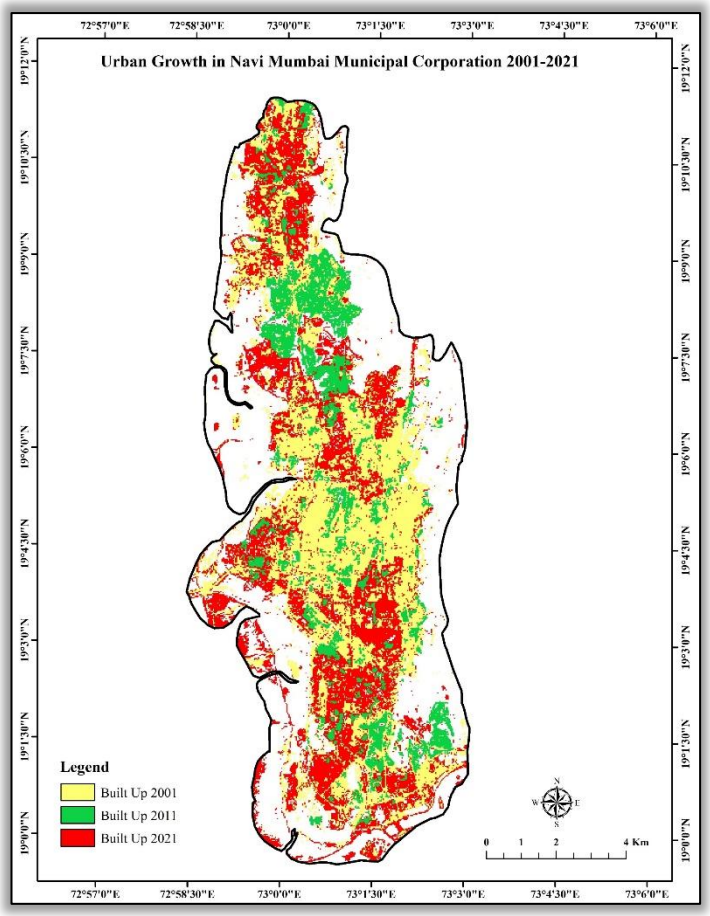

Figure 5: Urban Growth in Navi Mumbai Municipal Corporation from 2001 to 2021

- **Urban Growth**

The data reveals a prominent narrative of urban expansion within the bounds of the Navi Mumbai Municipal Corporation (NMMC) during the period 2001-2021, notably characterized by a discernible north-south trajectory along the pivotal Thane Belapur Road corridor. This corridor has evidently emerged as a nucleus propelling the urban transformation. During the first phase, 2001-2011, there was a substantial augmentation of built-up areas, expanding by 19.33 sq.km, manifesting a growth rate of 36.60%. This initial phase set the stage for the subsequent decade, which witnessed a continuing urban dynamic along the same corridor. Specifically, from 2011 to 2021, a further extension of 20 sq.km was observed in built-up areas, indicative of a growth rate of 27.72%. When considering the entire expanse of 2001-

2021, the cumulative urban expansion attains a remarkable dimension, encompassing 39.33 sq.km, reflecting an impressive growth rate of 74.47%.

Remarkably, the proliferation of urban spaces within Navi Mumbai resonates with a distinct focus on key growth catalysts that have substantively contributed to its evolving urban fabric. This evolution reflects the strategic utilization of several factors instrumental in shaping its urban landscape. The strategic location of Navi Mumbai, strategically nestled adjacent to Mumbai, one of India's major metropolises, has played a crucial role in driving urban growth. The presence of well-planned infrastructure, including commercial centers, educational institutions, and recreational facilities, has rendered Navi Mumbai an attractive destination for businesses, residents, and investors alike. Additionally, the concerted efforts toward environmental sustainability, urban amenities, and improved quality of life have further augmented its appeal. This holistic approach to urban development aligns seamlessly with the larger narrative of urban planning, where the convergence of these factors synergistically fosters urban growth. Navi Mumbai exemplifies a city that has leveraged its strategic advantages to cultivate balanced, sustainable urban expansion, solidifying its position as a vibrant hub of growth and opportunity.

- **Accuracy Assessment**

The accuracy assessment results indicate a commendable precision in the classification of various land use and land cover (LULC) classes for each evaluated year: 2001, 2011, and 2021. The producer's accuracy (PA) and user's accuracy (UA) values, both consistently high across different LULC classes, underscore the reliability of the classification process. Notably, the overall accuracy surpasses 94% for all three years, reaffirming the accuracy of the classification outcomes. The Kappa coefficients, which measure the agreement between observed and predicted classifications, are also robust, exceeding 0.85 for all years. This indicates a strong level of agreement beyond chance and underscores the credibility of the classification results. Collectively, these results affirm the accuracy and consistency of the LULC classification, attesting to the robustness of the methodology employed in this study.

Table 5: Accuracy Assessment

LULC Class	2001		2011		2021	
	PA (%)	UA (%)	PA (%)	UA (%)	PA (%)	UA (%)
Built-Up	81.94	90.77	88.06	93.65	87.76	93.48
Open land	92.59	96.15	81.63	90.91	89.66	96.3
Vegetation	88.37	92.68	87.93	94.44	83.78	93.94
Mangrove	94.34	100	92.16	94	92.86	95.12
Wetland/Swamp	89.47	95.77	95.51	96.59	78.79	83.87
Water body	84.09	88.1	96.55	96.55	95.65	100
Overall	**94.44**		**94.21**		**95.64**	
Kappa Coefficient	**0.857**		**0.866**		**0.872**	

5. Conclusion

In conclusion, the analysis and discussion conducted within this conversation shed light on the intricate dynamics of urban growth and land use transitions in the Navi Mumbai Municipal Corporation (NMMC) area from 2001 to 2021. The utilization of Geographic Information Systems (GIS) and Remote Sensing (RS) technologies, particularly in conjunction

with Landsat imagery, has provided a comprehensive perspective on the evolution of the urban landscape. The study elucidated a distinctive pattern of urban expansion, primarily along key growth corridors, underscoring the role of strategic transport routes in shaping Navi Mumbai's growth. This growth has been accompanied by noteworthy shifts in land use and cover classes. The expansion of built-up areas, alongside reductions in open lands and vegetation, poses vital ecological and sustainability considerations. The decline in mangroves, despite conservation efforts, prompts reflection on the intersection of urban development and environmental preservation.

Wetlands and swamps displayed resilience and growth, reflecting the potential success of conservation initiatives. Accurate accuracy assessment results substantiated the robustness of the GIS and RS methodologies employed, further validating the study's findings.

Overall, this study enriches our understanding of urbanization's multifaceted impact on the Navi Mumbai region. It underscores the need for a balanced and sustainable approach to urban growth, where infrastructural development aligns harmoniously with ecological preservation. The insights garnered contribute to the larger discourse on urban planning, offering valuable perspectives for policy formulation and future research in urban dynamics.

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