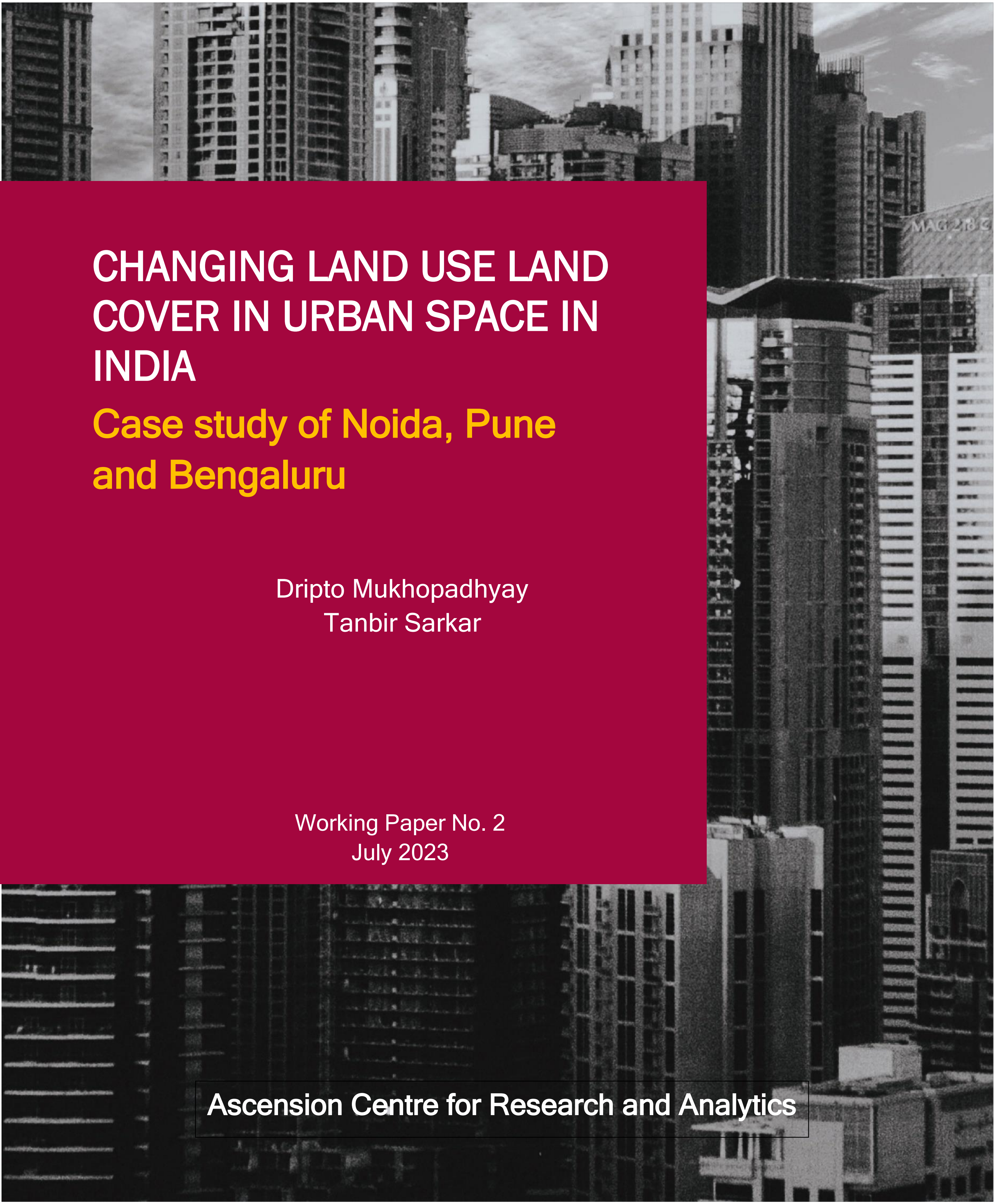

CHANGING LAND USE LAND COVER IN URBAN SPACE IN INDIA

Case study of Noida, Pune and Bengaluru

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Changing Land Use and Land Cover in Urban Space in India: Case Study of NOIDA, Pune and Bengaluru

ABSTRACT

Urban green areas are crucial for the wellbeing of the residents in any city. Expansion of urban areas and the conversion of lands into built-up surfaces are one of the major implications on land use land cover (LULC) of the city space including reduction of green space. Demand for more space and resources in urban areas is driven by the increasing population for multiple factors including economic reasons. Any planning and management of urban development requires a detailed analysis of LULC change and its impacts on the overall ecosystem of the region. This paper examines the changes in spatial-temporal patterns of LULC at granular geographic level (municipal sector/ward) in selected cities of India using remote sensing and GIS techniques. Three major cities were chosen, NOIDA, Pune and Bengaluru, based on their rapid urban expansion in recent time. LULC classification of three years over two decades (2001, 2010 and 2022) are executed using maximum likelihood technique to obtain 6 distinct classes – Water, vegetation, Urban, agriculture, fallow land and open green. One of the major findings is that the built-up area of the selected metropolitan cities has increased to a great extent during the last couple of decades, but not impacting other LULC characteristics in similar fashion. Contrary to the general perception, NOIDA shows an increase of vegetative area during 2001 to 2022, which are much higher compared to Bengaluru and Pune. The results suggest that the urbanization process in Bengaluru is at an alarming condition as built up spaces gradually sweeping out the vegetation, agriculture and other land use classes. This paper also constructed a livability index across granular geographies of Municipal sectors/wards. The research findings can be a useful as a decision-making tool for policymakers and urban planners with respect to the proposed city development plan to implement the sustainable development goal and manage the future land demand.

Changing Land Use and Land Cover in Urban Space in India: Case Study of NOIDA, Pune and Bengaluru

1.0 Introduction

Urban green space does not have any global definition that helps people in understanding equivalence of the concept. “Generally, urban green space (UGS) includes parks, gardens, street greenery, wetlands, community green spaces, natural woodland, etc., which is recognized as the optimized mechanism for human living environments and life quality (1). However, UGS delivers ecosystem services that are immensely beneficial for health of the residents, especially for women and the old by encouraging various physical activity behaviors and nature contact (2)). “Health” has been defined as “a state of complete physical, mental and social wellbeing, not merely the absence of disease or infirmity” (3). Recent years, especially Covid 19 pandemic, taught us that health as a state of both physical and mental well-being is extremely important. Studies suggest that greater use and coverage of UGS in residential spaces can improve behavioral development, reduce rate of Attention of Deficit Hyperactivity Disorder in children, help restorative psychological effects, and reduce the feelings of loneliness (4).

Rapid urbanisation leading towards changes in land use and land cover (LULC) is a major global concern (5). The population growth in cities coupled with unplanned and extensive development poses multiple challenges on sustainability and management of urban environments (6). The United Nations Population Fund (7) report says that India is anticipated to be world’s most populous country by 2023 having a population of close to 142 crore (7). Additionally, India’s urban population is expected to reach 40.76% by 2030 as compared to 34% in 2020 (8) and UNFPA (9). Population growth leads to intensive anthropogenic activities impacting infrastructure management and physical environment of the cities (10). These also limit availability and accessibility of public facilities causing irreversible losses to natural environment including water bodies, vegetation and similar ones.

Increased demand for commercial spaces, industrial zones, and infrastructure development leads to the expansion of built-up areas. An economic multiplier effect is seen in terms of population growth, investments, improvements in transport network and communication, better living standards, higher education facilities and employment opportunities (11, 12). These shifts in economic development transform the urban landscape, eventually leading to urban sprawl and finally urban agglomeration. As a consequence, LULC in these cities generally experience large scale changes which is reflected through depleting natural resources and quality of physical environment (13).

The Indian government launched multiple schemes to address land management, sustainable city development and urban infrastructure accessibility. Some of these schemes are Jawaharlal Nehru National Urban Renewal Mission (JNNURM-2005), Smart Cities Mission (2015), Atal Mission for Rejuvenation and Urban transformation (AMRUT-2015) and National Heritage City Development and

Augmentation Yojana (HRIDAY-2015), Housing for All by 2022[1]. With the introduction of such schemes, it is imperative that through analysis of the changes occurring because of these change management should also be a place to evaluate impacts. This evaluation requirement emphasises the need for assessing the current spatio-temporal land use dynamics of Indian cities. Such evaluation helps in comprehending the changes observed in LULC mosaic for effective urban planning. This also helps in viewing planning from the perspective of efficient natural resource management, distributive management of economic development and environmental conservation. These are more important considering the fact that climate change is real and is going to impact several cities adversely unless the planning process takes into consideration the implications of the same. Understanding the dynamics and consequences of changing urbanisation process is key for the policymakers and urban planners to make informed decisions regarding land requirements considering the current and future needs (15, 16).

Research studies acknowledged the significance of monitoring LULC changes at multiple spatial and temporal scales. The current study makes an attempt to understand the urban sprawl and LULC change dynamics in three major metropolitan cities in India that have seen exponential growth in recent time. The paper focuses on analysing the spatial changes over last couple of decades in terms of LULC including built-up expansion. The analysis has used remote sensing data and GIS techniques as a standard methodology. In addition to these, the paper illustrates imbalance in urban expansion at the expense of natural resource components in the said cities. According to the findings of the research, an integrated planning and management of urban development is required to balance competing demands for land use and to mitigate the negative effects of LULC change on natural resources and human well-being. Unless the planning process identifies the limits to growth considering the carrying capacities of the cities on multiple fronts, it would lead to disastrous consequences in future.

2.0 Study Area

One of the prime of this study is to understand how the land use land cover has changed in granular geographies in these cities. Therefore, we have chosen those cities that recorded rapid growth in recent times. All three cities selected have seen drastic changes in the last couple of decades. Renewed economic activities have attracted corporates to invest and as a consequence migration to these cities has increased manifold. As the population increases, demand for real estate and other urban amenities and infrastructure have also gone up significantly. As an obvious consequence urban expansion takes place. The existing literature suggested that the potential of a city and its growth to different stages of development, such as from a small city to metropolitan area, conurbation, megacity, and finally to a megalopolis, can be visualised and modelled (17, 18). Considering these three major Indian urban agglomerations, namely NOIDA, Pune, and Bengaluru were chosen to understand the growth pattern and also the differences in growth path of these cities. These Indian megacities has showed significant urbanisation over the past decade.

[1] https://mohua.gov.in/

The NOIDA (New Okhla Industrial Development Authority) is one of the largest industrial setups in National Capital Region (NCR) adjacent to Delhi, the capital of India. NOIDA is also known as one of the satellite cities of Delhi, located in Gautam Buddha Nagar district of Uttar Pradesh. It was developed under the U.P. Industrial Area Development Act, 1976, with the primary goal of decongesting the national capital and establishing an industrial area.[2] The city is divided into 189 sectors. The total population of NOIDA was recorded 6.37 lakh in as per latest population census in 2011 (22) which has reached to 8.2 lakh in 2023.[3] The presence of numerous industries, MNCs, and educational institutions attract a large number of people to this city.

Figure 1: Location of Selected Cities

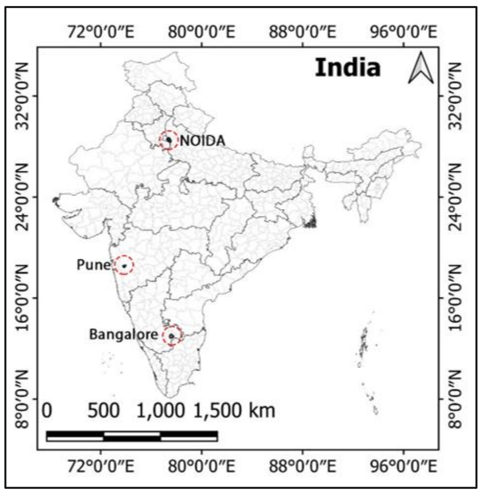
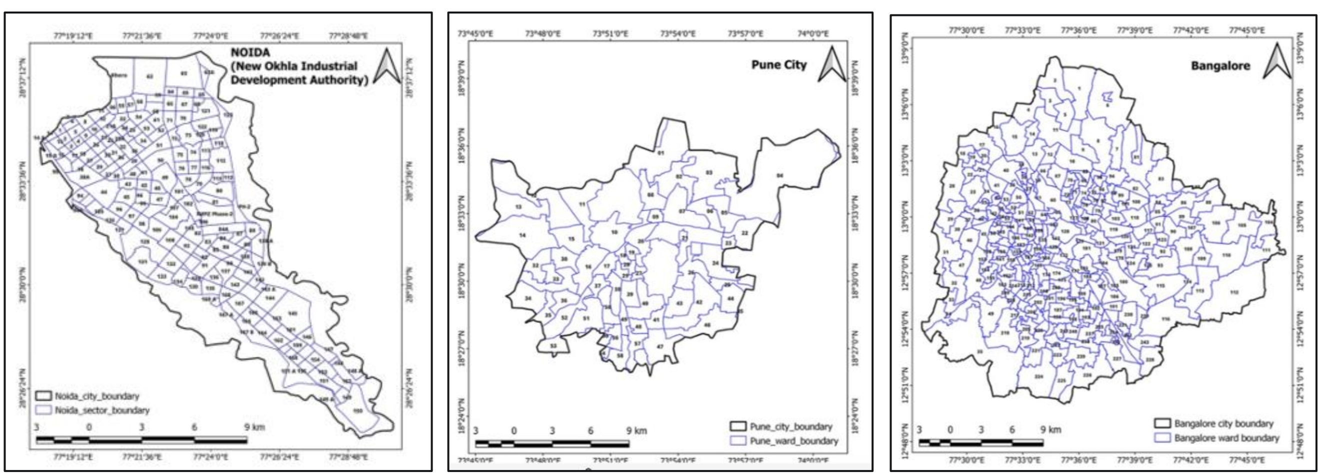


Figure 2: Sector/Ward Level Maps of NOIDA, Pune and Bengaluru



[2] NOIDA Master Plan
[3] https://www.findeasy.in/noida-population/

Pune is one of the eight megacities in India and the second largest and fastest-growing city in Maharashtra. Pune has emerged as an important location for manufacturing industries. It is now also recognised as the country's information technology and education hub (26). Pune city covers an area of 303.56 km^2 including all cantonment areas. As per India's population census of 2001 and 2011, Pune city has a total population of 25.38 lakh and 31.24 lakh respectively. In 2023 Pune's population is estimated to be 41.07 lakhs. In 2011 it had 76 general electoral wards. However, the current draft delimitation map for the 2022 elections proposes 58 electoral wards in Pune city. There are 564 slums in the Pune Municipal Corporation area.

Bengaluru, also known as Bruhat Bengaluru Mahanagara Palike (BBMP), is the administrative, commercial, cultural, industrial, and knowledge capital of Karnataka. It is composed of 243 wards and comes under Bengaluru urban district. Bengaluru is commonly referred to as the Silicon Valley of India due to its prominent position in the information technology (IT) industry.[4] Bengaluru city covers an area of 716.28 km^2. It is expanding rapidly fueled by economic growth, the availability of land, employment opportunities with a high standard of living and a favourable climate (36). From 2001 to 2011, the urban population of Bengaluru increased from 50.22 to a total of 96.21. In 2023 the population in Bengaluru is estimated to be 136 lakhs. However, rapid and intensive urbanisation in Bengaluru over the past few decades has led to environmental and social challenges, including the loss of vegetation and croplands, pollution, unprecedented traffic congestion, urban floods and urban heat island effect.

LANDSAT multi-temporal and multi-sensor images from 2001, 2010, and 2022 for the selected cities were used in this study. The satellite images were obtained through the USGS Earth Resource Observation Systems Data Centre.[5] The details of the Landsat satellite sensors are given in Table 1, 2 and 3 for the three selected cities. LANDSAT images are radiometrically corrected using QGIS 3.28 software for creating False Colour Composite (FCC) image to perform image classification are given below.

[4] Scalers.com
[5] USGS Earth Explorer website

Figure 6: FCC Images - NOIDA

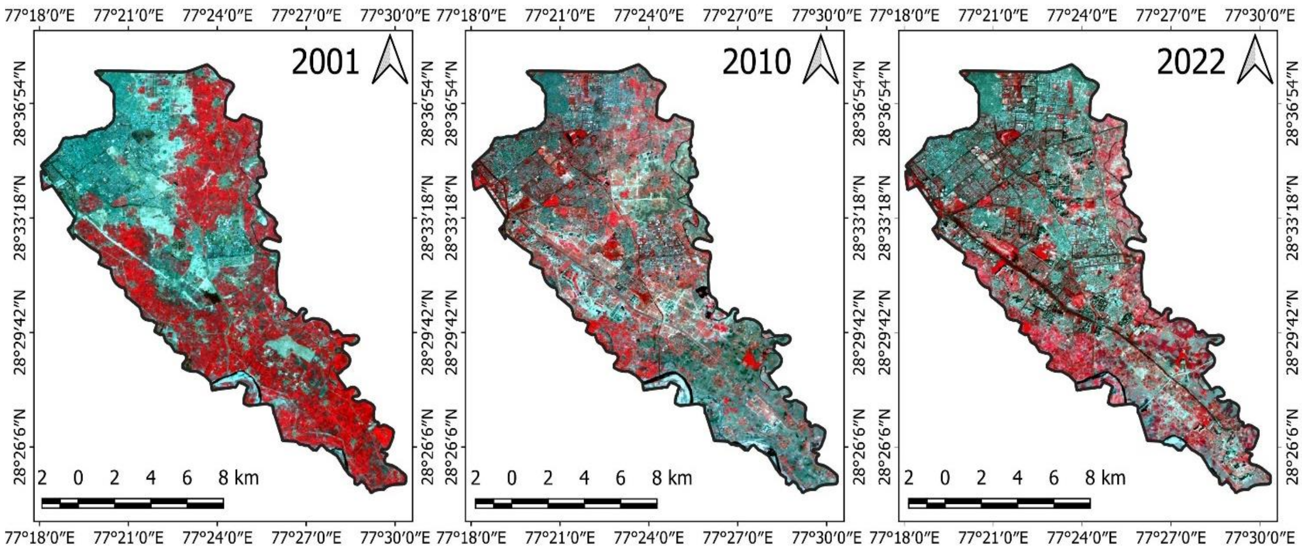


Figure 7: FCC Images - Pune

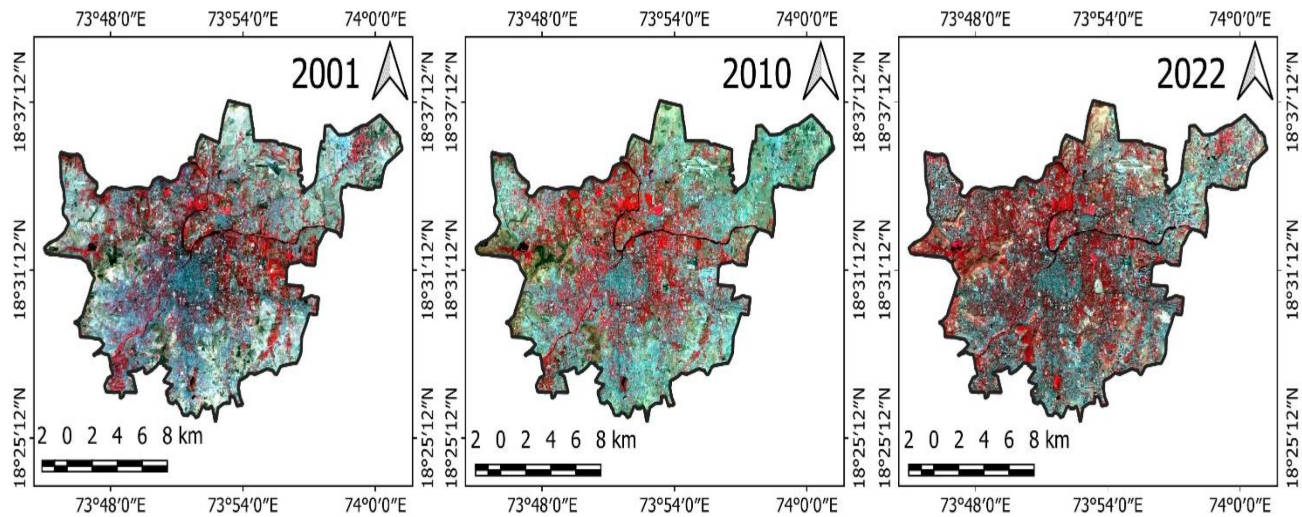
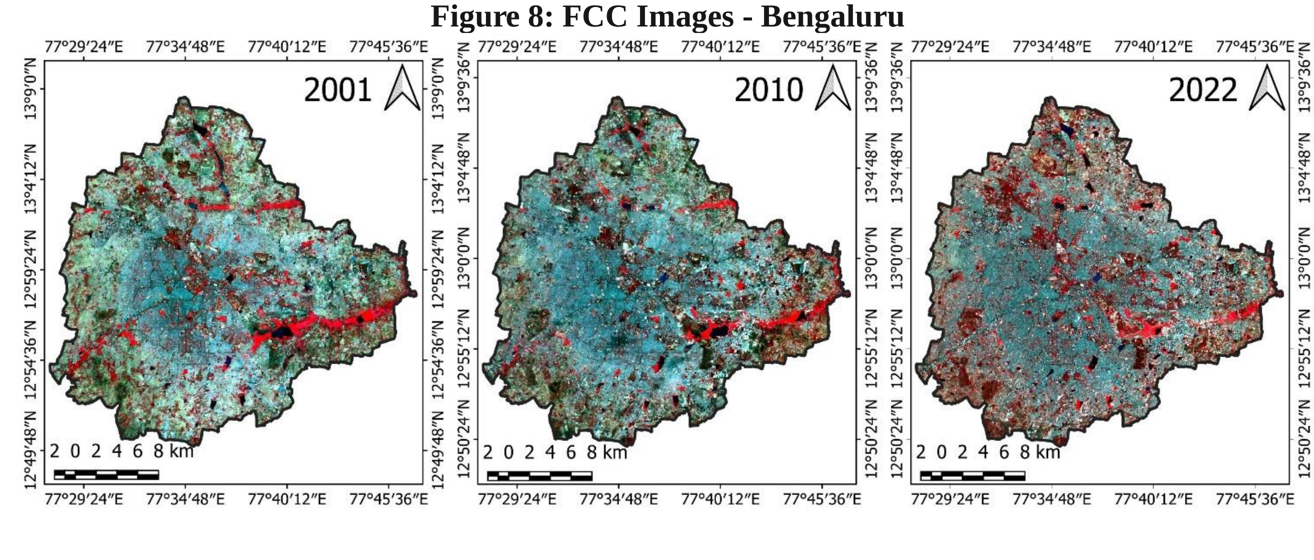


Figure 8: FCC Images - Bengaluru



3. LULC Classification Method

An urban area is a complex ecosystem composed of diverse materials. Concrete, asphalt, metals, plastic, soil cover, buildings, highways, and roads are examples of heterogeneous materials. The urban ecosystem can be classified into three components - impervious surface material, green vegetation, and exposed soil (46, 47). Some of the materials form distinct features that can be easily distinguished from the satellite image in False colour Composite (FCC), whereas others, such as scattered trees, individual buildings, soil with sparse vegetation, green croplands and other urban features are not easily identifiable due to the sensors' low spatial resolution and appear with a mixed coloured pixel instead of a singular pixel colour. This is thus crucial for satellite image classification to train the image with adequate sample size (70%) and use suitable algorithm based on distinguishable pixel values.

According to National Remote Sensing Centre (48,49) LULC classification based on mapping scale, consists of Level-I: 8 classes, Level-II: 24 classes and Level-III: 54 classes.[6] For this research purpose, broadly six LULC classes were determined from Level-I classes (discarding snow) using a supervised maximum likelihood classification (MLC) algorithm: (i) Water (rivers, lakes, ponds, and other reservoirs), (ii) Vegetation (tree cover, forest and dense vegetative areas) (iii) Urban (residential, industrial, commercial, and transportation network area), (iv) Agriculture (crop lands), (v) Fallow land (barren land, spare vegetative areas, arid and semi-arid spaces), and (vi) Open green (open green zones, playgrounds, parks, grassland). Previous research shows that MLC has the potential to achieve more accurate classification compared to various other algorithms (50, 51, 52). All Landsat satellite images of the selected cities for the years 2001, 2010 and 2022 were classified into these six classes to further measure the decadal change in LULC of the cities and compare those with each other.

This analysis has been extended in computing livability index for these three cities at the granular administrative level. Urban development requires a balance between urban facilities like built up area, transportation etc. along with the natural habitat. Unless the natural endowments are restored while expanding urban activities, it impacts sustainability of the city in near future since several ill impacts affect the residents. Abrupt changes in LULC leads to uncertainty of habitable condition of the cities. These ultimately will worsen the living condition and attractiveness of these cities resulting in traffic congestion, urban heat island effect, frequent flooding, landslides etc. (53, 54, 54, 55, 57. 58).

It is thus important to analyse the current livability condition of different sectors/ wards so that an informed decision can be made by all stakeholders including the urban civic body as well as residences. With an index live the livability index as used in this study, and an understanding the trend of change in livability index over the different time frames can indeed help strategy planning at the overall as well as individual level. The sectoral/ward-wise analysis of livability index for these there cities can help municipal governance to perform better from decision making point of view. Multi Criteria Decision Analysis (MCDA) technique has been used in computing the livability index. It is

[6] Technical document on LULC database for dissemination through Bhuvan and Remote Sensing Application by NRSC

one of the useful techniques where data-driven output in form of multiple and conflicting criteria helps in decision making (59, 60, 61). Though some of the other techniques are also available for similar purpose like Analytical Hierarchy Process (AHP), Multi-Attribute Rating Technique (SMART) etc., this method was preferred since only secondary data was used for this objective in absence of primary survey data. A scheme of subjective weights for each LULC variable is implemented to compute the livability index. Equal weights were not used to avoid conflicting results (62, 63, 70). The weight for each LULC variable was assigned on a scale of 0 to 5 based. The research team did an expert consultation and also used available literature to arrive at the weights (74, 75, 76).

The primary thumb rule used for the weighting scheme is the importance of each LULC parameter from an urban sustainability point of view. Urban sustainability aims to improve the social, economic, and environmental conditions of a city to ensure the quality of life and well-being of current and future residents.[7] A healthy and happy living can be defined as a balance between natural and man-made endowments of a place. For example, higher the built-up density in an area, it is less livable and also potential for further urban development is also lesser. Several areas turn into jungle of concretes in many cities that makes it a challenge from livability point of view. The sustainable development goal (SDG) are less likely to be achieved in these locations. As explained earlier, discussions with experts helped in deciding on the subjective weights for each LULC criteria.

After performing the sector/ward-wise livability index (LI) assessment using MCDA technique, the sectors/wards are ranked based on the performance score obtained using the following equation:

LI = $\sum_{n=1}^{n}(Water_n.W1_n + Vegetation_n.W2_n + Builtup\ area_n.W3_n + Agriculture_n.W4_n + Fallow\ land_n.W5_n + Open\ green_n.W6_n)$ ………………………..(1)

, where 'Wi_n' denotes the weights assigned to each corresponding LULC class (Table 7) and 'i' refers to the class no. from 1 to 6 as mentioned in Table 7. Finally, ranking is done based on the LI score. Highest LI score is ranked 1 and the lowest score is ranked the last among the sector/wards in each city.

4. Results

4.1 LULC change in NOIDA

NOIDA was predominantly an agricultural region in 2001 comprising 77% of the area covered with crop lands which was reduced to 49% in 2010 and subsequently to 24% in 2022. On the contrary the Urban area which was 13% of the total area in 2001 increased to 30% in 2010 and to 49% in 2022. In 2001 the urban areas were mostly concentrated in the north eastern part of the city which has closer proximity to Delhi. However, the maps presented in Figure 8 show that over time the urban areas sprawled to southeast and southern regions covering all parts of the city. Two other most notable changes are recorded for vegetation and fallow land. Normally one expects that vegetation cover

[7] https: /www.studysmarter.co.uk/explanations/human-geography/urban-geography/urban-sustainability/

decreases with increase in urban space in any city. Contrary to general belief vegetation cover has increased with growth in urban space as shown in Figure 9. The vegetation cover increased from 2% to 14% between 2001 to 2022. However, the growth in vegetation cover was smaller between 2010 to 2022 compared to that of 2001 to 2010. Satellite images of year 2010 and 2022 of sample areas where green cover has increased are presented in Figure 10. This signifies the engagement of the city dwellers (resident associations) and urban authorities towards urban green space maximization focusing on vegetation growth in parallel with construction activities. The newly developed sectors, such as sector 42, 47, 75, 137 etc., are developed following improved urban planning, considering restoring and maintenance of the green spaces. The open green space and water area is found to reduce after 2010 primarily due to rapid urbanization.

Figure 8: Change in Land Use and Land Cover from 2001 to 2022 NOIDA

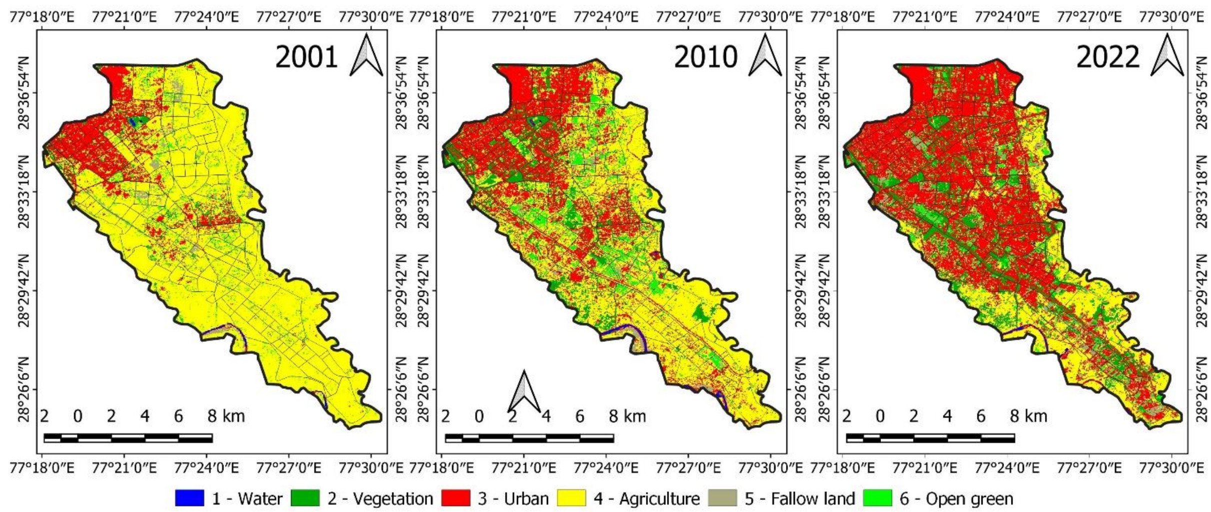


Figure 9: Distribution of LULC classes of NOIDA

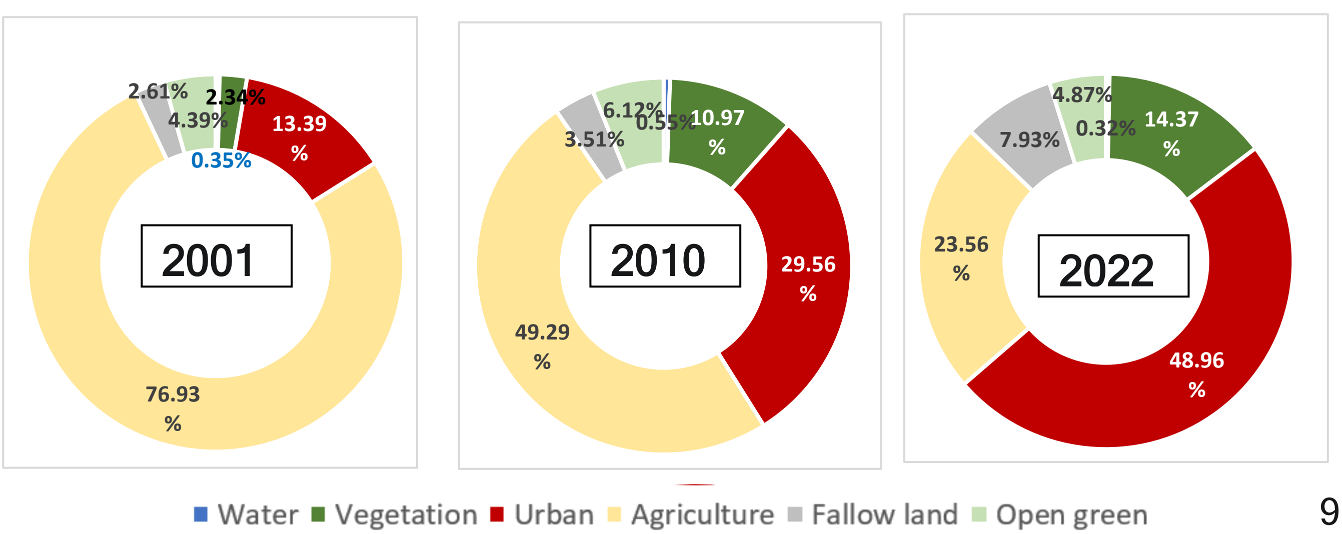


Figure 10: Sample Images of Increase in Green Space in NOIDA between 2010 to 2022

Note: Top - Land use type without green cover - 2010; Bottom - Conversion of land to green space (2022)

4.2 LULC changes in Pune

In contrast to NOIDA, Pune had predominantly fallow lands in 2001 comprising 42% of the total land area. However, it decreased to 35% in 2010 and further massive decrease was noted to 13% in 2022. Vegetation cover recorded a swing from 21% in 2001 to 13% in 2010 and again back to 22% in 2022. A significant increase in the share of urban space was noticed between 2001 to 2010 and 2010 to 2022. From 29% in 2001 the share of urban space increased to 41% in 2010 and in 2022 it reached a high of 52%. It can be assumed the first phase of urbanization process during 2001 to 2010 is predominantly expanded as the cost of vegetative area and fallow land, but after 2010 the urbanization primarily grew using the fallow lands (Figure 11). Surprisingly, the agricultural land of Pune observed marginal increase during 2001 to 2022. Water area has also shown marginal increase between 2001 to 2022. Open green space has also observed marginal increase during the study period. It signifies, development of open green areas in the city such as playgrounds, parks and preservation of grassland. A significant example can be the Khadki Cantonment regions which have succeeded in maintaining the green cover with public initiatives. Similarly, Taljai Hill (protected area under the control of the Ministry of Forest, Government of Maharashtra) has been transformed from barren land to green cover in the last decade. It may also be the reason that the vegetative cover has also increased during 2010 to 2022 in Pune (Figure 11). An increase in vegetation cover and open green space is definitely a good sign for the city.

Figure 11: Change in Land Use and Land Cover from 2001 to 2022 - Pune

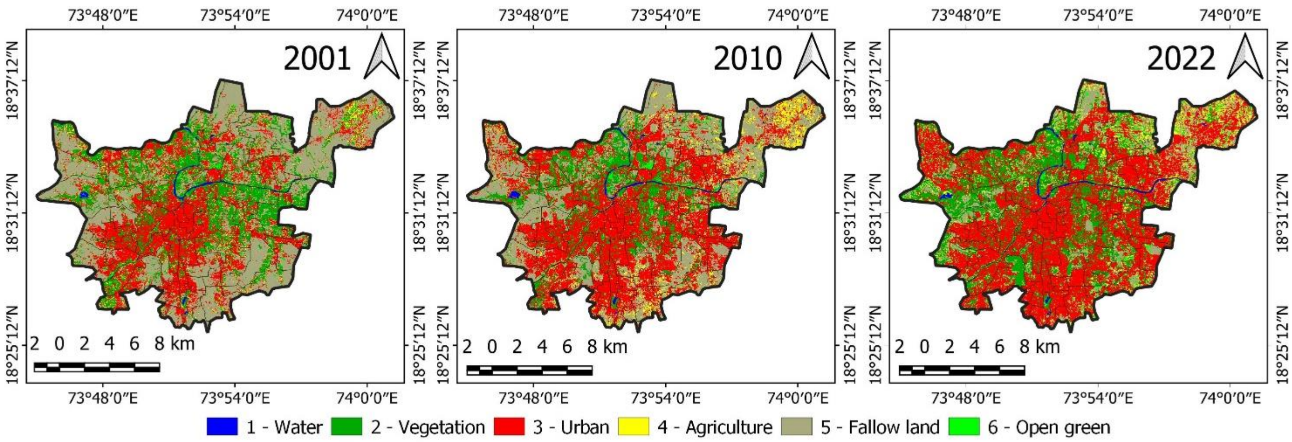


Figure 12: Distribution of LULC classes of Pune

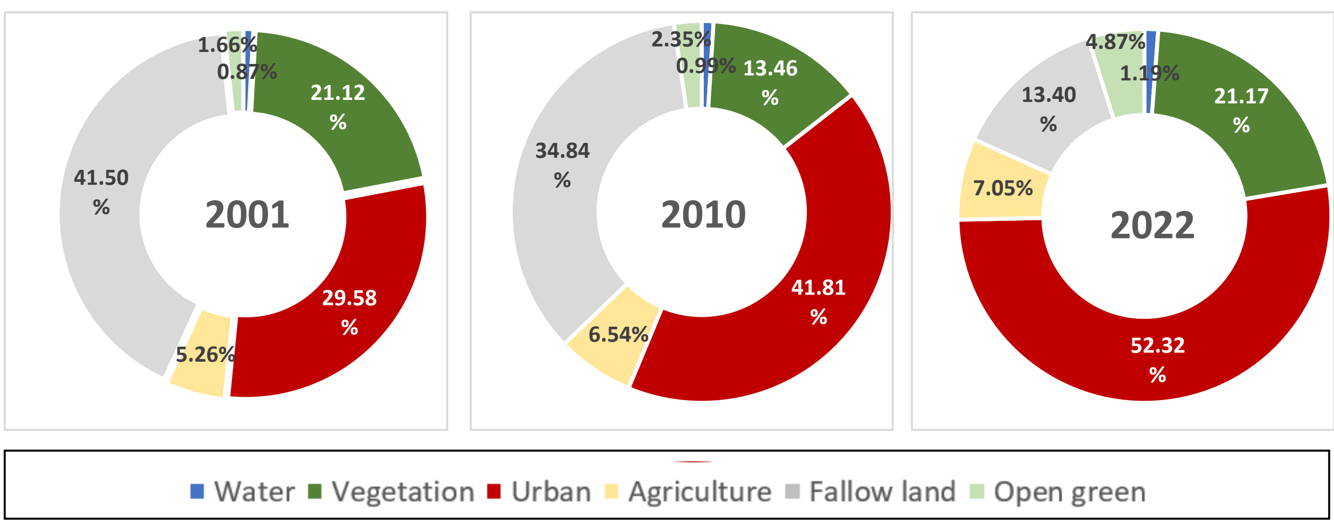


Figure 13: Green space maximization in Pune; Top - Land use type without green cover (during 2010 to 2013); Bottom - Conversion of other land use type converted to green space (2022)

4.3 LULC Change in Bengaluru

Urban growth of Bengaluru is observed to the worst and at alarming condition compared to NOIDA and Pune as it tends to almost reach the saturation with built-up surfaces. The city has so over growth with built-up area that there is hardly any breathable space left. The city grew concentrically and radially outwards over the decades. Bengaluru, the 'Silicon Valley of India' also known as lake city shows a rapid decline of waterbodies of 0.52% and 0.78% during 2001 to 2010 and 2010 to 2022 respectively as shown in Figure 14. Agricultural area decreased by 7.80% during 2001 to 2010 and even more during 2010 to 2022 by 20.50% (Figure 14). Vegetative cover also decreased by 4.04% during 2001 to 2010 and 1.65% during 2010 to 2022. Fallow land also decreased by 0.31% and 1.29% during 2001 to 2010 and 2010 to 2022 respectively. The open green space showed negligible increment of 0.03% during 2001 to 2022 primarily due to development of open green space, parks, stadiums, playgrounds etc. In contrast to the decrease of all other LULC classes, Urban space shows significant increment of 12.64% during 2001 to 2010, which was doubled up by 24.22% during 2010 to 2022. From Table 6 and Figure 14, it is evident from the rapid declination of agriculture area that the urban space is primarily increased at the cost of agriculture areas followed by vegetative areas and fallow land. The city is hardly left with any porous surface and that may be the prime reason of urban floods and frequent heatwave occurrence in Bengaluru [49, 50, 51]. Due to the rapid urbanization in Bengaluru the traffic congestion can also be assumed to be high [52].

Figure 14: Change in Land Use and Land Cover from 2001 to 2022 - Bengaluru

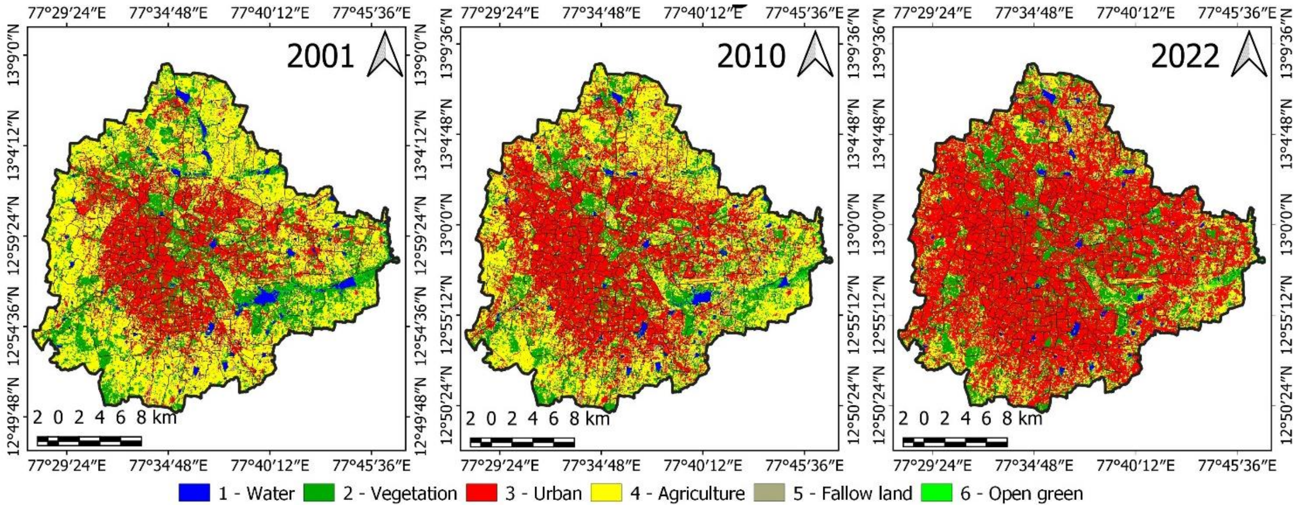
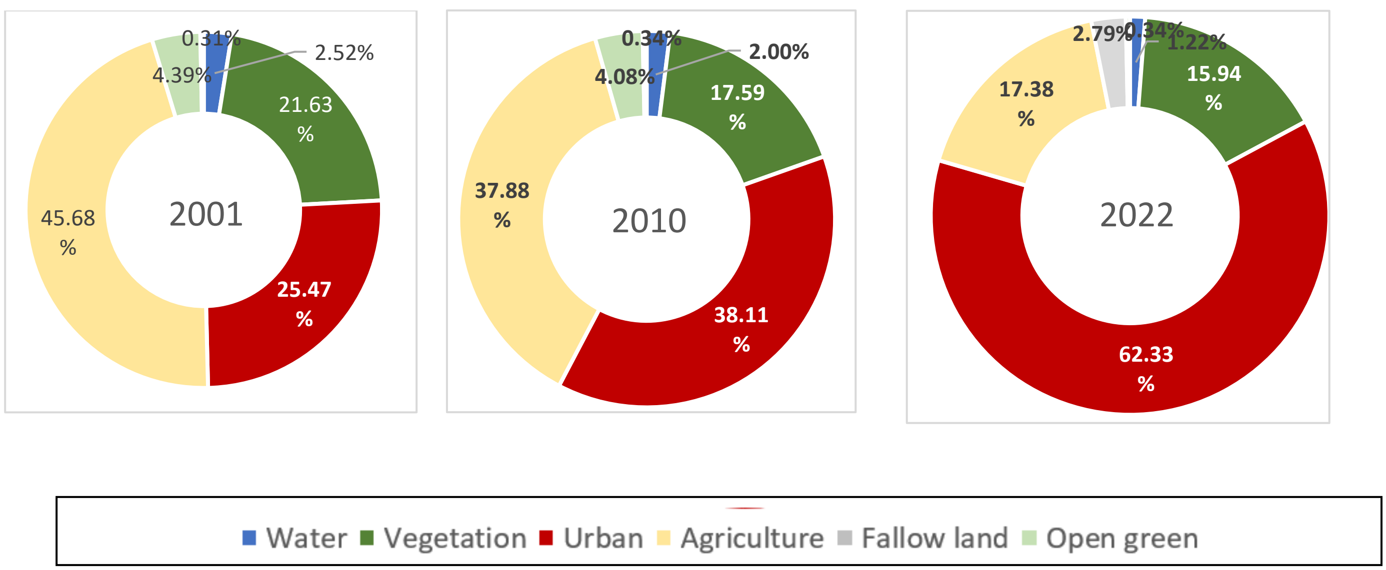


Figure 15: Change in Proportion of LULC Categories in Bengaluru



3.0 Sector-wise Urban Livability Index (ULI) assessment

The sectoral livability performance of the ward/sectors of NOIDA, Pune and Bengaluru based on scores obtained through the MCDA technique has been discussed below. While interpreting the scores and ranking, it is important to consider that the scores are computed based on LULC characteristics of the sector/wards of these cities. The reason for highlighting this point is to make sure that the one should not be confused between residential areas alone and the livability index. The livability index by default considers any and every land parcel in the city as given by the administrative boundaries of these municipalities. It includes various points of interest such as campus of academic institutes, stadiums, hospital, malls, industrial units and every other land use characteristic as experienced in any city. Therefore, comparing only residential areas with these scores or ranks would be misleading.

When the livability of a city ward/sector is determined, this can be done in two ways. The best one is to define benchmark scores for level of livability and define the allocation based on the score obtained for each of the ward/sector of the city. The scheme of weights to be used in a manner that the categories of livability are distinctly identified and represented. The second option, which is less complicated in terms of usage of weights, is to distribute the wards/sectors of these cities following a standard categorization method using the obtained scores. We have opted for the second method, since no literature was found that supports the weighting schemes to be used. The weighting scheme used in the paper for computing livability index is subjective in nature as it was derived based on consultation with experts. More concrete weights schemes would be appropriate to use such complicated method as discussed for option one.

The wards/sectors of these cities are categorized into 5 groups based on level of livability. Those are namely, *very high, high, moderate, poor* and *very poor*. The categorization used mean and standard deviation of the LI scores to obtain this distribution which is a standard and more scientific method. This says that the categories are more relative to each other in nature instead of representing an absolute one.

We have presented the distribution only for 2022 since with a relative year specific measure for categorization, comparison of three time points might not represent the changes in true sense. The distribution suggests that in Noida and Pune close to 40% of the wards/sectors fall under *very high* and *high* category, of course with a small proportion of *very high* category (4.2% and 6.9% for Noida and Pune respectively). In both cities the wards/sectors in moderate category are close to 20%. On the contrary, in Bengaluru sectors in *very high* livability category is close to 9%, which is higher than Noida and Pune, but *very high* and *high* together account for about 30% of the total wards in the city, which is significantly lower compared to other two cities. The wards in *moderate* category in Bengaluru are also higher compared to Noida and Pune. One interesting fact is the % of wards in *poor* category in Bengaluru is about 30% which is more or less similar to that of the other cities, but none of the wards falls under *very poor* category. On the other hand, in both Noida and Pune 6% and 10% wards/sectors fall under *very poor* category.

Though apparently it seems that Bengaluru might be a better city in terms of livability based on the distribution as discussed above, it is not true. It looks like that because of the fact that the categorization represents a relative scenario only in comparison to the wards within each of these cities. The basic parameters as presented in Table 1 suggest that Noida and Pune are better placed when livability is considered. Since the same weights were used LULC categories for each of these cities, the livability scores are comparable across these cities. The mean score of LI is significantly higher in Noida and Pune compared to Bengaluru. The distribution of LI score also shows that the median score in Noida and Pune is almost 3 times to that of Bengaluru. Bengaluru also records highest standard deviation among these three cities. The coefficient of variation, which represents variability of LI within each city is also much higher in Bengaluru compared to that of Noida and Pune. From an overall perspective, Noida is the best city in terms of livability followed by Pune. Bengaluru is way behind these two cities when livability is considered as computed with the help of LULC categories.

Table 1: Basic Statistical Parameters of Livability Index

Parameter	Noida	Pune	Bengaluru
Total Wards/Sector	189	58	243
Standard Deviation	88	100	107
Mean	293	282	222
Median	322	327	112
Coefficient of Variation	30.19	134	48.12

Figure 16: Livability Distribution of Sectors - NOIDA 2022

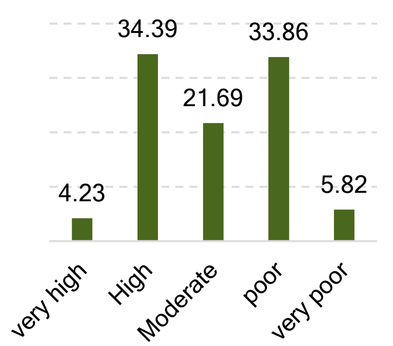


Figure 17: Livability Distribution of Sectors - Pune 2022

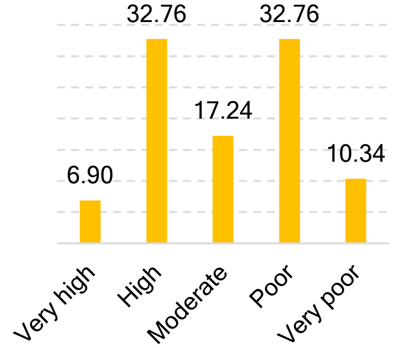


Figure 18: Livability Distribution of Sectors - Bengaluru 2022

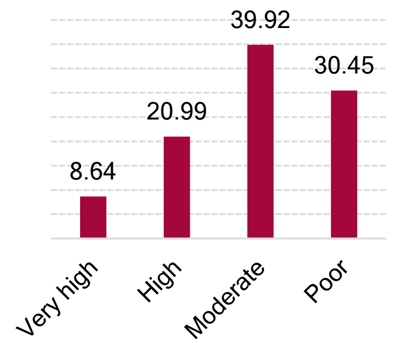


Table 2 to Table presents the top 10 best and bottom 10 least livable sectors wards/sectors of NOIDA, Pune and Bengaluru along with their LI scores.

Table 2: Top 10 Highly Liveable and Least Liveable Sectors in NOIDA - 2022

Sector	Sector area (in ha)	LI Score	LI Rank
Top 10 Best Liveable Sectors			
93 B	57.29	469	1
143 A	25.8	452	2
154	62.54	449	3
148 A	114.06	448	4

113	42.2	445	5
104	177.97	443	6
38A	174.27	436	7
93 A	68.81	427	8
14 A	6.85	426	9
135	90.01	421	10
10 Least Liveable Sectors			
5	54.07	127	180
9	32.88	121	181
2	39	118	182
16	24.56	114	183
10	32.33	112	184
Khora	397.04	110	185
22	71.62	109	186
102	106.82	108	187
59	47.55	108	188
66	70.78	102	189

Table 3: Top 10 Highly Liveable and Least Liveable Sectors in Pune - 2022

Ward no	Ward area (ha)	LI Score	LI Rank
Top 10 Highly Liveable Sectors			
51	597.43	476	1
11	709.04	472	2
8	403.38	462	3
15	478.36	443	4
21	832.98	422	5
10	740.47	419	6
22	429.47	388	7
14	1296.65	383	8
3	1211.02	381	9
7	689.61	373	10
10 Least Liveable Sectors			
31	184.33	197.05	49
39	270.54	196.19	50
56	199.04	195.33	51
49	149.31	191.47	52
18	109.73	122.61	53
55	145.59	110.96	54
29	124.79	104.14	55
19	103.3	102.21	56
28	81.81	101.5	57

27	94.38	101.37	58

Table 5: Top 10 Highly Liveable and Least Liveable Sectors in Bengaluru - 2022

Ward no	Ward area (ha)	LI Score	LI Rank
Top 10 Highly Liveable Sectors			
39	226.79	484	1
40	552.76	474	2
118	377.23	471	3
60	746.5	467	4
15	735.51	465	5
13	444.84	464	6
115	948.95	453	7
119	365.06	448	8
129	354.16	426	9
73	152.3	423	10
10 Least Liveable Sectors			
69	81.81	101	234
185	105.6	101	235
169	45.74	101	236
166	43.96	101	237
164	106.56	100	238
194	68.44	100	239
55	65.93	100	240
160	45.42	100	241
63	64.51	100	242
138	71.21	100	243

6. Concluding Remarks

In the past few decades Indian urban space have experienced rapid changes on all fronts, especially in terms of land use and land cover changes. The changes in land use land cover have reshaped many Indian cities with urban built forms at the loss of agriculture lands and green areas. This phenomenon has led to many natural calamities in these cities gradually transforming it into poor livable ones. Urban flooding, Drought, irregular monsoon rains have become frequent due these intensified LULC change. These anthropogenic activities have also led to degradation of natural elements of habitable built environment such as land, air, water. Most of the previous research was only limited to analysing the changing pattern of land use landcover at more macro-city level. This study is an attempt to compare three Indian metropolitan cities at granular level to analyse the sector/ward wise changes LULC pattern over the past couple of decades. The study helps to identify different sectors/wards where intensified urban activities have already taken place and also the potential locations for new development, especially from livability perspective. It facilitates monitoring the livability performance within the city at granular level. From this analysis we can identify which sector needs immediate urban planning management plan to mitigate the extensive increase of built-up density and lack of greenery and other natural elements required in residential areas. If the authorities intend to monitor the changes in LULC pattern at granular locations it will help the cities and their residents to live a healthy life which is also beneficial from economic productivity point of view.

7. References

1. Van den Berg AE, Maas J, Verheij RA, Groenewegen PP. Green space as a buffer between stressful life events and health. Soc Sci Med. (2010) 23:1203– 10. doi: 10.1016/j.socscimed.2010.01.002 2.
2. Van den Berg M, van Poppel M, van Kamp I, Andrusaityte S, Balseviciene B, Cirach M, et al. Visiting green space is associated with mental health and vitality: a cross-sectional study in four european cities. Health Place. (2016) 38:8–15. doi: 10.1016/j.healthplace.2016.01.003 3. Wang H, Dai X, Wu J, Wu X, Nie X. Inf
3. Hartig T, Mitchell R, De Vries S, Frumkin H. Nature and health. Annu Rev Public Health. (2014) 35:207–28. doi: 10.1146/annurev-publhealth-032013-182443
4. Amoly E, Payam D, Forns J, López-Vicente M, Basagaña X, Julvez J, et al. Green and blue spaces and behavioral development in barcelona schoolchildren : the BREATHE Project. Childrens Health. (2014) 122:1351– 8. doi: 10.1289/ehp.1408215
5. Bhat, P. A., ul Shafiq, M., Mir, A. A., & Ahmed, P. (2017). Urban sprawl and its impact on landuse/land cover dynamics of Dehradun City, India. *International Journal of Sustainable Built Environment*, *6*(2), 513-521.
6. Sharma, S., Hussain, S., & Singh, A. N. (2023). Impact of land use and land cover on urban ecosystem service value in Chandigarh, India: a GIS-based analysis. *Journal of Urban Ecology*, *9*(1), juac030.
7. United Nations Population Fund (UNFPA) State of World Population report (SWOP2023-ENGLISH-230329-web.pdf (unfpa.org)).
8. World Bank Data (Urban population (% of total population) - India | Data (worldbank.org)).
9. State of World Population 2007, Unleashing the Potential of Urban Growth by United Nations Population Fund(UNFPA) (EN-SOWP07-FINAL_PDF.QXD (unfpa.org)).
10. Nuissl, H., & Siedentop, S. (2021). Urbanisation and land use change. *Sustainable land management in a European context: a co-design approach*, 75-99.
11. Hoselitz, B. F. (1957). Urbanization and economic growth in Asia. *Economic Development and Cultural Change*, *6*(1), 42-54.
12. Zhang, P., Li, Y., Jing, W., Yang, D., Zhang, Y., Liu, Y., ... & Qin, M. (2020). Comprehensive assessment of the effect of urban built-up land expansion and climate change on net primary productivity. *Complexity*, *2020*, 1-12.
13. Fang, C., & Yu, D. (2017). Urban agglomeration: An evolving concept of an emerging phenomenon. *Landscape and urban planning*, *162*, 126-136.
14. 6 Urban Development Schemes You Should Know About by Proptiger. (https://www.proptiger.com/).
15. Gu, C. (2019). Urbanization: Processes and driving forces. *Science China Earth Sciences*, *62*, 1351-1360.
16. Kumar, D. A., & Rai, A. K. (2014). Urbanization process, trend, pattern and its consequences in India. *Neo Geographia*, *3*.
17. Li, R. Y. M., & Hung, R. (2013). Rostow's Stages of Growth Model,'Urban Bias' and Sustainable Development in India. *Li, Rita Yi Man and Hung Ronald (2013) Rostow's Stages of Growth Model,"Urban Bias" and Sustainable Development in India, Journal of Contemporary Issues in Business Research*, *2*(5), 170-178.
18. Birch, D. L. (1971). Toward a stage theory of urban growth. *Journal of the American Institute of Planners*, *37*(2), 78-87.
19. Noida Authority (2019) Master plan 2031 (https://noidaauthorityonline.in/site/writereaddata/siteContent/201902081033447759MASTERPLAN2031-Detail.pdf).
20. Climatedata.org (Greater Noida climate: Temperature Greater Noida & Weather By Month - Climate-Data.org).

21. Noida Town Population Census 2011 – 2023 (Noida City Population 2023 | Literacy and Hindu Muslim Population (census2011.co.in))
22. Office of the Registrar General & Census Commissioner, India. Population Census 2001. Table Town directory, Uttar Pradesh – 2001.
23. Sinha, S. K. (2015). Urban growth of Noida city, Uttar Pradesh. *Population*, *75000*(200000), 400000.
24. Sharma, R., Pradhan, L., Kumari, M., & Bhattacharya, P. (2022). Urban Green Space Planning and Development in Urban Cities Using Geospatial Technology: A Case Study of Noida. *Journal of Landscape Ecology*, *15*(1), 27-46.
25. Mandlik, D. D. (2020). Pune Traffic Congestion: Reality, Cause and Regulation a Case Study. *International Journal of Management (IJM)*, *11*(3).
26. Mundhe, N. N., & Jaybhaye, R. G. (2017). Chronological development of Pune from 758-2014 AD. *International Journal of Environment, Ecology, Family and Urban Studies*, *7*(5), 33-50.
27. Time and date (Climate & Weather Averages in Pune, Maharashtra, India (timeanddate.com)).
28. Census 2011 (Pune Population, Caste Data Pune Maharashtra - Census India).
29. Pune Town Population Census 2011 – 2023 (Pune Municipal Corporation City Population Census 2011-2023 | Maharashtra).
30. Open city urban data portal (Pune Wards Info - Pune Electoral Wards Map - 2017 - OpenCity - Urban Data Portal).
31. Pune Municipal Corporation (PMC) (Election Department | Home | Pune Municipal Corporation (pmc.gov.in)).
32. General features of Pune District (Microsoft Word - CHAPTER1.doc (mpcb.gov.in)).
33. Slums in Pune by Pune Municipal Corporation (PMC) (Slums In Pune | Pune Municipal Corporation (pmc.gov.in)).
34. The Scalers' (How Bengaluru Became Asia's Silicon Valley (thescalers.com)).
35. Weatherbasea (Bengaluru, India Koppen Climate Classification (Weatherbase)).
36. Sudhira, H. S., & Nagendra, H. (2013). Local assessment of Bengaluru: graying and greening in Bengaluru–impacts of urbanization on ecosystems, ecosystem services and biodiversity. *Urbanization, biodiversity and ecosystem services: Challenges and opportunities: A global assessment*, 75-91.
37. Urbannet (Bengaluru: A Vibrant and Dynamic Indian City With An Uncertain Future? - Urbanet).
38. karnataka.com (Bengaluru economic growth | Bengaluru GDP | Global Cities Report (karnataka.com)).
39. Office of the Registrar General & Census Commissioner, India. Population Census 2001. Table Final population totals, Karnataka, District Bengaluru – 2001
40. Census of India 2011 - Karnataka - Series 30 - Part XII A - District Census Handbook, Bengaluru (India - Census of India 2011 - Karnataka - Series 30 - Part XII A - District Census Handbook, Bengaluru (censusindia.gov.in)).
41. USGS Earth Explorer website (https://earthexplorer.usgs.gov/).
42. Esri India GIS Online (Living Atlas of the World) (https://livingatlas-dcdev.opendata.arcgis.com/maps/47c0654348a2475882b86786a3ffb286/explore?location=28.504605%2C77.400200%2C10.69).
43. QGIS plugin repository (https://plugins.qgis.org/plugins/QuickOSM/).
44. Open city urban data portal (https://data.opencity.in/dataset/bbmp-ward-information/resource/bbmp-ward-map---2022).
45. Open city urban data portal (https://data.opencity.in/dataset/pune-wards-info).
46. Ridd, M. K. (1995). Exploring a VIS (vegetation-impervious surface-soil) model for urban ecosystem analysis through remote sensing: comparative anatomy for cities. *International journal of remote sensing*, *16*(12), 2165-2185.
47. Xu, H. (2007). Extraction of urban built-up land features from Landsat imagery using a thematicoriented index combination technique. *Photogrammetric Engineering & Remote Sensing*, *73*(12), 1381-1391.

48. Technical Document on – Land Use / Land Cover Database for Dissemination through Bhuvan (lulc.pdf (nrsc.gov.in)).
49. Remote Sensing Application by NRSC (Part_1 vap (nrsc.gov.in)).
50. Li, G., Lu, D., Moran, E., & Sant'Anna, S. J. S. (2012). Comparative analysis of classification algorithms and multiple sensor data for land use/land cover classification in the Brazilian Amazon. *Journal of Applied Remote Sensing*, *6*(1), 061706-061706.
51. Mishra, V. N., Prasad, R., Kumar, P., Gupta, D. K., & Srivastava, P. K. (2017). Dual-polarimetric C-band SAR data for land use/land cover classification by incorporating textural information. *Environmental Earth Sciences*, *76*, 1-16.
52. Verma, P., Raghubanshi, A., Srivastava, P. K., & Raghubanshi, A. S. (2020). Appraisal of kappa-based metrics and disagreement indices of accuracy assessment for parametric and nonparametric techniques used in LULC classification and change detection. *Modeling Earth Systems and Environment*, *6*, 1045-1059.
53. Gupta, A. K., & Nair, S. S. (2011). Urban floods in Bengaluru and Chennai: risk management challenges and lessons for sustainable urban ecology. *Current Science*, 1638-1645.
54. Ramachandra, T. V., & Kumar, U. (2010). Greater Bengaluru: Emerging urban heat island. *GIS development*, *14*(1), 86-104.
55. Ramachandra, T. V., & Mujumdar, P. P. (2009). Urban floods: Case study of Bengaluru. *Disaster Dev*, *3*(2), 1-98.
56. Ramachandra, T. V., Sellers, J., Bharath, H. A., & Setturu, B. (2019). Micro level analyses of environmentally disastrous urbanization in Bengaluru. *Environmental monitoring and assessment*, *191*, 1-13.
57. Rosenzweig, C., Solecki, W. D., Hammer, S. A., & Mehrotra, S. (Eds.). (2011). *Climate change and cities: First assessment report of the urban climate change research network*. Cambridge University Press.
58. Leal Filho, W., Wolf, F., Castro-Díaz, R., Li, C., Ojeh, V. N., Gutiérrez, N., ... & Bönecke, J. (2021). Addressing the urban heat islands effect: A cross-country assessment of the role of green infrastructure. *Sustainability*, *13*(2), 753.
59. Dodgson, J. S., Spackman, M., Pearman, A., & Phillips, L. D. (2009). Multi-criteria analysis: a manual.
60. Belton, V., & Stewart, T. (2002). *Multiple criteria decision analysis: an integrated approach*. Springer Science & Business Media.
61. Talukder, B., & Hipel, K. W. (2021). Review and selection of multi-criteria decision analysis (MCDA) technique for sustainability assessment. In *Energy Systems Evaluation (Volume 1) Sustainability Assessment* (pp. 145-160). Cham: Springer International Publishing.
62. Kumar, T., & Jhariya, D. C. (2015). Land quality index assessment for agricultural purpose using multi-criteria decision analysis (MCDA). *Geocarto International*, *30*(7), 822-841.
63. Dinca, C., Badea, A., Rousseaux, P., & Apostol, T. (2007). A multi-criteria approach to evaluate the natural gas energy systems. *Energy Policy*, *35*(11), 5754-5765.
64. Pilavachi, P. A., Stephanidis, S. D., Pappas, V. A., & Afgan, N. H. (2009). Multi-criteria evaluation of hydrogen and natural gas fuelled power plant technologies. *Applied Thermal Engineering*, *29*(11-12), 2228-2234.
65. Afgan, N. H., & Carvalho, M. G. (2002). Multi-criteria assessment of new and renewable energy power plants. *Energy*, *27*(8), 739-755.
66. Afgan, N. H., & Carvalho, M. G. (2004). Sustainability assessment of hydrogen energy systems. *International journal of hydrogen energy*, *29*(13), 1327-1342.
67. Afgan, N. H., & Carvalho, M. G. (2008). Sustainability assessment of a hybrid energy system. *Energy Policy*, *36*(8), 2903-2910.
68. Begić, F., & Afgan, N. H. (2007). Sustainability assessment tool for the decision making in selection of energy system—Bosnian case. *Energy*, *32*(10), 1979-1985.
69. Lipošćak, M., Afgan, N. H., Duić, N., & da Graça Carvalho, M. (2006). Sustainability assessment of cogeneration sector development in Croatia. *Energy*, *31*(13), 2276-2284.
70. Więckowski, J., & Zwiech, P. (2021). Can weighting methods provide similar results in MCDA problems? Selection of energetic materials study case. *Procedia Computer Science*, *192*, 4592-4601.
71. Wang, J. J., Jing, Y. Y., Zhang, C. F., & Zhao, J. H. (2009). Review on multi-criteria decision analysis aid in sustainable energy decision-making. *Renewable and sustainable energy reviews*, *13*(9), 2263-2278.

72. Diakoulaki, D., & Karangelis, F. (2007). Multi-criteria decision analysis and cost–benefit analysis of alternative scenarios for the power generation sector in Greece. *Renewable and sustainable energy reviews*, *11*(4), 716-727.
73. Bandyopadhyay, S. (2021). Comparison among multi-criteria decision analysis techniques: A novel method. *Progress in Artificial Intelligence*, *10*(2), 195-216.
74. Ram, C., Montibeller, G., & Morton, A. (2011). Extending the use of scenario planning and MCDA for the evaluation of strategic options. *Journal of the Operational Research Society*, *62*(5), 817-829.
75. Odu, G. O. (2019). Weighting methods for multi-criteria decision making technique. *Journal of Applied Sciences and Environmental Management*, *23*(8), 1449-1457.
76. Ezell, B., Lynch, C. J., & Hester, P. T. (2021). Methods for weighting decisions to assist modelers and decision analysts: A review of ratio assignment and approximate techniques. *Applied Sciences*, *11*(21), 10397.
77. Cinelli, M., Kadziński, M., Gonzalez, M., & Słowiński, R. (2020). How to support the application of multiple criteria decision analysis? Let us start with a comprehensive taxonomy. *Omega*, *96*, 102261.
78. Nurmalini, N., & Rahim, R. (2017). Study approach of simple additive weighting for decision support system. *Int. J. Sci. Res. Sci. Technol*, *3*(3), 541-544.

Appendix

A1: Sensor details of Landsat images collected for NOIDA

Year	Sensor	Scene ID	Acquisition Date	Time (GMT)
2001	Landsat-7 ETM	LE07_L2SP_146040_20010128_20200917_02_T1	2001-01-28	05:09:21
2010	Landsat-5 TM	LT05_L2SP_146040_20101129_20200823_02_T1	2010-11-29	05:08:39
2022	Landsat-9 OLI_TIRS	LC09_L2SP_146040_20221208_20230318_02_T1	2022-12-08	05:19:17

A2: Sensor details of Landsat images collected for Pune

Year	Sensor	Scene ID	Acquisition Date	Time (GMT)
2001	Landsat-5 TM	LT05_L2SP_147047_20010212_20200906_02_T1	2001-02-12	05:07:50
2010	Landsat-5 TM	LT05_L2SP_147047_20100325_20200824_02_T1	2010-03-25	05:18:45
2022	Landsat-9 OLI_TIRS	LC09_L2SP_147047_20221231_20230315_02_T1	2022-12-31	05:28:15

A3: Sensor details of Landsat images collected for Bengaluru

Year	Sensor	Scene ID	Acquisition Date	Time (GMT)
2001	Landsat-5 TM	LT05_L2SP_144051_20010327_20200906_02_T1	2001-03-27	04:51:02
2010	Landsat-5 TM	LT05_L2SP_144051_20100216_20200824_02_T1	2010-02-16	05:01:46
2022	Landsat-9 OLI_TIRS	LC09_L2SP_144051_20220225_20230426_02_T1	2022-02-25	05:10:57