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DETECTING URBAN EXPANSION AND ENVIRONMENTAL CHANGE THROUGH REMOTE SENSING AND GIS: CASE OF GULBARGA CITY

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ABSTRACT

Geoinformatics based approach is used to detect the long-term spatio-temporal dynamics of land use/land cover (LULC), environmental indices, land surface temperature (LST), and air quality in Gulbarga city. For the assessment of integrated analysis, multi-temporal satellite-derived indices were utilized which was the primary objective. The various factors like, environmental impacts of urban expansion, including NDVI, NDBI, and NDWI, along with thermal and air pollution parameters were evaluated. The overall impact of change was detected by comparing multi-year remote sensing data for vegetation cover, built-up areas, and surface water bodies, which was further correlated with surface temperature and atmospheric conditions.

There was a substantial increase in built-up areas with a consistent decline in vegetation cover and surface water extent. There were prominent changes during the recent decade, and the transformations were strongly associated with rising land surface temperatures. The comparative analysis showcased higher thermal intensity in built-up regions when compared to vegetated and water-covered areas. This created an inverse relationship between vegetation and temperature which was clearly observed. Lastly, particulate matter and gaseous pollutants showed elevated levels in an annual air quality analysis, due to the influence of urban activities such as traffic, industrial emissions, and dust.

In conclusion, there has been noticeable environmental degradation due to increased thermal stress caused by the rapid urbanization which also affected the ecological balance, and air quality. The advancement in multi-temporal geospatial techniques helped in tracking in-depth tangible understanding about urban environmental changes with regards to urban growth. This study reflects the high demand for sustainable planning strategies for urban growth management.

KEYWORDS: Geoinformatics, Land Use/Land Cover (LULC), Normalized Difference Vegetation Index (NDVI), Land Surface Temperature (LST), Urbanization, Air Pollution

1. INTRODUCTION

Rapid urban expansion now drives environmental change in Indian cities, especially in semi-arid regions with limited natural resources. Over the past few decades, the population and infrastructure in Gulbarga City, Karnataka, has grown substantially. These forces have transformed land use/land cover (LULC), altered vegetation patterns, reduced surface water availability, and changed thermal characteristics. Such changes intensify environmental stress, raise land surface temperatures (LST), and increase urban air pollution levels.

Remote sensing and Geographic Information Systems (GIS) form an effective framework to monitor long-term urban environmental changes. To assess

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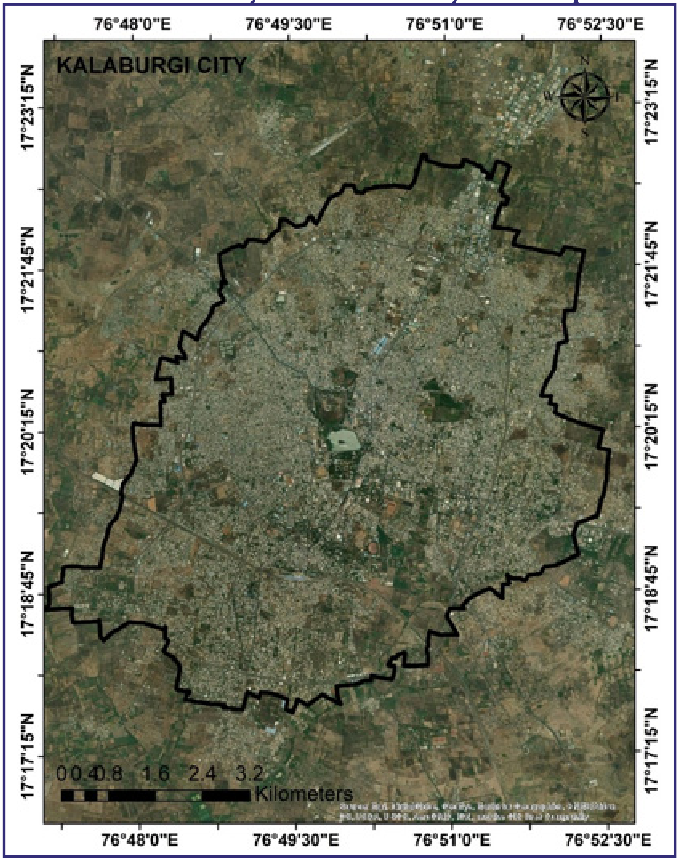
the land-cover dynamics and their environmental impacts, multi- temporal satellite data is obtained. Vegetation health and density is evaluated by Normalized Difference Vegetation Index (NDVI) and for the urban expansion patterns LULC classification method is practiced. Thermal infrared bands are considered critical indicators to derive Land Surface Temperature (LST) to detect urban heat island effects which are always liked to impervious surfaces and reduced green cover. In addition to land-cover and thermal changes, air quality is also influenced by urbanization. Expansion of built-up areas is always linked with increased vehicular emissions and industrial activities and causes reduced vegetation. It all collectively contributes to elevated concentrations of atmospheric pollutants such as nitrogen dioxide (NO_2), carbon monoxide (CO), Sulphur dioxide (SO_2), ozone (O_3), and particulate matter ($PM_{2.5}$ and PM_{10}). Due to the advancement in geo-informatics, we can now conduct spatial assessments remotely through Satellite-based atmospheric observations and verify it with traditional ground-based monitoring for city-scale pollution analysis.

Existing remote sensing and GIS studies in this domain are often limited to short-term analyses with narrow temporal scales, restricting a comprehensive understanding of complex, interconnected factors. These factors span environmental, socio-economic, and spatial dimensions, making them inherently interdisciplinary. Therefore, there is a strong need for integrated, long-term analyses that effectively capture interactions and provide a cumulative assessment of multiple variables.

This study was conducted to assess urban expansion and its environmental impacts on Gulbarga City through a multi-temporal analysis of LULC, NDVI, LST, and air pollution. Multi temporal satellite data dating from the year 2000–2025 was considered for the analysis. The results detected the land-cover dynamics, vegetation changes, surface temperature variations, and pollutant distributions. The study highlights the causes and gives the reason behind long-term urban environmental change. These findings help guide sustainable urban planning, heat mitigation strategies, and pollution management in rapidly growing cities like Gulbarga.

1.1. Study Area

Fig. 1: Gulbarga city satellite image with considered study area boundary 54.99 sq. km



Gulbarga city also known as Kalburgi is in northeastern Karnataka, India, and experiences a semi-arid climate. The city has undergone rapid urban growth in recent decades. The study area includes urban, peri-urban, agricultural, and water-covered regions, resulting in land-use transformation from agricultural and open land to built-up areas, making it suitable for analyzing land-cover changes and surface temperature variations. The region is characterized by; Semi-arid climate, Seasonal vegetation cover, Expanding built-up areas, Limited surface water resources.

2. MATERIALS AND METHODS:

2.1 Satellite Data

Multi-temporal satellite datasets were used to analyze LULC, NDVI, for the years 2000, 2010, 2020, and 2025 and for the Land surface temperature (LST). For the air pollution check, and years data of 2025 on monthly basis was conducted.

The different data sources and their technical specifications are mentioned below in table 1 which are used in this study. Multiple satellites were referred to analyzing each variable. for land use, thermal patterns, and air quality. Landsat 5 TM, Landsat 7 ETM+, and Landsat 8 OLI with a spatial resolution of 30 m was used to determine Land Use/Land Cover (LULC) and vegetation dynamics (NDVI). Daytime Land Surface Temperature (LST) was obtained from Landsat thermal bands (originally 100 m, resampled to 30 m), while nighttime LST was derived from MODIS (MOD11A2) at 1 km resolution. Atmospheric pollutants including NO_2, CO, SO_2, and O_3 were retrieved from Sentinel-5P (TROPOMI) data at an approximate spatial resolution of 7 km. Lastly, Particulate matter concentrations ($PM_{2.5}$ and PM_{10}) were estimated using Aerosol Optical Depth (AOD)-based approaches. All datasets were projected to the WGS 84 / UTM Zone 43N coordinate system to ensure consistency and comparability and they were processed within the ArcGIS environment.

Parameter	Satellite / Sensor	Resolution
LULC, NDVI	Landsat 5 TM, Landsat 7 ETM+, Landsat 8 OLI	30 m
LST (Day)	Landsat Thermal Bands	100 m (resampled to 30 m)
LST (Night)	MODIS (MOD11A2)	1 km
Air Pollution (NO_2, CO, SO_2, O_3)	Sentinel-5P (TROPOMI)	~7 km
$PM_{2.5}$, PM_{10}	AOD-based estimation	Variable

2.2 Image Pre-Processing

Satellite images were pre-processed to ensure consistency across sensors and time periods. The steps included:

In the first step radiometric and atmospheric correction is applied to remove sensor noise and atmospheric distortions, converting raw digital numbers into reliable surface reflectance values. In the second step, Cloud and shadow masking is performed to eliminate contaminated pixels to improve the data quality. Thirdly, Image is subset using KSRSAC city boundary to define the study area boundary this step helps in reducing the volume to be more precise and to increase the focus. To maintain uniformity among datasets with varying resolutions, spatial resolution harmonization was performed, resampling all images to a common scale. Finally, geometric correction and reprojection were carried out to align all datasets within a consistent coordinate system to ensure accurate spatial overlay and analysis in a GIS environment.

2.3 Methodology

This study followed the multi-source geospatial integrated methodology to assess urban environmental changes from 2000 to 2025. Satellite datasets from Landsat, MODIS, and Sentinel-5P compiled for land cover–thermal analysis and air pollution analysis. Firstly, Land Use/Land Cover (LULC) classification is performed using supervised methods (MLC) and then the NDVI–Land Surface Temperature (LST) analysis day and night are done separately to evaluate urban expansion, vegetation dynamics, and thermal patterns. In the second step, atmospheric pollutants (NO_2, CO, SO_2, O_3) and particulate matter ($PM_{2.5}$, PM_{10}) are analyzed to assess the variations in air quality. All the above extracted data will then be examined for spatial and temporal variability. Lastly, all the variables are integrated to provide a final comprehensive urban environmental assessment report highlighting all the influencing factors such as urban growth, vegetation loss, rising LST, and pollution-induced thermal hotspots.

3. RESULTS AND DISCUSSION

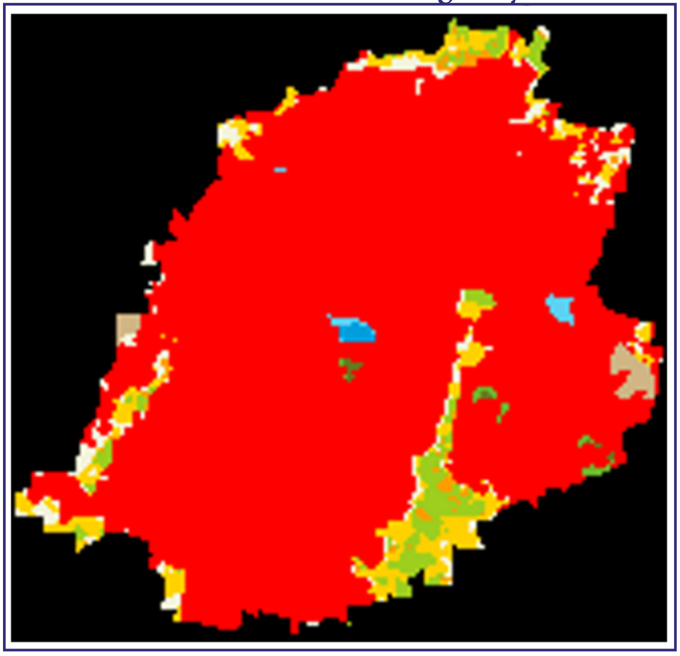
3.1 Land Use / Land Cover (LULC) Classification

LULC maps were generated using a supervised classification approach with the Maximum Likelihood Classifier. Four LULC classes were identified:

1.Water bodies 2. Built-up land
3.Vegetation 4. Soil / Road

Class-wise area and percentage cover were calculated for each year with a 5 years difference starting from 2000, 2005, 2010, 2015, 2020, 2025 using the

Fig. 2: Land Use / Land Cover (LULC) Classification Gulbarga city



Tabulate Area tool in ArcGIS. Multi-temporal LULC change analysis was performed to quantify urban expansion and loss of natural land covers. The total area which was considered for the analysis is 54.99 sq. km – KSRSAC City Boundary

Table 2: Land Use/Land Cover (LULC) Distribution for the Year 2000

2000	LULC	Area in sq km	% Cover
	Water bodies	5.7	5.1
	Builtup land	20.1	41.2
	Vegetation	25.8	48.1
	Soil /Road	5.1	6.1
	LULC	56.7	100.5

Table 3: Land Use/Land Cover (LULC) Distribution for the Year 2005

2005	LULC	Area in sq km	% Cover
	Water bodies	4.1	3.5
	Builtup land	22.6	45.2
	Vegetation	21.8	41.1
	Soil /Road	6.9	9.1
	LULC	55.4	98.9

Table 4: Land Use/Land Cover (LULC) Distribution for the Year 2010

2010	LULC	Area in sq km	% Cover
	Water bodies	3.1	2.9
	Builtup land	26.6	55.1
	Vegetation	18.8	31.1
	Soil /Road	7.2	10.1
	LULC	55.7	99.2

Table 5: Land Use/Land Cover (LULC) Distribution for the Year 2015

2015	LULC	Area in sq km	% Cover
	Water bodies	2.1	2.2
	Builtup land	29.6	65.1
	Vegetation	15.8	20.1
	Soil /Road	8.9	11.1
	LULC	56.4	98.5

Table 6: Land Use/Land Cover (LULC) Distribution for the Year 2020

2020	LULC	Area in sq km	% Cover
	Water bodies	1.3	1.4
	Builtup land	32.2	69.1
	Vegetation	12.8	18.1
	Soil /Road	8.3	10.8
	LULC	54.6	99.4

Table 7: Land Use/Land Cover (LULC) Distribution for the Year 2025

2025	LULC	Area in sq km	% Cover
	Water bodies	1.2	1.4
	Builtup land	35.3	71.3
	Vegetation	9.8	15.7
	Soil /Road	7.3	11.6
	LULC	53.6	100

3.2 Vegetation Analysis (NDVI)

NDVI was computed to assess spatial and temporal changes in vegetation using

$$NDVI = \frac{(NIR - Red)}{(NIR + Red)}$$

NDVI values were categorized into dense vegetation, sparse vegetation, and non-vegetated areas. Declining NDVI values were interpreted as indicators of vegetation loss and reduced pollution absorption capacity.

3.3 Land Surface Temperature (LST) Analysis

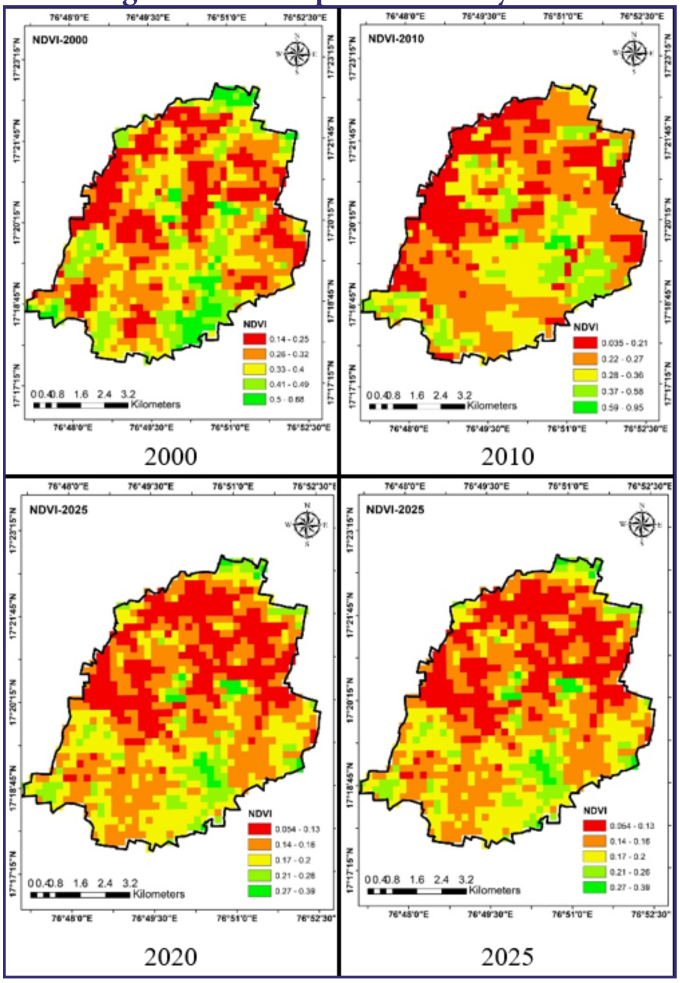
Daytime LST

Daytime LST was derived from Landsat thermal bands through:

1. Conversion of digital numbers to spectral radiance
2. Radiance to brightness temperature
3. Emissivity correction using NDVI-based method

LST maps were classified into temperature zones to identify urban heat island regions on monthly basis for the year 2025.

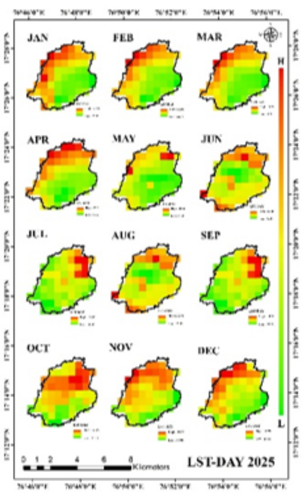
Fig 3: NDVI Maps of the Study Area



Night-time LST

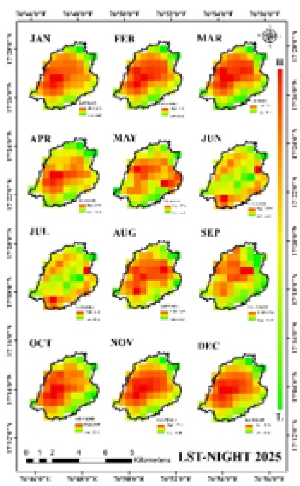
Night-time LST data were obtained from MODIS MOD11A2 products. Temporal averaging was applied to analyze nocturnal heat retention associated with dense built-up areas on monthly basis for the year 2025.

Fig: 4 Day time LST analysis



Mont hs	LST-DAY	
	HIGH	LOW
Jan	30.98	27.95
Feb	36.36	32.78
Mar	39.69	35.81
Apr	39.70	35.63
May	42.04	34.23
Jun	32.21	26.42
Jul	29.63	29.35
Aug	29.71	25.53
Sep	31.50	27.51
Oct	32.35	27.52
Nov	28.93	26.86
Dec	26.98	24.74

Fig. 5: Night time LST analysis (2025)



Months	LST-DAY	
	HIGH	LOW
Jan	22.92	18.19
Feb	26.50	22.01
Mar	28.81	25.15
Apr	28.60	24.65
May	29.69	25.65
Jun	25.25	23.54
Jul	22.23	19.05
Aug	26.43	23.35
Sep	25.52	22.77
Oct	25.08	22.14
Nov	22.50	17.86
Dec	21.24	15.74

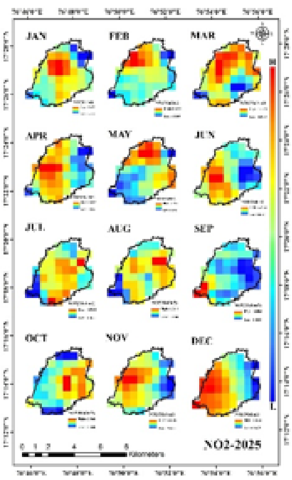
3.5. Air Pollution Analysis

Air pollution assessment focused on the following pollutants:

- Nitrogen Dioxide (NO_2)
- Carbon Monoxide (CO)
- Sulphur Dioxide (SO_2)
- Ozone (O_3)
- Particulate Matter ($PM_{2.5}$ and PM_{10})

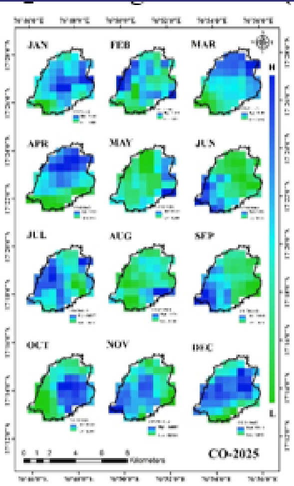
Satellite-based pollutant concentration maps were generated using Sentinel-5P TROPOMI data. $PM_{2.5}$ and PM_{10} concentrations were estimated using aerosol optical depth (AOD), NDVI, and LST relationships. Pollutant levels were classified into low, moderate, and high concentration zones.

Fig. 6: Nitrogen Dioxide (NO_2) analysis (2025)



Months	NO2(Mol/m2)	
	HIGH	LOW
Jan	4.9622	4.2914
Feb	5.2480	4.5490
Mar	5.3033	4.9609
Apr	4.6867	4.0960
May	4.1549	3.6063
Jun	2.7192	1.6033
Jul	2.0312	1.1619
Aug	2.7213	1.4340
Sep	2.5566	1.1031
Oct	2.7063	2.0148
Nov	3.4746	2.6435
Dec	4.4248	3.3273

Fig. 7: Carbon Monoxide (CO) analysis (2025)



Months	NO2(Mol/m2)	
	HIGH	LOW
Jan	4.9622	4.2914
Feb	5.2480	4.5490
Mar	5.3033	4.9609
Apr	4.6867	4.0960
May	4.1549	3.6063
Jun	2.7192	1.6033
Jul	2.0312	1.1619
Aug	2.7213	1.4340
Sep	2.5566	1.1031
Oct	2.7063	2.0148
Nov	3.4746	2.6435
Dec	4.4248	3.3273

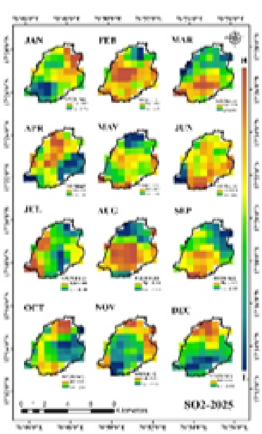
3.6 Integrated Urban–Environmental Analysis

Spatial overlay and correlation analyses were conducted to examine relationships among:

- Built-up land and pollutant concentration
- NDVI and particulate matter
- LST (day and night) and air pollution

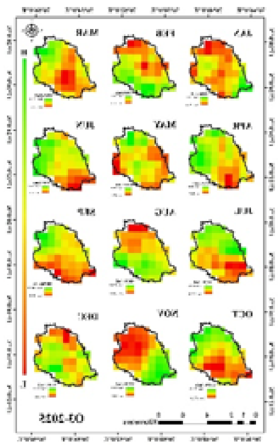
This integrated analysis helped identify urban heat and pollution hotspots.

Fig. 8: Sulphur Dioxide (SO_2) analysis (2025)



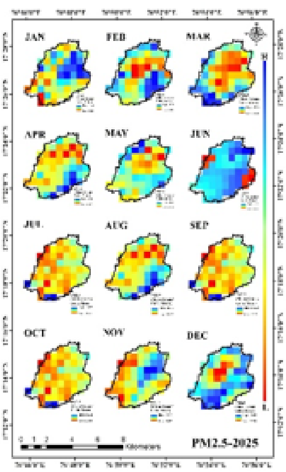
Months	SO2(Mol/m2)	
	HIGH	LOW
Jan	0.0002	-6.1546
Feb	0.0001	-7.5329
Mar	0.0001	3.9084
Apr	0.0001	-2.5851
May	7.2031	-4.4500
Jun	6.5746	-5.5962
Jul	0.0001	-0.0001
Aug	5.4200	-5.7275
Sep	2.9944	-0.0001
Oct	0.0001	1.9401
Nov	0.0001	-2.5129
Dec	0.0001	-6.4594

Fig. 9: Ozone (O_3) analysis (2025)



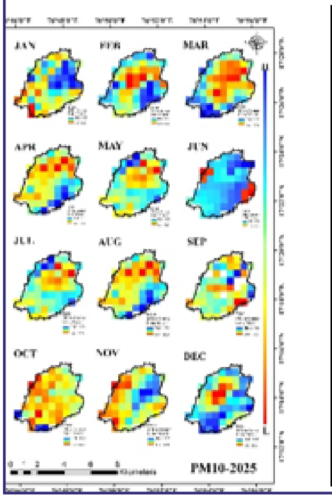
Months	O3(Mol/m2)	
	HIGH	LOW
Jan	255.07	254.4
Feb	259.52	258.76
Mar	271.96	270.01
Apr	287.49	286.69
May	288.55	287.35
Jun	284.07	282.94
Jul	278.72	278.08
Aug	277.42	276.63
Sep	276.74	275.51
Oct	271.23	270.1
Nov	258.37	256.81
Dec	253.3	252.77

Fig. 10: Particulate Matter $PM_{2.5}$ analysis (2025)



Months	PM2.5(Micrograms /Cubic meter)	
	HIGH	LOW
Jan	31.66	28.49
Feb	35.15	32.82
Mar	38.56	34.16
Apr	45.58	41.43
May	35.21	30.28
Jun	41.06	31.87
Jul	31.27	18.46
Aug	26.12	17.47
Sep	31.20	23.9
Oct	32.21	34.9
Nov	32.25	28.17
Dec	30.91	25.78

Fig. 11: Particulate Matter PM_{10} analysis (2025)



Months	PM10(Micrograms/ Cubic meter)	
	HIGH	LOW
Jan	51.83	45.81
Feb	58.45	54.03
Mar	64.90	56.56
Apr	78.23	70.36
May	58.56	49.21
Jun	69.66	52.22
Jul	51.09	26.78
Aug	51.09	26.78
Sep	48.82	33.17
Oct	50.94	37.11
Nov	52.95	45.2
Dec	50.40	40.66

2.7 Accuracy Assessment
Classification accuracy was evaluated using confusion matrices and kappa statistics based on reference data from high-resolution imagery and secondary sources.

2.8 Output Generation
The final outputs included:
- Multi-temporal LULC maps
- NDVI and LST (day and night) maps
- Air pollution distribution maps
- Change detection and hotspot map

These outputs provide a comprehensive assessment of urban expansion and environmental change in Kalaburagi City.

3. CONCLUSIONS
The findings of this study clearly demonstrate that rapid urban expansion in Gulbarga city has significantly altered the environmental landscape over the study period. The consistent decline in vegetation cover has been noticed alongside the marked increase in built-up areas. There was a significant shift in land-use patterns driven by urban growth. This transformation has also contributed to a noticeable reduction in surface water extent, resulting in a concurrent rise in land surface temperatures. The most significant change was within densely developed zones. The inverse relationship between vegetation indices and surface temperature was observed. A positive association between built-up areas and thermal intensity was also detected, highlighting the role of land-cover changes in intensifying urban heat. Additionally, there was deterioration in air quality—primarily influenced by particulate matter and urban emissions. This could be due to the environmental pressures associated with unplanned urbanization. Overall, the study emphasizes that the combined effects of land use change, thermal variation, and air pollution are closely interconnected and collectively contribute to environmental degradation in Gulbarga. These findings reinforce the need for integrated geoinformatics-based planning approaches to support smart, stable and sustainable urban development, which can be enhanced through green cover, and also mitigate urban heat and pollution impacts.

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