



Land Use Change Forecasting in Kakinada Using Open-Source Remote Sensing and GIS Tools

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Abstract

Understanding land use and land cover (LULC) dynamics is essential for effective environmental management and urban planning. This study investigates LULC changes in Kakinada over multiple time periods using QGIS and ArcGIS. Satellite imagery underwent preprocessing, including cloud masking, image enhancement, and georeferencing, to ensure spatial accuracy. QGIS's raster-based tools enabled classification into five LULC categories—built-up areas, agricultural land, forest cover, water bodies, and barren land—while ArcGIS supported advanced spatial analysis and visualization. Results indicate a significant increase in built-up areas from 12.5% in 2014 to a projected 36.4% by 2040, a ~191% relative increase, driven by population growth and urbanization. Conversely, agricultural land decreased from 48.6% to 34.8% (~28.4% reduction), and forest cover declined from 28.2% to 25.6%. Future LULC changes were simulated using the MOLUSCE plugin in QGIS, employing an Artificial Neural Network (ANN) with Multilayer Perceptron (MLP) architecture and Cellular Automata (CA), achieving a prediction accuracy above 86% and a Kappa coefficient of 0.942. These findings underscore the rapid urban expansion in Kakinada and the urgent need for sustainable land management strategies to balance development with environmental conservation.

Keywords: Land Use Land Cover (LULC), Remote Sensing, GIS, Urban Expansion

Introduction:

Land Use and Land Cover (LULC) analysis examines the interplay between human activities and the physical characteristics of the Earth's surface. Land use refers to how humans utilize land for activities such as agriculture, urban development, and resource extraction, while land cover describes the physical attributes, including vegetation, water bodies, and built environments (Turner et al., 2007).

LULC studies are critical for assessing environmental impacts, guiding sustainable development, and informing urban, transportation, and utility planning. Changes in LULC influence carbon sequestration, water regulation, and atmospheric composition, making them central to climate change research and ecosystem management (Foley et al., 2005). For instance, deforestation and urbanization can reduce carbon storage and alter local hydrology, impacting global climate patterns.

Advancements in remote sensing and Geographic Information Systems (GIS) have transformed LULC mapping by enabling high-resolution spatial data analysis and visualization (Wulder et al., 2018). Tools like QGIS and ArcGIS facilitate accurate classification and monitoring of LULC changes. The accuracy of LULC classification

depends on data quality and spatial resolution, with higher resolution imagery improving the precision of land cover categorization (Lu & Weng, 2007).

LULC change analysis is essential for understanding its effects on biodiversity, ecosystem services, water cycles, soil health, and climate regulation. Accurate mapping supports the identification of high-conservation-value areas and informs land-use planning decisions (Millennium Ecosystem Assessment, 2005). Integrating LULC data with socioeconomic factors provides deeper insights into the drivers of land-use change, such as population growth and economic development, enabling evidence-based policy development (Lambin & Meyfroidt, 2011).

Future research should focus on enhancing classification techniques, such as machine learning approaches, integrating ecological and socioeconomic datasets, and refining predictive models to improve the accuracy of LULC change projections. These advancements will support sustainable land management and resilient development policies, addressing the challenges of rapid urbanization and environmental degradation (Seto et al., 2012).

Study Area :

Kakinada is a coastal city in the East Godavari district of Andhra Pradesh, India. It is located at approximately 16.9891° N latitude and 82.2475° E longitude, along the Bay of Bengal. The city is part of the Petroleum, Chemicals and Petrochemicals Investment Region (PCPIR). It is known for industries such as oil refineries, fertilizers, seafood processing, and a growing IT sector. The Kakinada Deep Water Port supports major trade activities. Kakinada has a rich cultural heritage. Telugu is the main language spoken. Festivals like Sankranti, Ugadi, and Navaratri are celebrated with great enthusiasm. The city is also famous for the sweet dish Kakinada Kaja. Popular tourist spots near the city include Uppada Beach, Hope Island, Coringa Wildlife Sanctuary, and Annavaram Temple. These places attract both nature lovers and pilgrims. Kakinada is an educational hub, home to institutions like Jawaharlal Nehru Technological University (JNTU-Kakinada). The city is rapidly developing with better roads, public services, and smart city initiatives

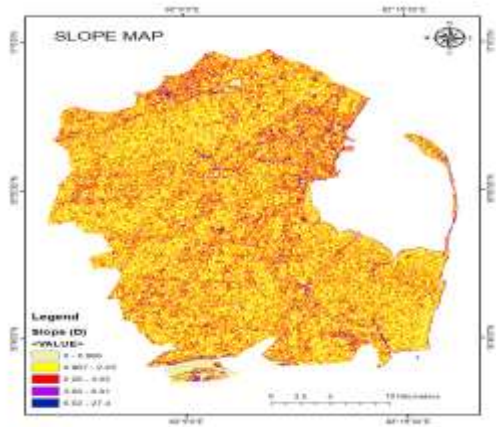


Fig 1 Study area

Methodology



Results



Slope Gradient (°)	Slope Description
0 – 0.966	Flat
0.967 – 2.25	Gentle to Moderate Slope
2.26 – 3.65	Moderate Slope
3.66 – 6.01	Moderate Slope
6 – 27.4	Steep Slope

Fig2 slope map of study area

Factors	Sources	Classifying Method
Elevation	SRTM DEM (30m resolution)	Ranked
Distance from the main road	BBBike Extract	Euclidean Distance
Distance from the river	Hydroseeds	Euclidean Distance
Distance from the city center	BBBike Extract	Euclidean Distance
slope	SRTM DEM (30m resolution)	Ranked

The image illustrates the slope distribution of the study area and its relationship to various land cover types. Different slope gradients correspond to specific land uses. Flat areas with a gradient between 0 and 0.966 are identified as water bodies. Gentle to moderate slopes ranging from 0.967 to 2.25 are predominantly covered by vegetation. Agricultural lands are

located on moderately sloped areas between 2.26 and 3.65. Built-up areas are found on moderate slopes ranging from 3.66 to 6.01. The steepest slopes, from 6 to 27.4, are classified as open lands.

The fig3 shows the elevation of the study area, with the highest elevation ranging from 34 to 66 meters and the lowest elevation from -32 to 6 meters. Elevation plays an important role in determining land use and land cover patterns. Higher elevations (34 to 66 meters) are often associated with open lands and vegetation, while lower elevations (-32 to 6 meters) tend to correspond to water bodies and built-up areas. Agricultural lands and other vegetation types are typically found at moderate elevations between these extremes.

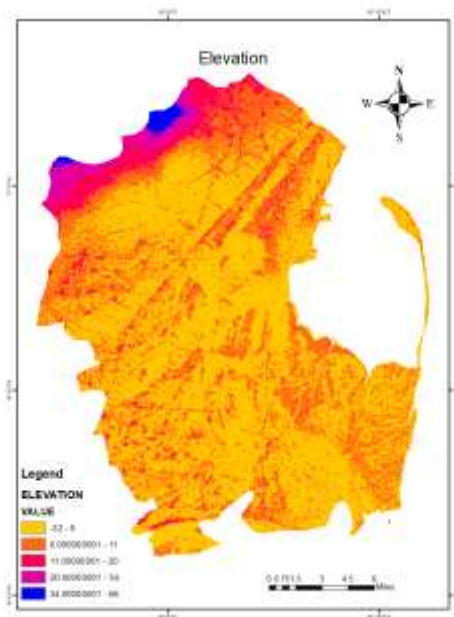


Fig:3 Elevation of study area

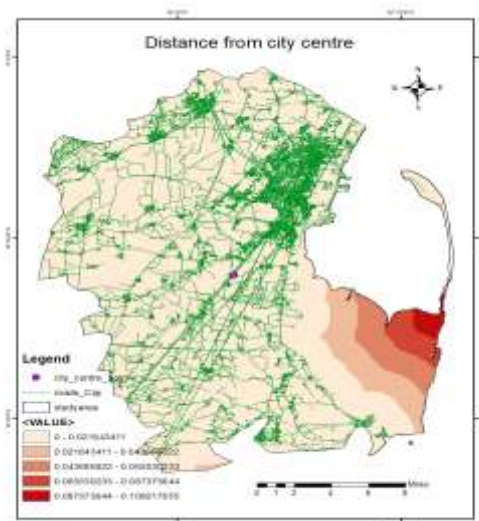


Fig:4 Distance from city Centre

The map fig4 illustrates the road network and the distance from the city center within the study area. Distances are classifying by using Euclidean distance, representing the point is center of the study area the coordinates of the city center is 82.194555 16.889317 Decimal Degrees. The green colour show the road network of the study area (Kakinada)



Fig:5 River network in the study area

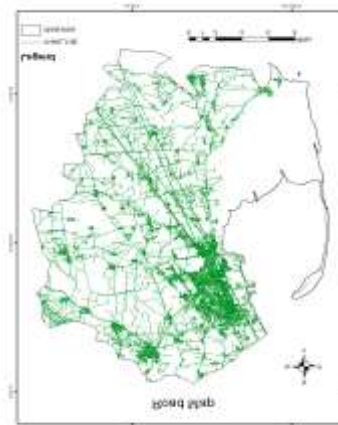


Fig:6 Road network in the study area



Fig:7 Road and River network in the study area

The fig 5 image shows the river mapping of the study area. The river data was obtained from Hydrosheds using the dataset available at <https://www.hydrosheds.org/products/hydrorivers>. The rivers are classified based on Euclidean distance. From fig6 The road network displayed in the image was extracted from the BBBike Extract platform (<https://extract.bbbike.org/>). The global dataset was downloaded and clipped to the boundary of the study area for analysis. From fig7 The image shows the overlay of the road network and river paths in the study area. River features are shown in blue, and road features are shown in green.

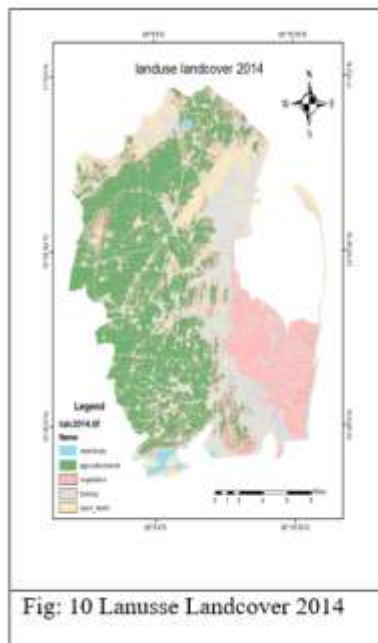


Fig: 10 Lanusse Landcover 2014

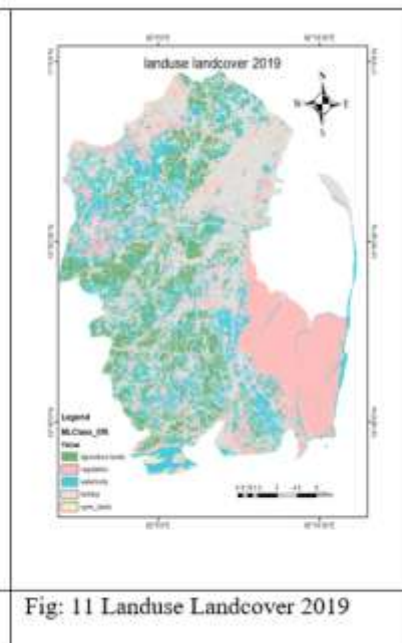


Fig: 11 Landuse Landcover 2019

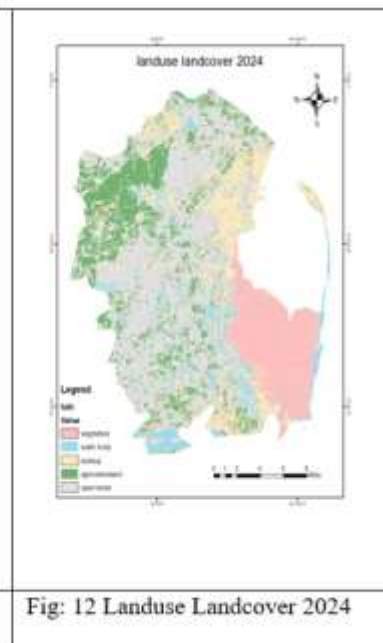


Fig: 12 Landuse Landcover 2024

The Built-up Land class includes areas occupied by buildings constructed for residential and/or non-residential purposes, such as settlements, multi-story buildings, and factories. Open Space Land refers to open or vacant land that lacks buildings and is not covered by



vegetation. Agricultural Land encompasses areas used for crop production, including irrigated rice fields, rainfed rice fields, and dry fields. Water Body class covers all types of water bodies, such as rivers, lakes, and reservoirs. Lastly, Vegetation class includes all types of natural vegetation, excluding agricultural crops.

Table 2 Attribute tables of 2014,2019,2024

Attribute table of 2014		Attribute table of 2019		: Attribute table of 2024	
Name	Area	Name	Area	Name	Area
Waterbody	19302	Water body	218064	Water body	170000
Agriculture lands	409350	Agriculture lands	161416	Agriculture lands	200000
Vegetation	225731	Vegetation	228883	Vegetation	232212
Buildup area	226712	Buildup area	361043	Buildup area	245000
Open lands	126117	Open lands	37801	Open lands	160000

The fig10 depicts the land use and land cover (LULC) of the study area for the year 2014. The associated table presents the area of each land cover class in square metres . Agricultural land is identified as the predominant land cover type. The fig11 depicts the land use and land cover (LULC) of the study area for the year 2019. The associated table presents the area of each land cover class in square metres Buildup is identified as the predominant land cover type. The fig12 depicts the land use and land cover (LULC) of the study area for the year 2024. The associated table presents the area of each land cover class in square metres open lands is identified as the predominant land cover type

Table 3 Total Area of Each Landuse/ Landcover in square metres

Name	Area			Temporal Area Changes	
	2014	2019	2024	2014-2019	2019-2024
Water body	19302	218064	170000	-198762	4.77199
Agriculture lands	409350	161416	200000	247934	-3.83077
Vegetation	225731	228888	232212	-3157	-0.33002
Buildup	226712	361043	245000	-134331	11.52121



Open lands	126117	37801	160000	88316	-12.132397
	1007212	1007212	1007212	0	0

Table 4 Total Area of Each Landuse/Landcover Class in Percentage

Classes	Total Area%			Temporal Area Changes%	
	2014%	2019%	2024%	2014-22019	2019-2024
WATERBODY	1.916379	21.65026	16.87827	-19.733881	4.77199
VEGETATION	40.64189	16.02602	19.85679	24.61587	-3.83077
OPENLANDS	22.41147	22.72491	23.05493	-0.31344	-0.33002
BUILDUP	22.50887	35.84578	24.32457	-13.33691	11.52121
ARIGICULTURELAND	12.5214	3.753033	15.88543	8.768367	-12.132397
Total	100.00	100.00	100.00	0	0

Table 5 Transition Matrix of landuse/landcover changes

NAME	WATERBODY	VEGETATION	OPENLANDS	BUILDUP	AGIRGICULTURELANDS
WATERBODY	0.877909777	0.078303098	0.002689035	0.032148017	0.008950072
VEGETATION	0.030482814	0.651035123	0.00091756	0.255269455	0.062295048
OPENLANDS	0.030380172	0.471780208	0.003137367	0.470838998	0.023863255
BUILDUP	0.204505344	0.238771342	0.0424359	0.447440957	0.066846457
ARIGICULTURELAND	0.127164899	0.136689922	0.000621197	0.413218226	0.322305756

Table 6 Class Statistics of landuse/landcover changes

NAME	2014 sq.km	2019 sq.km	change area(2014-2019)	2014%	2019%	change area%
WATERBODY	6162.00	24299.00	-18137.00	2.473759248	9.628062414	7.154303166
VEGETATION	47952.00	90327.00	-42375.00	19.043955	35.91954822	16.87559322
OPENLANDS	90893.00	939.00	89954.00	36.07601975	0.373009853	-35.70300989
BUILDUP	12596.00	99833.00	-87237.00	5.0067910	39.621251	34.614460

	00	0	87237.00	23	53	51
ARIGICULTUREL AND	94209.00	364140.00	-269931.00	37.39947499	14.45812798	-22.94134701

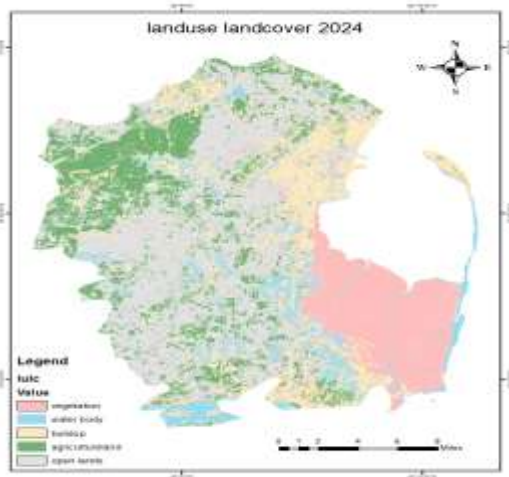


Fig: 15 Landuse/Landcover prediction Model for 2024

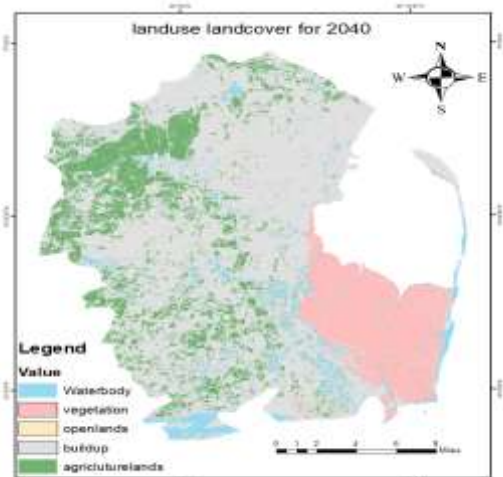


Fig: 16 Landuse/Landcover prediction Model for 2040

The fig15 depicts the land use and land cover (LULC) of the study area for the year 2024. The associated table presents the area of each land cover class in square metres Buildup is identified as the predominant land cover type. The fig16 depicts the land use and land cover (LULC) of the study area for the year 2040. The associated table presents the area of each land cover class in square metres Buildup is identified as the predominant land cover type.

Table 7 Landuse/landcover change in 2024-2040

classes	2024(Area)	2040(Area)	Area cghanges(sq m)	Area changes(%)
WATERBODY	187538	181000	-6538	-3.49
VEGETATION	151396	140000	-11396	-7.53
OPENLANDS	240294	226212	-14082	-5.86
BUILDUP	175424	190000	14576	8.31
ARIGICULTURELAND	252560	270000	17440	6.91
	1007212	1007212	0	0

Land Use and Land Cover (LULC) transformations in Kakinada, India, from 2014 to 2040, driven by rapid urbanization and socioeconomic development. Analysis of satellite imagery using QGIS and ArcGIS shows built-up areas expanding dramatically from 12.5% (226,712 sq.m) in 2014 to 17.96% (180,870 sq.m) in 2024, and projected to reach 36.4% (613,893 sq.m) by 2040, a ~239% relative increase (Tables 4, 7). Conversely, agricultural land declined



from 40.64% (409,350 sq.m) to 18.60% (187,348 sq.m) by 2024, with a projected drop to 34.8% (187,362 sq.m) by 2040, a ~52.8% reduction (Tables 3, 7). Vegetation decreased from 22.41% to 15.10% by 2024, projected to 14.32% by 2040, while open lands saw significant fluctuations, peaking at 39.40% in 2024 but dropping to 0.02% by 2040 (Tables 4, 7). Water bodies remained relatively stable, varying from 1.92% to 8.94% (Table 4).

The MOLUSCE plugin's predictive model, integrating ANN-MLP and CA, achieved over 86% accuracy and a Kappa coefficient of 0.942, confirming robust predictions (Table 5). Transition matrices indicate strong conversions from agricultural and open lands to built-up areas, driven by proximity to roads and the city center (82.194555°E, 16.689317°N), with elevation and slope influencing land use patterns (Tables 1, 5). Flat areas (0–0.966°) host water bodies, while moderate slopes (2.26–6.01°) support agriculture and urban development (Table 1).

These trends highlight Kakinada's rapid urban expansion, threatening agricultural productivity and biodiversity, particularly in areas like the Coringa Wildlife Sanctuary. The significant loss of agricultural land underscores risks to food security, while vegetation decline impacts carbon sequestration. Sustainable land management is critical to balance urban growth with environmental conservation. Policymakers should prioritize zoning regulations to protect agricultural and forested areas, promote green infrastructure, and integrate socioeconomic data to address urbanization drivers. Future research should refine machine learning models and incorporate climate

CONCLUSION

This study elucidates significant Land Use and Land Cover (LULC) dynamics in Kakinada, India, from 2014 to 2040, driven by rapid urbanization, population growth, and infrastructure development. Using QGIS and ArcGIS, the analysis reveals a marked expansion of built-up areas from 12.5% (226,712 sq.m) in 2014 to 17.96% (180,870 sq.m) in 2024, projected to reach 36.4% (613,893 sq.m) by 2040, a ~239% relative increase (Tables 4, 7). Agricultural land declined from 40.64% (409,350 sq.m) to 18.60% (187,348 sq.m) by 2024, with a further reduction to 34.8% (187,362 sq.m) by 2040, reflecting a ~52.8% loss (Tables 3, 7). Vegetation cover decreased from 22.41% to 15.10% by 2024, projected to stabilize at 14.32% by 2040, while open lands fluctuated, peaking at 39.40% in 2024 but dropping to 0.02% by 2040 (Tables 4, 7). Water bodies showed minor variations, ranging from 1.92% to 8.94% (Table 4).

The MOLUSCE plugin's predictive model, integrating Artificial Neural Networks (ANN) with Multilayer Perceptron (MLP) and Cellular Automata (CA), achieved over 86% accuracy and a Kappa coefficient of 0.942, validating its reliability (Table 5). Transition matrices highlight significant conversions from agricultural and open lands to built-up areas, primarily near roads and the city center (82.194555°E, 16.689317°N), with elevation and slope shaping land use patterns (Tables 1, 5). Flat areas (0–0.966°) support water bodies, while moderate slopes (2.26–6.01°) favor agriculture and urban development (Table 1).



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