Spatio-Temporal Analysis of Land Use and Land Cover (LULC) Changes in Tumkur District, Karnataka Using Sentinel-2 Imagery (2020–2024)

Sharanya Sunkara Venkatappa (Corresponding Author) and Konehalli Lakshmaiah Prakash
Department of Environmental Science, Bangalore University, Bangalore, India

Abstract

This study investigates Land Use and Land Cover (LULC) changes in Tumkur, Kunigal, and Gubbi taluks of Karnataka, India, over a 4-year period (2020–2024) using multi-temporal Sentinel-2 satellite data. The analysis utilized supervised classification and Normalized Difference Vegetation Index (NDVI) to assess seven LULC classes. Findings reveal an increase in vegetation, built-up areas, and water bodies, while croplands and rangelands have notably declined. These changes reflect urban expansion, changing land management practices, and ecological transitions in the region.

1. Introduction

Land Use and Land Cover (LULC) dynamics have become critical indicators of environmental health, socio-economic development, and urban planning in the context of rapid globalization and population expansion (Arfanuzzaman, & Dahiya, 2019; Gaur & Singh, 2023). LULC refers to the spatial distribution and characterization of the Earth's surface features encompassing natural elements like vegetation, water bodies, and soil, as well as human-induced modifications such as agricultural fields, built-up areas, and infrastructure (Gebreegzibher et al., 2025; Mir et al., 2025). As landscapes evolve due to anthropogenic activities and climatic variability, understanding the spatial-temporal changes in land use becomes essential for sustainable land management and policy formulation (Zhai et al., 2021; Roy et al., 2022).

India, like many developing nations, is experiencing a rapid urbanization, agricultural intensification, and infrastructure development, often at the expense of natural ecosystems (Bhattacharyya et al., 2023; Patel eta al., 2024). Karnataka, located in southern India, is one of the states witnessing significant transformations in its rural and semi-urban landscapes. Tumkur district, in particular, lies at the cusp of rural-urban transition, characterized by diverse land uses including croplands, forests, rangelands, and rapidly expanding urban settlements (Sharma et al., 2024). The taluks of Tumkur, Kunigal, and Gubbi serve as microcosms for this broader trend, exhibiting a compound relationship between agriculture, urban sprawl, ecological conservation, and water management (Aithal & Ramachandra, 2012).

Remote sensing technology and geospatial analytics have emerged as powerful tools in monitoring these LULC transformations (Mohanrajan et al., 2020; Mashala et al., 2023). With the availability of high-resolution multispectral satellite imagery, particularly from platforms like Sentinel-2, it is now possible to analyze land surface changes with greater temporal and spatial precision (Phiri et al., 2020). These technologies facilitate the extraction of thematic information through supervised classification methods and vegetation indices like the Normalized Difference Vegetation Index (NDVI), which together provide a nuanced understanding of land surface dynamics (Segarra et al., 2020).

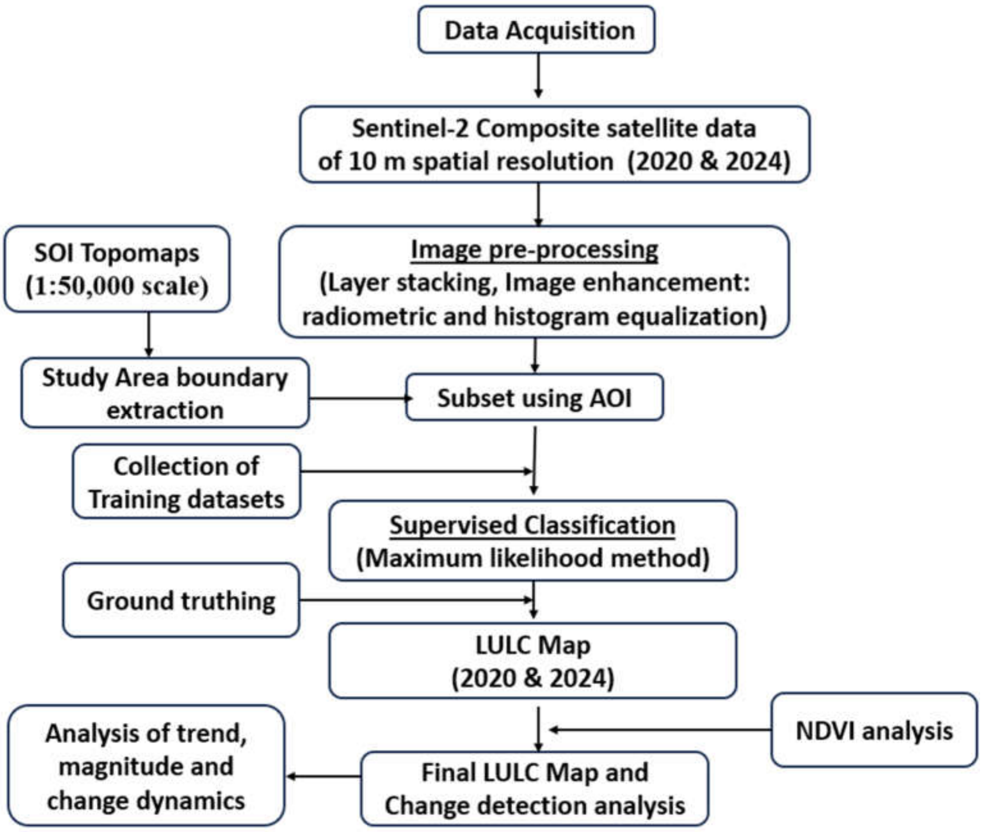
This study exhibit Sentinel-2 imagery from the years 2020 and 2024 to perform a detailed classification and rapid change detection of LULC across the Tumkur district. By applying supervised classification using the Maximum Likelihood Algorithm and NDVI analysis, the research aims to quantify the extent and nature of LULC changes over the 4-year period, and identify key transformation patterns, such as the conversion of croplands to built-up areas or rangelands to vegetation. The outcomes of this research not only offer empirical evidence on land transformation processes but also contribute to informed decision-making for land use planning, conservation strategies, and climate adaptation measures.

2. Methodology

2.1 Land Use-Land Cover (LULC) Assessment

Land cover can be intended as the (bio-)physical cover on the observed surface. This can be ascertained directly using satellite imagery, which reveals regions such as shrublands, bare soil, forests, or water. Land use refers to how certain land is utilized, encompassing agricultural, transportation, industrial, and recreational activities, as well as parks. The Sentinel-2 composite data, with a 10m spatial resolution, multitemporal, and multispectral data from 2020 and 2024 **(Table 1)**, were applied to generate LULC maps. Geometric and radiometric corrections were applied to the satellite data, and the layers were stacked. A Sentinel-2 image of the study area was then clipped using the study area boundary, and supervised classification was carried out using the maximum likelihood approach (Karra et al., 2021)for the years 2020 and 2024to create LULC maps **(Flowchart 1).**Satellite images had been processed using the UTM projection, with the datum set to WGS84. The NDVI (Normalized Difference Vegetation Index) was developed to enhance the accuracy of LULC

(Land Use and Land Cover) classification. Lastly, the products of the classified images have been utilized in the change detection analysis of the years 2020 and 2024.Satellite views of the study area for the years 2020 and 2024 are given in **Figure 1.**



Flowchart 1. Study flowchart

Table 1.Sentinel-2 band information used for LULC classification

Data layer	Bands used	Central wavelength (µm)	Spatial resolution (m)	Projection details
Sentinel-2 MSI data	Band 2 - Blue	0.490	10	Map projection = "UTM" (Universal Transverse Mercator coordinate system) Projection units = "METERS" Datum = "WGS84" Ellipsoid = "WGS84" UTM zone = 43N Spacecraft_id = "NORAD ID 40697" Sensor_id = "MSI (Multispectral Imager) instrument" Output_format = "geotiff" Spatial resolution = 10 m
	Band 3 - Green	0.560	10	
	Band 4 - Red	0.665	10	
	Band 8- NIR	0.842	10	

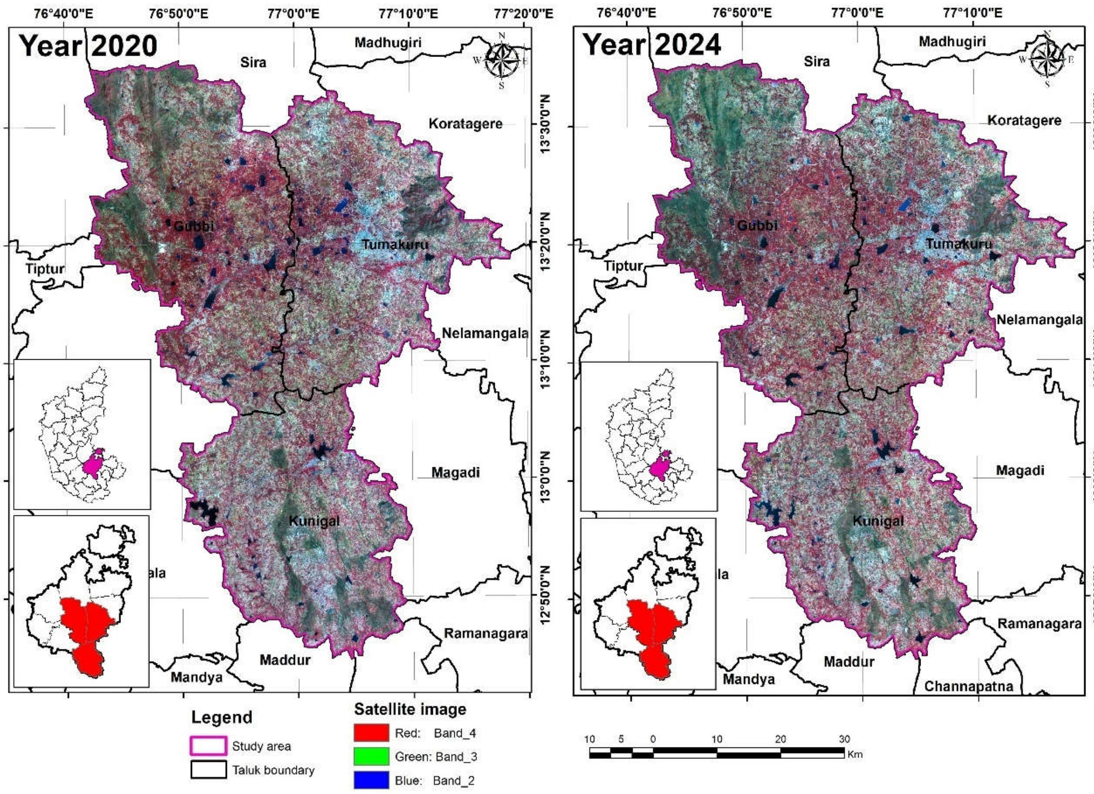


Fig 1. Satellite view of Sentinel-2 data of the study area for the years 2020 and 2024

3. Results

Supervised classification yielded a total of seven LULC classes (viz., built-up, vegetation, croplands, water bodies, barren ground, rangelands, and flooded vegetation). Areal statistics for Tumkur, Kunigal, and Gubbi taluks for the years 2020 and 2024 are presented in **Tables 1 to 3**, respectively**. LULC** statistics for the entire study area are summarized in **Table 4.**LULC maps were created for Tumkur, Kunigal, and Gubbi taluks, which are shown in **Figures 2 to 4. Figure 5** illustrates the LULC classification for the entire study area, while **Figure 6** presents the NDVI map for the entire study area. Crops (agricultural land), vegetation, rangeland, and built-up area were the major LULC classes during both years in all three studied taluks as well as the entire study area.

For Tumkur taluk, LULC classification statistics are presented in **Table 2**, and the spatio-temporal distribution of LULC coverage is illustrated in **Fig. 2**. It is evident that Tumkur taluk has experienced an increase in waterbodies (1 %), vegetation (2%), and built-up (3.7%) area between 2020 and 2024. Alternately, a decrease in cropland (2.9%) and rangeland (3.8%) areas was apparent from the present analysis.Vegetation has increased by 21.6 Km^2, while built-up areas have increased by 38.3 Km^2 during the study period. Interestingly, croplands and rangelands have declined by 30.0 Km^2 and 39.0Km^2 respectively.

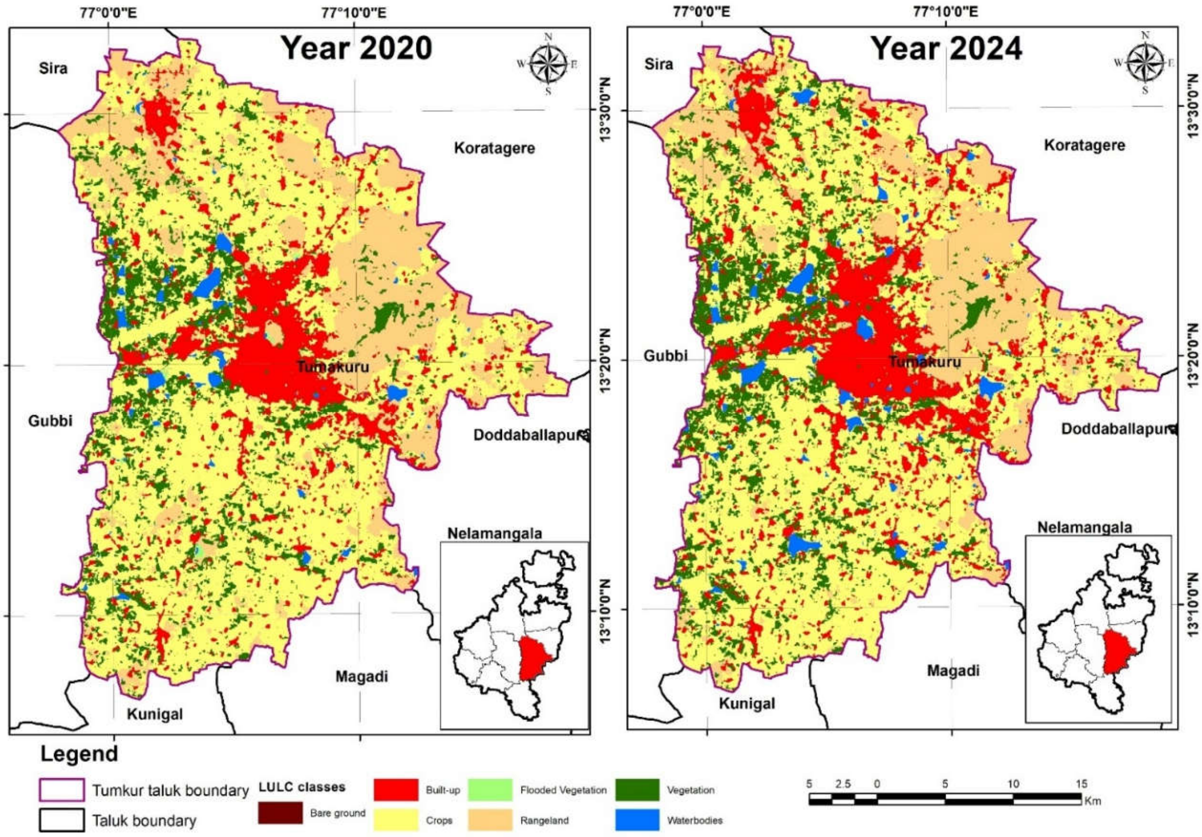


Fig 2. LULC map for Tumkur taluk

Table 2. Areal statistics for LULC classification for Tumkur taluk

Sl. No	LULC classes	2020		2024		LULC Change for 2020-2024 (Sq.km)
		Area (km2)	%	Area (km2)	%	
1	Waterbodies	15.3	1.5	25.0	2.4	+9.7
2	Vegetation	120.5	11.7	142.1	13.8	+21.6
3	Flooded Vegetation	1.2	0.1	0.5	0.0	-0.7
4	Crops	542.5	52.8	512.5	49.9	-30.0
5	Built-up	141.4	13.8	179.7	17.5	+38.3
6	Bare ground	0.1	0.009	0.1	0.009	---
7	Rangeland	207.1	20.1	168.1	16.3	-39.0
Total area		**1028.0**	**100.0**	**1028.0**	**100.0**	**----**

Note: '+' means increase and '-' means decrease

For Kunigal taluk, LULC classification statistics are presented in **Table 3**. The spatio-temporal distribution of LULC coverage is shown in **Fig. 3**. The results indicate that in parts of Kunigal taluk, there has been an increase in waterbodies (0.8%), vegetation (2.8%), crops (3.4%), and built-up areas (1.4%) between 2020 and 2024. Alternatively, a decline in rangeland area (8.5%) was evident from the present analysis. Vegetation, croplands, built-up areas, and water bodies have increased by 27.3, 33.7, 13.6, and 8.6 km², respectively, during the study period. Interestingly, rangelands have declined by 82.7 Km² between 2020 and 2024.

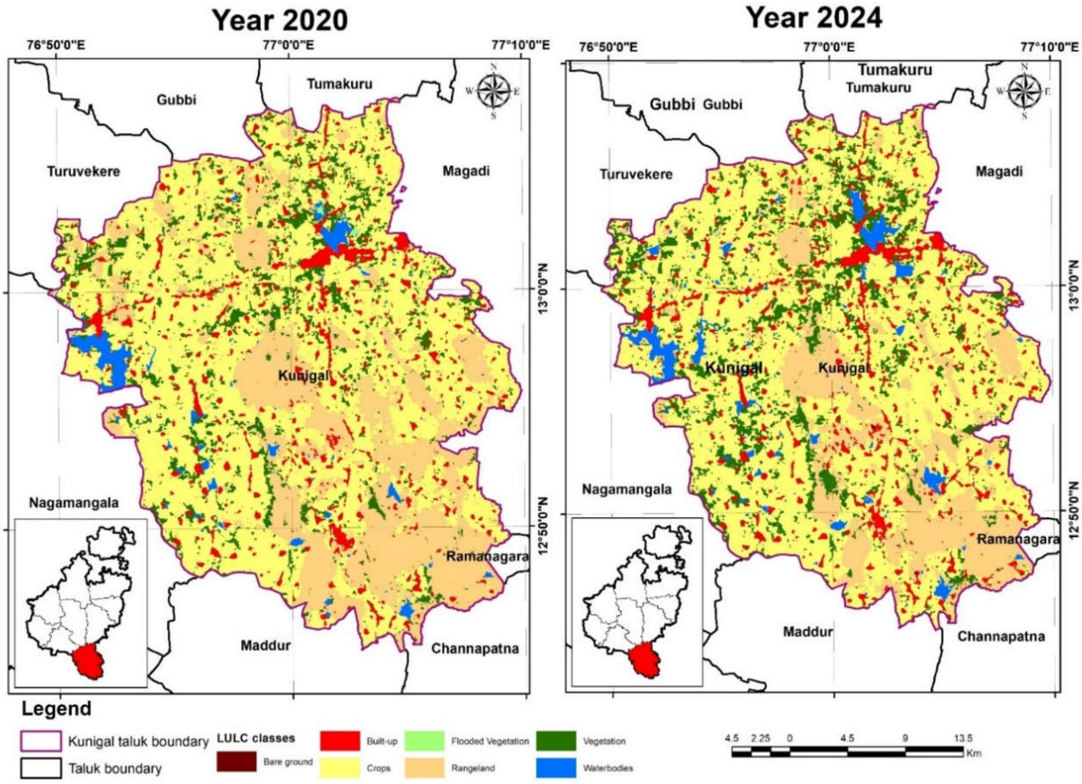


Fig 3. LULC map for Kunigal taluk

Table 3. Areal statistics for LULC classification for Kunigal taluk

Sl. No	LULC classes	2020		2024		LULC Change for 2020-2024 (Sq.km)
		Area (km2)	%	Area (km2)	%	
1	Water bodies	21.1	2.2	29.7	3.0	+8.6
2	Vegetation	85.3	8.7	112.6	11.5	+27.3
3	Flooded Vegetation	0.8	0.08	0.1	0.01	-0.7
4	Crops	552.9	56.4	586.6	59.8	+33.7
5	Built-up	67.0	6.8	80.6	8.2	+13.6
6	Bare ground	0.1	0.01	0.3	0.03	+0.2
7	Rangeland	253.8	25.9	171.1	17.4	-82.7
Total area		**981.0**	**100.0**	**981.0**	**100.0**	**----**

Note: '+' means increase and '-' means decrease

For Gubbi taluk, LULC classification statistics are presented in **Table 4**. The spatio-temporal distribution of LULC coverage is shown in **Fig. 4**. The results indicate that in parts of Kunigal taluk, there has been an increase in vegetation (7.7%) and built-up areas (1.2%) between 2020 and 2024. Alternatively, declines were observed in water bodies (0.2%), crops (3.7%), and rangeland area (5.1%) in Gubbi taluk. Vegetation and built-up regions have increased by 94.7 and 15.0 km², respectively, during the study period. Interestingly, water bodies, croplands, and rangelands have declined by 2.4, 45.6, and 62.2 Km² between 2020 and 2024.

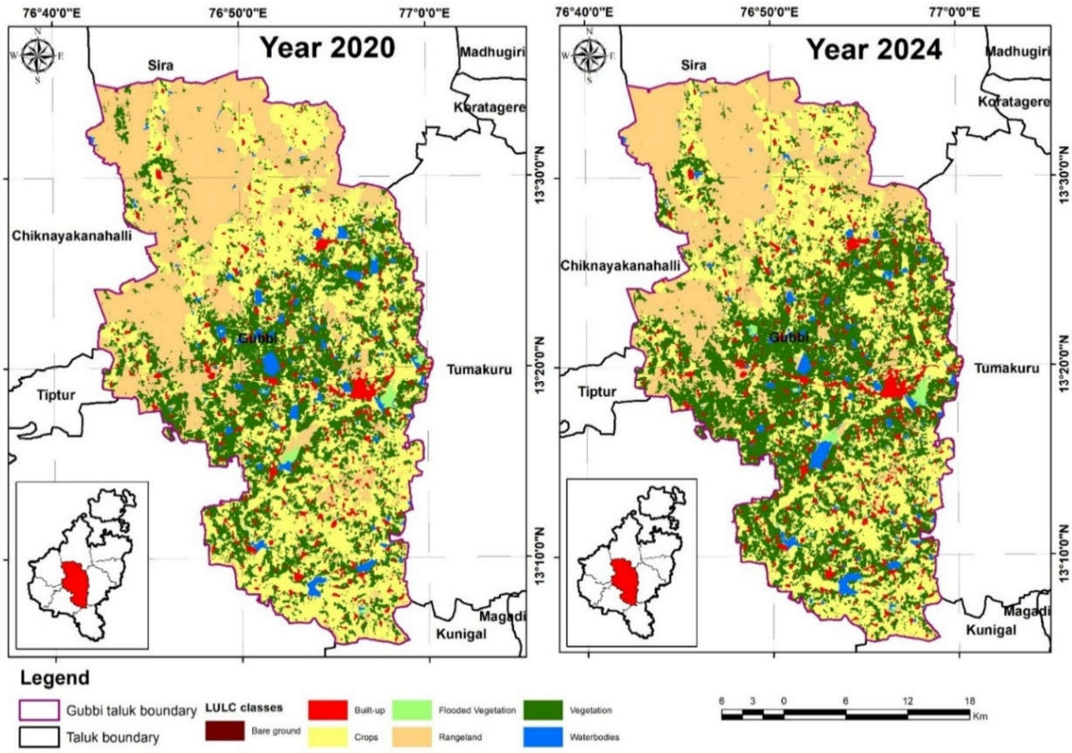


Fig 4. LULC map for Gubbi taluk

Table 4. Areal statistics for LULC classification for Gubbi taluk

Sl. No	LULC classes	2020 Area (km2)	2020 %	2024 Area (km2)	2024 %	LULC Change for 2020-2024 (Sq.km)
1	Water bodies	31.1	2.5	28.7	2.3	-2.4
2	Vegetation	305.2	25.0	399.9	32.7	+94.7
3	Flooded Vegetation	5.0	0.4	5.6	0.5	+0.6
4	Crops	469.0	38.4	423.4	34.7	-45.6
5	Built-up	56.1	4.6	71.1	5.8	+15.0
6	Bare ground	0.1	0.008	0.2	0.016	+0.1

7	Rangeland	354.4	29.0	292.2	23.9	-62.2
Total area		**1221.0**	**100.0**	**1221.0**	**100.0**	**----**

Note: '+' means increase and '-' means decrease

Combined LULC classification statistics for the entire study area are presented in Table 5, while LULC and NDVI maps are shown as Figures 5 and 6, respectively**.** The results indicate that vegetation area has increased by 4.5%, built-up regions by 2.1% followed by water bodies (0.5 %) during 2020-2024. Contrastingly, cropland areas decreased by 1.3% and rangeland areas decreased by 5.7% during the study period. The LULC changes in the study area identified the establishment of nearly 143.6 km^2 of vegetation areas, 66.7 km^2 of built-up areas, and 15.9km^2 of water bodies between 2020 and 2024. The difference is evident in **Figure 5**, which is represented by the increased green, red, and blue regions, respectively. Contrastingly, the decrease in the extent of the orange patch in **Fig. 5** substantiates the decrease in rangeland areas (183.9 Km^2) during the study period. Cropland decreased by 41.8 Km^2 during 2020-2024 in the study area. The NDVI map (Fig. 6) supported these findings, as NDVI values ranged from -0.39 to 0.732 and from -1.0 to 0.891, respectively, for the years 2020 and 2024. An increase in vegetation can be easily justified with the help of an NDVI map, as indicated by increased red patch areas, water bodies marked by blue patches, and built-up areas denoted by cyan-colored patches.

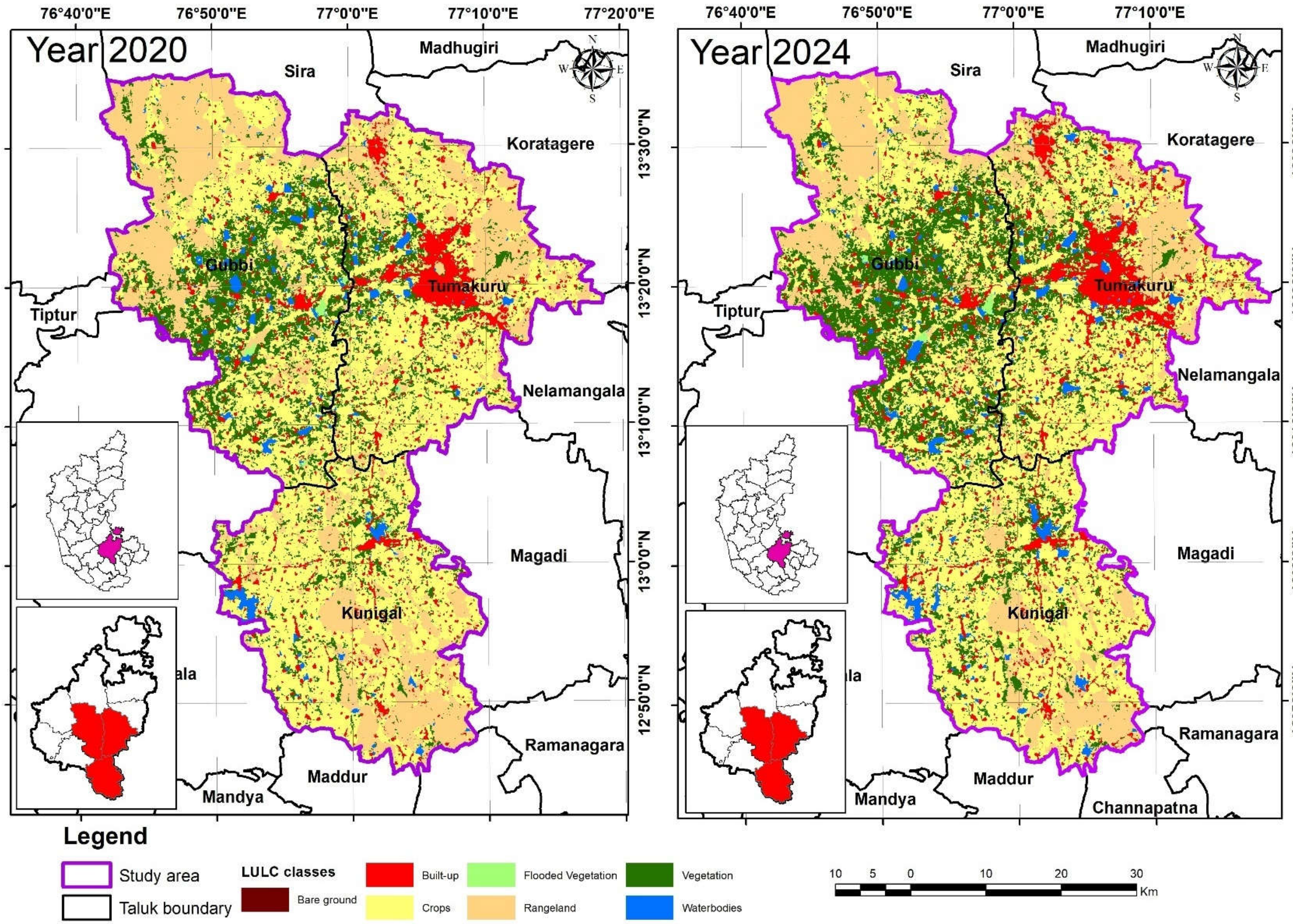


Fig 5. LULC map for the Entire Study area

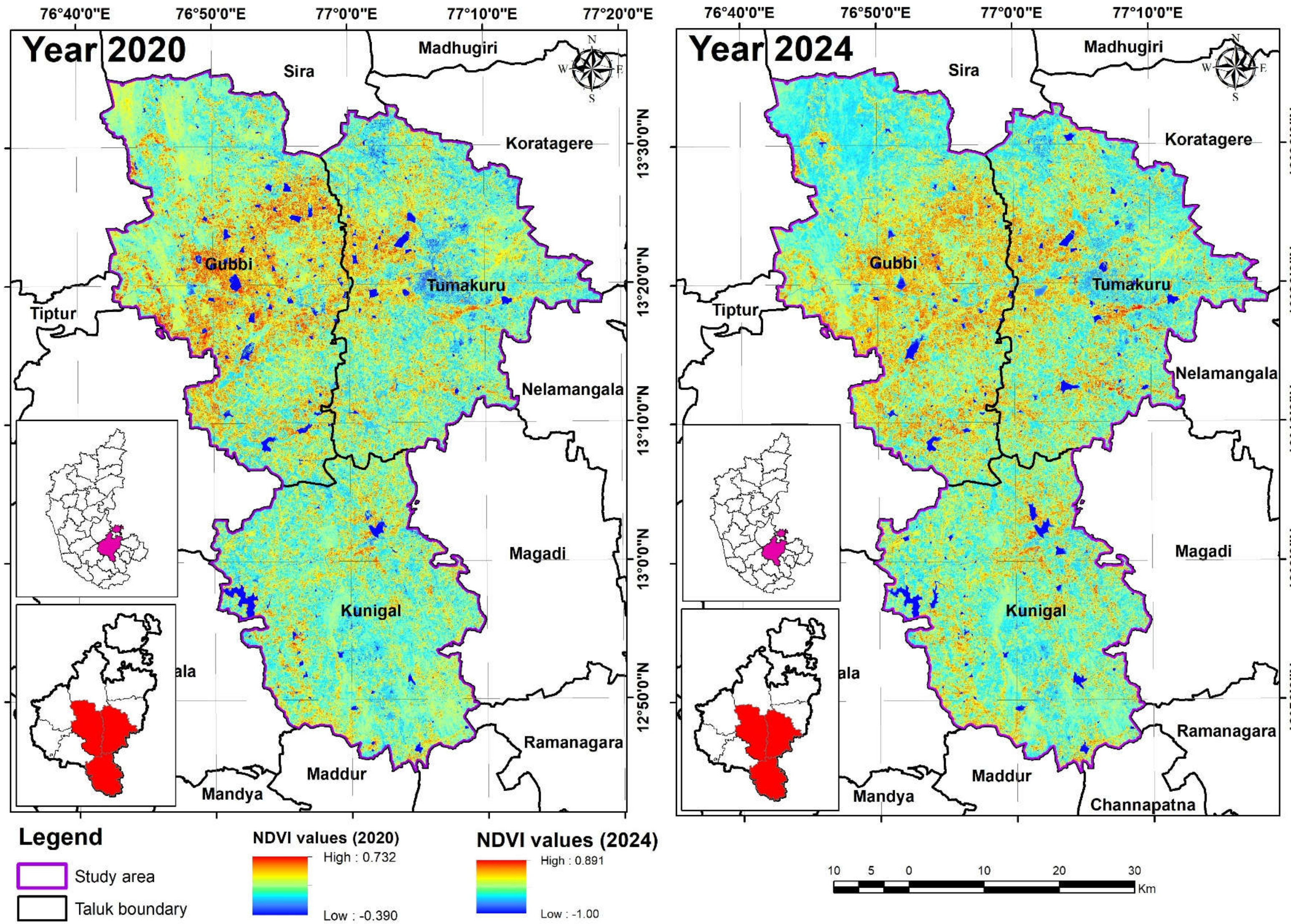


Fig. 6. NDVI map of the study area

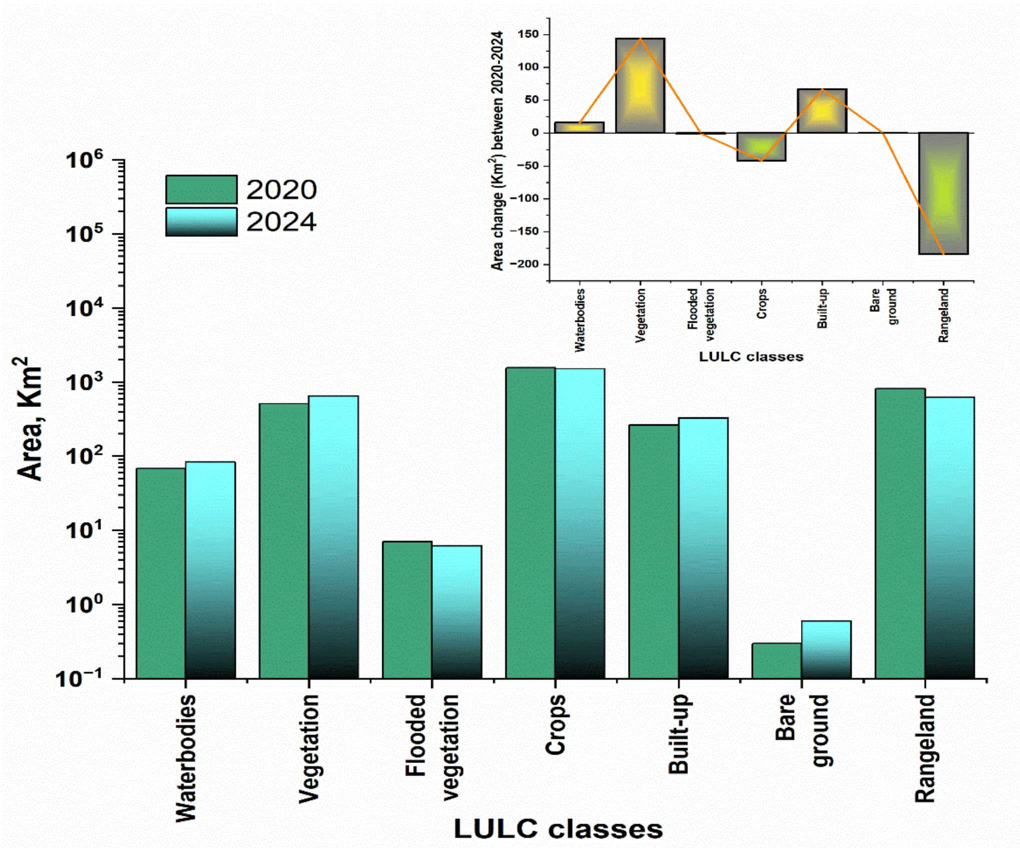


Fig 7. LULC change between 2020 and 2024

Table 4. Areal statistics for LULC classification for the Entire Study area

Sl. No	LULC classes	Year 2020		Year 2024		LULC Change for 2020-2024 (Sq.km)
		Area (km2)	%	Area (km2)	%	
1	Water bodies	67.5	2.1	83.4	2.6	+15.9
2	Vegetation	510.9	15.8	654.5	20.3	+143.6
3	Flooded Vegetation	7.0	0.2	6.2	0.2	-0.8
4	Crops	1564.5	48.4	1522.7	47.1	-41.8
5	Built-up	264.6	8.2	331.3	10.3	+66.7
6	Bare ground	0.3	0.009	0.6	0.018	+0.3
7	Rangeland	815.2	25.2	631.3	19.5	-183.9
Total area		**3230.0**	**100.0**	**3230.0**	**100.0**	----

Note: '+' means increase and '-' means decrease

4. Change detection analysis

Change detection is a crucial stage of this research, yielding highly reliable results that enable the identification and localization of vegetated regions. Change detection captures the spatial changes in multi-temporal satellite images due to artificial or natural phenomena. Hence, change detection analysis was performed using the LULC maps for the years 2020 and

2024to understand the differences **(Fig.8).** The red patches in the map represent the land use change from one type to another during the study period.

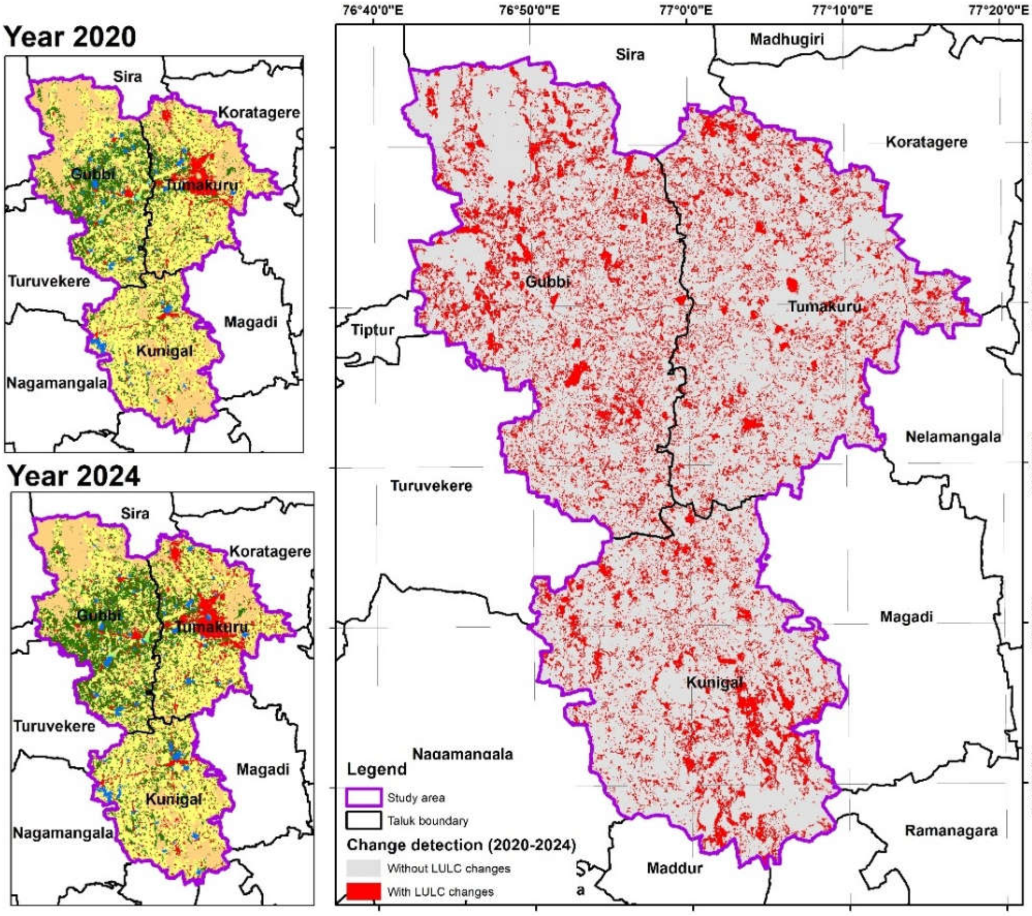


Fig 8. LULC Change detection map for the Study area (2020-2024)

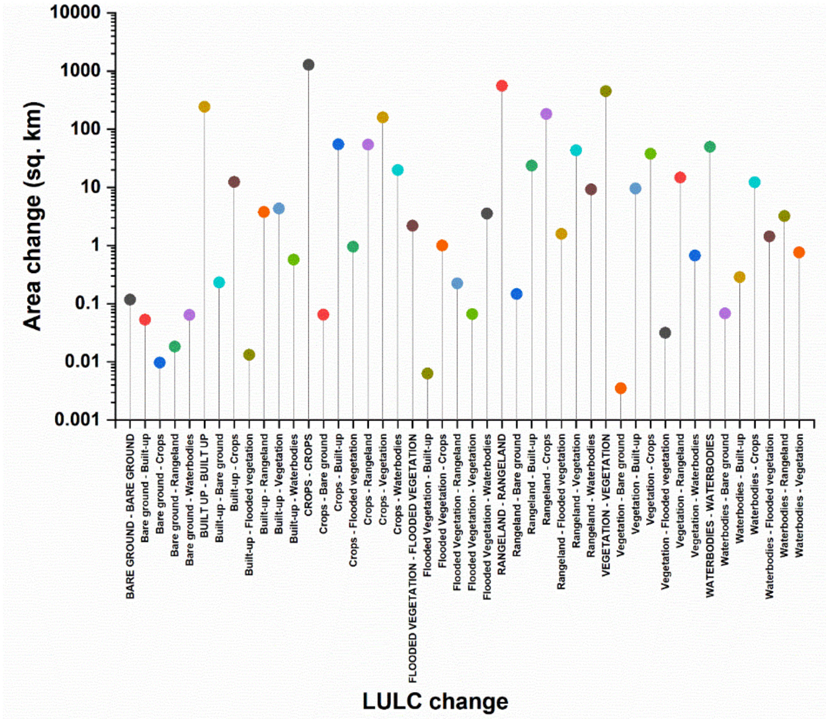


Fig 9. Change dynamics in LULC between 2020 and 2024

The outcome of the change detection analysis is shown in **Fig.9,** and detailed statistics on LULC change during 2020-2024 are summarized in **Table 5.**

Table 5. Areal statistics on LULC change detection analysis between 2020 and 2024

Sl. No.	Land Use change pattern	Area (Km2)	Area (Km2)
1	**Bare ground -Bare ground**	**0.12**	**0.12 (0.004%)**
2	Bare ground -Built-up	0.05	
3	Bare ground -Crops	0.01	0.14
4	Bare ground -Rangeland	0.02	**(0.004%)**
5	Bare ground -Waterbodies	0.06	
6	**Built-up -Built-up**	**243.47**	**243.47 (7.54%)**
7	Built-up -Bare ground	0.23	
8	Built-up -Crops	12.36	
9	Built-up -Flooded vegetation	0.01	21.27
10	Built-up -Rangeland	3.77	(0.66%)
11	Built-up -Vegetation	4.33	
12	Built-up -Waterbodies	0.57	
13	**Crops -Crops**	**1277.91**	**1277.91 (39.54%)**
14	Crops -Bare ground	0.06	
15	Crops -Built-up	54.52	
16	Crops -Flooded vegetation	0.95	287.6
17	Crops -Rangeland	54.33	(8.90%)
18	Crops -Vegetation	158.01	
19	Crops -Waterbodies	19.73	
20	**Flooded Vegetation -Flooded vegetation**	**2.19**	**2.19 (0.07 %)**

21	Flooded Vegetation -Built-up	0.01	4.82 (0.15%)
22	Flooded Vegetation -Crops	1.00	
23	Flooded Vegetation -Rangeland	0.22	
24	Flooded Vegetation -Vegetation	0.07	
25	Flooded Vegetation -Waterbodies	3.52	
26	**Rangeland -Rangeland**	**555.37**	**555.37 (17.18%)**
27	Rangeland -Bare ground	0.15	260.37 **(8.1%)**
28	Rangeland -Built-up	23.69	
29	Rangeland -Crops	182.36	
30	Rangeland -Flooded vegetation	1.58	
31	Rangeland -Vegetation	43.39	
32	Rangeland -Waterbodies	9.20	
33	**Vegetation -Vegetation**	**448.37**	**448.37 (13.87%)**
34	Vegetation -Bare ground	0.00	62.87 **(1.90 %)**
35	Vegetation -Built-up	9.49	
36	Vegetation -Crops	37.89	
37	Vegetation -Flooded vegetation	0.03	
38	Vegetation -Rangeland	14.79	
39	Vegetation -Waterbodies	0.67	
40	**Waterbodies -Waterbodies**	**49.65**	**49.65 (1.54 %)**
41	Waterbodies -Bare ground	0.07	17.93 (0.55%)
42	Waterbodies -Built-up	0.29	
43	Waterbodies -Crops	12.15	
44	Waterbodies -Flooded vegetation	1.44	
45	Waterbodies -Rangeland	3.22	
46	Waterbodies -Vegetation	0.76	
	Total area (Km2)	**3232.1**	**3232.1**

From **Table 5**, it is evident that 287.6 Km^2 of cropland area have transformed into other land use classes, of which a significant part of it has been converted into either vegetated areas (158.01 Km^2), built-up (54.52 Km^2), or rangelands (54.33 Km^2). Similarly, a 260.37 Km^2 area of rangeland has been converted to cropland (182.36 Km^2), vegetation (43.39 Km^2), and built-up area (23.69 Km^2).Among the vegetation areas, 67.87 Km^2 witnessed land use transformation, with a significant portion being used as croplands (37.89 Km^2), followed by rangeland (14.79 Km^2) and built-up area (9.49 Km^2). A considerable part (12.15 Km^2) of the water body area has been converted into croplands, and a part of the built-up area (12.36 Km^2) has been transformed into croplands (12.36 Km^2), vegetation (4.33 Km^2), or rangeland (3.77 Km^2). Overall, croplands, rangeland, and vegetation areas have experienced the highest amount of land use conversion to other land use types during the study period. Other changes or land use conversions below 3% were negligible.

5. Discussion

It is well established that LULC changes are a consequence of urban redefinition, natural development, the enhancement of quality of life, expanded occupational opportunities, and rural-urban migration, which are the five primary factors related to urban growth (World Bank, 2007; Kafy et al., 2021). In this regard, numerous studies have been conducted worldwide, employing various methodologies and utilizing satellite data; some of these have been discussed below:

Kafi et al. (2014) carried out a similar study, evaluating LULC change in Bauchi City, north-eastern Nigeria, over a decade. All LULC classes other than the farmland and other land classes were found to have been increased with 138 % in the built-up area and 90.2 % in the wet land and a rampant growth rate of 696.7 % in shrub/grass land and an extreme decline of 178 % in the farmland between 2003 and 2013 painting a picture of an extreme urban sprawl (rapid urbanization) that has taken place in Bauchi city. In comparison, the urban area and built-up lands were reported to have increased in the last decade, rising from 10.9 km^2 in 1976 to 113.2 km^2 in 2014, due to population growth and economic expansion, as noted by Al-Saady et al. (2015). In addition, the observation indicated that an increase in natural vegetation, crop land, and water in the wet season during the study period is associated with climatic conditions.

The study conducted by Agaton et al. (2016) on LULC change within the Citarum watershed (Indonesia) indicated that there is a significant change in LULC type between 1997-2005 and 2005-2014. The results were tabulated as a 14% and 4% decrease in bushland cover, a 41% and 35% decrease in forest cover, and a 12% and 10% decrease in waterbodies between the two study periods. Conversely, the increase in agricultural land by 8 and 2 percent during the two time periods was accompanied by an increase in built-up areas by 100 and 65 percent, respectively. Interestingly, there was a 56% increase in bare land between 1997 and 2005, followed by a decline of 15% between 2005 and 2014. Lastly, researchers have also deduced that the rapid rate of urbanization was the source of change that led to the LULC in the investigated area.

Twisa and Buchroithner's (2019) study LULU changes for the Kinyasungwe and Wami Sub-catchments (Wami River Basin) for 2000, 2006, 2011, and 2016. LULC classes tended to be converted to cropland upstream and downstream of the basin, except for most land use types. This conversion extended to 23, 18, 8, 6, 2, and 1% as bushland, grassland, woodland, swamp, water, and forest, respectively, upstream. Downstream conversion rates were similarly 27%, 18%, 18%, 11%, and 10% for bushland, grassland, woodland, forest, and swamp, respectively.

In a study by Abijith and Saravanan (2022), the study area was separated into zone-1 (3842.8 sqkm), which included Tiruvallur, Chennai, and Kanchipuram districts, with an extent of 3842.8 sqkm, and zone-2 (2604.29 sqkm), which included Villupuram, Cuddalore district, and Pondicherry union territory areas. This study aimed to examine the LULC shifts during 2009. The area of study was prone to inland floods, sea floods, and other calamities. There was a 25.12, 18.25, and 120.8 % rise in vegetation, forest, and built-up areas, and a 12.56 and 16.5 % decrease in barren land and water bodies in zone-1. In zone 2, the percentages of forest and barren land increased by 7.16% and 50.42%, respectively, while water bodies decreased by 57.7%. The built-up area also doubled, by 208.3%. Notably, the decreasing trend in vegetation by zone 2, as opposed to the increasing trend by zone 1, amounts to 125.1%. They concluded that the barren land and vegetation classes are being developed into built-up areas, and the water body is on a decreasing trend, while built-up areas have been increasing in both zones.

6. Conclusion

This study provides a comprehensive spatio-temporal analysis of Land Use and Land Cover (LULC) changes across the Tumkur, Kunigal, and Gubbi taluks of Karnataka using Sentinel-2 multispectral imagery over a four-year period (2020–2024). The integration of supervised classification techniques, NDVI analysis, and change detection methodologies has enabled a detailed understanding of landscape dynamics within the study region.

The findings clearly demonstrate that the district has undergone significant transformations. Notably, vegetation and built-up areas have experienced considerable expansion, increasing by 143.6 km² and 66.7 km² respectively, signaling ongoing urbanization and perhaps reforestation or land reclamation initiatives. Conversely, croplands and rangelands have witnessed marked reductions 41.8 km² and 183.9 km² respectively highlighting a transition away from traditional agricultural and pastoral practices toward urban and infrastructural land uses.

The results of the change detection analysis further underscore the complexity of these transitions. Large tracts of cropland have been converted to built-up areas and vegetated land, while rangelands have also been repurposed significantly for urban development or agriculture. These changes reflect broader socio-economic drivers such as population growth, industrial development, and rural-to-urban migration. Moreover, the increase in waterbody area by 15.9 km² suggests potential improvements in water resource management or climate-induced hydrological shifts.

This transformation is consistent with patterns observed in other regions experiencing urban expansion, such as the Citarum watershed in Indonesia (Agaton et al., 2016) or Bauchi City in Nigeria (Kafi et al., 2014). However, the increase in vegetation cover, contrary to typical deforestation trends associated with urban growth, is a unique and encouraging feature of this study, potentially indicating successful afforestation efforts or shifts in land conservation policy.

In conclusion, the study highlights the urgent need for sustainable land management practices and policy interventions in Tumkur district. As built-up areas continue to grow and natural landscapes are increasingly altered, balancing development with ecological integrity will be crucial. The findings serve as a vital resource for planners, policymakers, and environmental managers aiming to guide land use decisions that are both economically viable and environmentally sustainable.

Future research should consider incorporating socio-economic datasets, climate variables, and predictive modeling (e.g., CA-Markov models) to forecast future land use scenarios and assess long-term environmental impacts. Additionally, engaging with local stakeholders and integrating community-level data could enhance the contextual understanding of LULC drivers and reinforce participatory planning frameworks.

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Additional descriptions/information on LULC Classes

1. **Water bodies:** Areas where water was predominantly present throughout the year; may not cover areas with sporadic or ephemeral water; contains little to no sparse vegetation, no rock outcrop, no built-up features like docks; examples: rivers, ponds, lakes, oceans, flooded salt plains.
2. **Vegetation / Trees -** Any significant clustering of tall (~15 feet or higher) dense vegetation, typically with a closed or dense canopy; examples: wooded vegetation, clusters of dense tall vegetation within savannas, plantations, swamp or mangroves (dense/tall vegetation with ephemeral water or canopy too thick to detect water underneath).
3. **Flooded vegetation** - Areas of any vegetation with obvious intermixing of water throughout a majority of the year; seasonally flooded area that is a mix of grass/shrub/trees/bare ground; examples: flooded mangroves, emergent vegetation, rice paddies, and other heavily irrigated and inundated agriculture.
4. **Crops** - Human-planted/plotted cereals, grasses, and crops not at tree height; examples: corn, wheat, soy, fallow plots of structured land.
5. **Built-up Area** -Human-made structures; major road and rail networks; large homogeneous impervious surfaces including parking structures, office buildings, and residential housing; examples: houses, dense villages/towns/cities, paved roads, asphalt.
6. **Bare ground** - Areas of rock or soil with very sparse to no vegetation for the entire year; large areas of sand and deserts with no to little vegetation; examples: exposed rock or soil, desert, and sand dunes, dry salt flats/pans, dried lake beds, mines.
7. **Rangeland** - Open areas covered in homogeneous grasses with little to no taller vegetation; wild cereals and grasses with no apparent human plotting (i.e., not a plotted field); examples: natural meadows and fields with sparse to no tree cover, open savanna with few to no trees, parks/golf courses/lawns, pastures. Mix of small clusters of plants or single plants dispersed on a landscape that shows exposed soil or rock; scrub-filled clearings within dense forests that are clearly not taller than trees; examples: moderate to sparse cover of bushes, shrubs, and tufts of grass, savannas with very sparse grasses, trees or other plants.