FORECASTING LAND USE AND LAND COVER (LULC) CHANGES USING REMOTE SENSING AND GIS: A CASE STUDY OF DISTRICT, KHAIRPUR MIRS, SINDH

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Abstract

*The changes in land use and land cover (LULC) have a significant impact on the regional climatic regimes, hydrological balance, and ecosystem services, thus making them an arduous challenge to the realization of the global sustainable development. These changes have been rapidly accelerated in the District of Khairpur Mirs, Sindh, Pakistan, by the volatility of climatic conditions, agricultural intensification, and high urbanization. In present study, the approach to sustainable land-use planning and environmental stewardship is the use of Geographic Information Systems (GIS) and Remote Sensing (RS) techniques to evaluate LULC transitions that happened during the past years (2010, 2020, 2022) and to predict the future scenarios up to 2050. Built-up regions, barren terrain, water bodies, agriculture land and forests are the five main LULC categories into which ArcGIS processed and classified Landsat satellite images from 2010 to 2022 and Prediction up to 2050. Spatial and temporal dynamics were assessed using supervised classification, post-classification comparison, and change detection methods, and future land-use trends were simulated using predictive modeling approaches. The Classification/analysis and prediction show the changes in land use/land cover, 1. **Forest:** A continuous decline from **6% to 1%** indicates increasing deforestation and land-use conversion pressure. 2. **Water Bodies:** An overall reduction from **10% to 2%** reflects water scarcity and encroachment impacts. 3. **Bare Land:** A gradual decrease from **46% to 38%** suggests conversion into built-up and agricultural areas. 4. **Built-up Area:** A consistent increase from **18% to 39%** highlights rapid urban expansion and infrastructure development. 5. **Agriculture:** Minor fluctuations indicate pressure from urban growth with partial land retention.*

This study will be able to provide policy makers and planners with an empirically based model of the possibility of achieving a balance between economic growth and environmental sustainability in the face of global land-use pressures in Khairpur Mirs District to protect the long-term ecological integrity and resource security of the area.

1. INTRODUCTION

The world's population has increased from 2.6 billion to 7.7 billion since the 1950s, and by 2050, it is predicted to reach roughly 9.7 billion [1]. The demand for energy, food, housing, water, transportation, and healthcare rises with population growth. The Earth's surface has changed as a result of human exploitation of natural resources to meet these demands. The most evident sign of changes in the Earth's surface is changes in land use and land cover (LULC) [2,3]. The distribution of LULC fluctuates in geography and time due to the social and physical aspects of populations. The detrimental effects of several environmental and socioeconomic elements on the Earth's surface, such as climate, water balance, biodiversity, and terrestrial ecosystems, can be demonstrated by LULC change, according to recent studies [4,5,6]. Researchers are now primarily interested in studying how the LULC affects the ecology [3,7,8,9,10]. Remote sensing (RS) equipment have gathered important data from Earth's surfaces over the past few decades. Standard software packages are not entirely functional for providing a comprehensive solution for managing and interpreting Earth data, even if RS offers researchers useful data [10,11]. Many RS sensors have been launched in recent decades, including Landsat, Sentinel 2, Satellite Pour observation de la Terre (SPOT), and Moderate Resolution Imaging Spectroradiometer (MODIS) [12,13]. Various techniques have been developed and presented to extract information from these remotely sensed data. The only sensor that has been collecting data for more than 40 years and is still in operation is Landsat.

To assess the significant effects of upcoming LULC patterns, numerous researchers have been using different geographic modeling of LULC alterations. [14]. For example, Leta et al. [15] used the MLC technique to assess the LULC spatiotemporal variations in the Nashe watershed and projected LULC maps for 2035 and 2050 by taking probable driving variables into account. Abijith and Saravanan [16] used the CA-Markov modeling technique to simulate LULC maps of 2025 and 2030 and used random forest classification to create LULC maps on the Northern TN coast. For land use policy and planning to be as successful as possible, it is necessary to accurately assess land use demand and simulate it in various future scenarios [17]. Assessing regional, local, and global environmental change requires the identification of LULC [18] and [19]. The Land Change Modeller (LCM), which is based on an integrated CA [20] and Markov chain (MC) resulting in a CA-Markov chain model, has been demonstrated in numerous studies to be an excellent model for the analysis and forecasting of LULC change and urban growth [17] [21][22][23][24] and [25]. The CA-Markov chain combination can be used to simulate the spatiotemporal elements of LULC dynamics [26] and [27]. The LCM included within TerrSet was used to forecast the LULC in the future based on the previously classified photos. The CA-Markov model is a dependable method for both quantity estimation and spatial and temporal modeling of LULC dynamics. Changes in different LULCs and the shift from one category of LULC change to another can be simulated by the CA-Markov model [28] and [29]. In order to support Climate-resistant farming, provide long-term ecological equilibrium throughout the period of fast land-use changes in Khairpur Mirs, and inform sustainable urban growth, evaluation of LULC fluctuation in the past and future forecasting is essential. This report assists regional planning efforts by providing an overall analysis of LULC from 2010 to 2022 and anticipating trends till 2050.

2. RESEARCH AREA

Khairpur district is situated along the left bank of the Indus River in the center and northern quadrant of Sindh, Pakistan. The district is divided into eight administrative tehsils: Khairpur (the district seat), Kangri, Gambat, Sobhodero, Kot Diji, Nara, Thari Mirwah, and Faiz Gunj. The district's geographical coordinates are 27°3146.13 -68°454212. The international border with India forms the eastern border; Shikarpur and Sukkur form the northern border; Sanghar and Shaheed Benazeerabad form the southern border; and

Larkana and Naushahro Feroz form the western border. The district has a typical upper-Sindh climate with two distinct seasons: the hot summer season, which lasts from the end of March to October and peaks in May, June, and July. The average daily maximum temperature is nearly 42 degrees Celsius, while the average daily minimum temperature is 27 degrees. On the other hand, the average maximum temperature lowers to 25 °C and the lowest temperature dips to 7 °C during the winter months of December, January, and February.
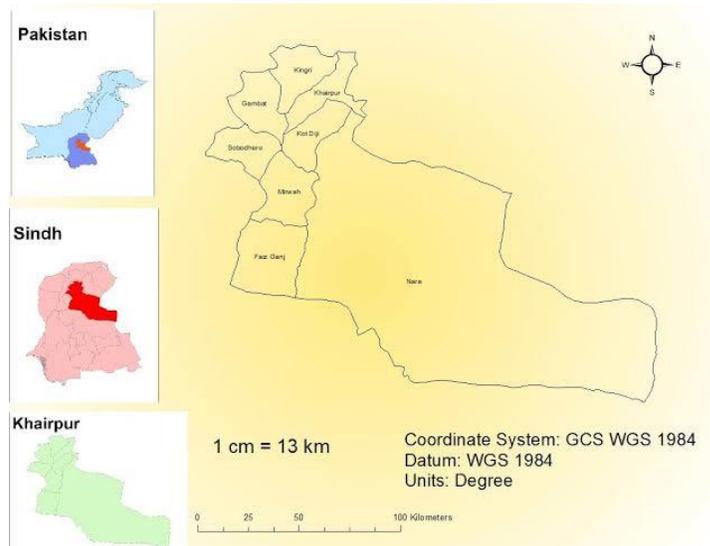

Figure 1: The Study Area (District Khairpur Mirs)

Figure 2: Google Earth Image of Study Area

3. Methods of Research

3.1 Information Gathering

The USGS Earth Explorer platform provided satellite photos from Landsat 4–5 TM, Landsat 8–9 OLI/TIRS, and Sentinel 2 for the years 2010, 2020, and 2022. The photos were chosen based on the study area's full spatial coverage and a minimal cloud cover of less than 10%. When a scene did not fully capture the study area, several nearby photos were downloaded and then mosaicked to guarantee full coverage.

Table 1: Satellite Data Used in the Study

Year	Sensor	Resolution (m)	Path/Row	Cloud Cover (%)
2010	Landsat 5 TM	30	151/42	<10%
2020	Landsat 8 OLI	30	151/42	<10%
2022	Landsat 8 OLI	30	151/42	<10%

3.2 Shapefile Generation

ArcGIS Pro was used to draw the boundaries of the study region. A polygon shapefile that represented the research area's boundaries was digitized, and a reference base map was georeferenced using known geographic coordinates. Subsequent analysis and satellite image cutting were done using this shapefile.

3.3 Preprocessing Images

ArcGIS Pro was used to preprocess the downloaded Landsat scenes. To produce multispectral images, a band composite was made for every year. The digital shapefile was used to trim the composite photos to the boundaries of the study region. Since TerrSet does not directly accept raster file formats, the clipped raster datasets were exported into ASCII format to allow for additional analysis in TerrSet software.

3.4 Land Classification System

TerrSet employed the Maximum Likelihood Classifier (MIXLIKE) for supervised classification. Five land use/land cover (LULC) groupings were created specifically for this study: The first five categories are built-up areas, bare terrain, forests, water bodies, and agriculture. Training samples were collected from the satellite images for each class, and many representative samples were provided to improve classification accuracy. The classified maps were then used to calculate the areal extent of each type of land cover.

3.5 LULC Change Assessment

Post-classification comparison was used to quantify LULC differences between the selected years. The areal extent of each land cover class was determined using the attribute tables of the classified maps. Changes were then calculated by comparing class-wise regions over the course of the study years.

3.6 Preparing Variables

ArcGIS Pro was used to prepare three explanatory variables: distance to roadways, distance to disturbances, and distance to metropolitan areas. The BBBike database was used to download the pertinent vector layers, which were then clipped to the research region and transformed into Euclidean distance rasters using the Spatial Analysis tool. Later, TerrSet was used to represent transition potentials using these variables.

Three explanatory variables distance to roads, distance to disturbances, and distance to metropolitan areas where prepared using IS Pro. The relevant vector layers were downloaded from the BBBike database, trimmed to the study area, and converted into Euclidean distance rasters using the Spatial Analysis tool. These variables were later used to represent transition potentials in TerrSet.

3.7 LULC Change Prediction:

TerrSet's Land Change Modeler (LCM) was used to model potential future land cover. The categorized maps from 2010, 2020, and 2022 were used as calibration inputs, and the 2020 map was

used for validation. Transition potential maps were made using the explanatory variables. Change demand was projected for the years 2030, 2040, and 2050. By comparing the forecast outputs with the 2010, 2020, and 2022 classifications, the model's accuracy was evaluated.

4.RESULT AND DISCUSSION

This section presents the results of the land use/land cover (LULC) change analysis and discusses the spatio-temporal dynamics observed in the study area over the selected time period, along with predicted future trends

4.1 Results of LULC Analysis

The results for the analysis of LULC for the district Khairpur Mirs on the basis of GIS evaluation are discussed as under:
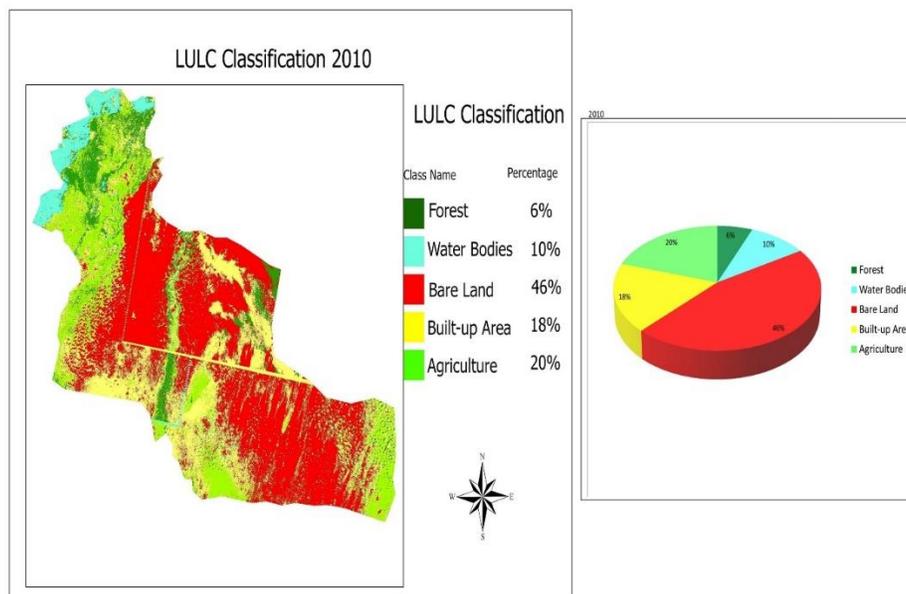

Figure 3: LULC Analysis for the Year 2010

Table 2: LULC Classification/Analysis 2010

Sr. No	Class Name	Area (km²)	%
01	Forest	954.60	6%
02	Water Bodies	1,591.00	10%
03	Bare Land	7,318.60	46%
04	Built-up Area	2,863.80	18%
05	Agriculture	3,182.00	20%
Total Area		15,910.00	100%

According to the 2010 LULC analysis, District Khairpur Mirs was dominated by bare land, which made up almost half of the total area. This indicates that there is little vegetation and a lot of open space. Together, built-up and agricultural land made up a sizable part, demonstrating the district's growing urbanization and agrarian foundation. Water bodies made up a substantial portion, but the amount of forest cover was still quite low, indicating the scarcity of natural vegetation. Overall, the 2010 land-use pattern points to a landscape that is mostly made up of agriculture and bare land, with limited forest resources and increasing urbanization, highlighting the need for better land management and environmental preservation.
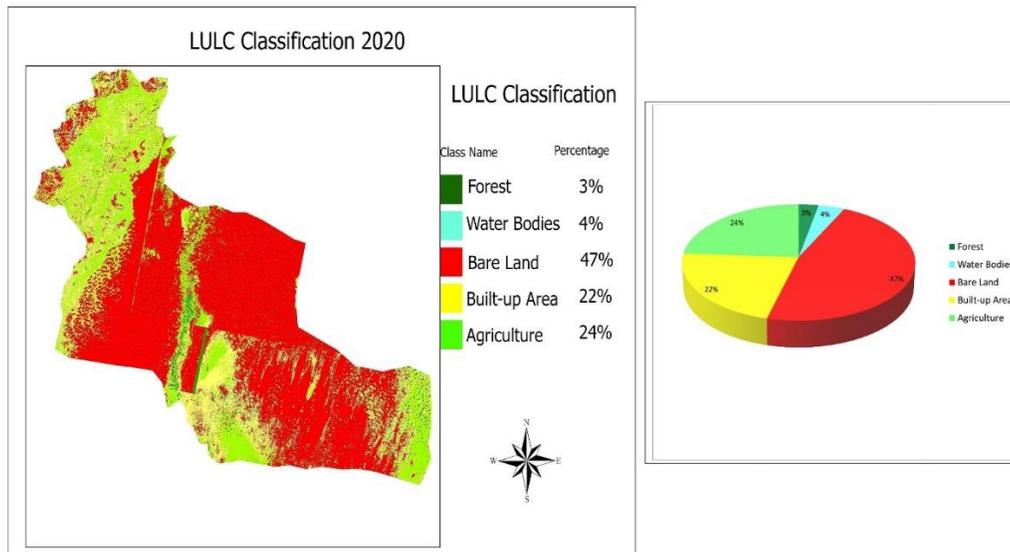
Figure 4: LULC Analysis for the Year 2020

Table 3: LULC Classification /Analysis 2020

Sr. No	Class Name	Area (km²)	%
01	Forest	477.30	3%
02	Water Bodies	636.40	4%
03	Bare Land	7,477.70	47%
04	Built-up Area	3,500.20	22%
05	Agriculture	3,818.40	24%
	Total Area	**15,910.00**	**100%**

In District Khairpur Mirs, bare ground remained the most common land cover, accounting for around half of the total area, according to the 2020 LULC analysis. Its continued importance to the local economy was demonstrated by the fact that a sizable amount of the land was used for agriculture. The built-up area increased, a sign of ongoing urbanization and infrastructure development. However, the amount of forest cover and water bodies declined, indicating that natural resources are under stress. Overall, by emphasizing the acceleration of urbanization and agricultural activities at the expense of biological land covers, the 2020 land-use pattern highlights the necessity of sustainable land-use planning and resource protection.
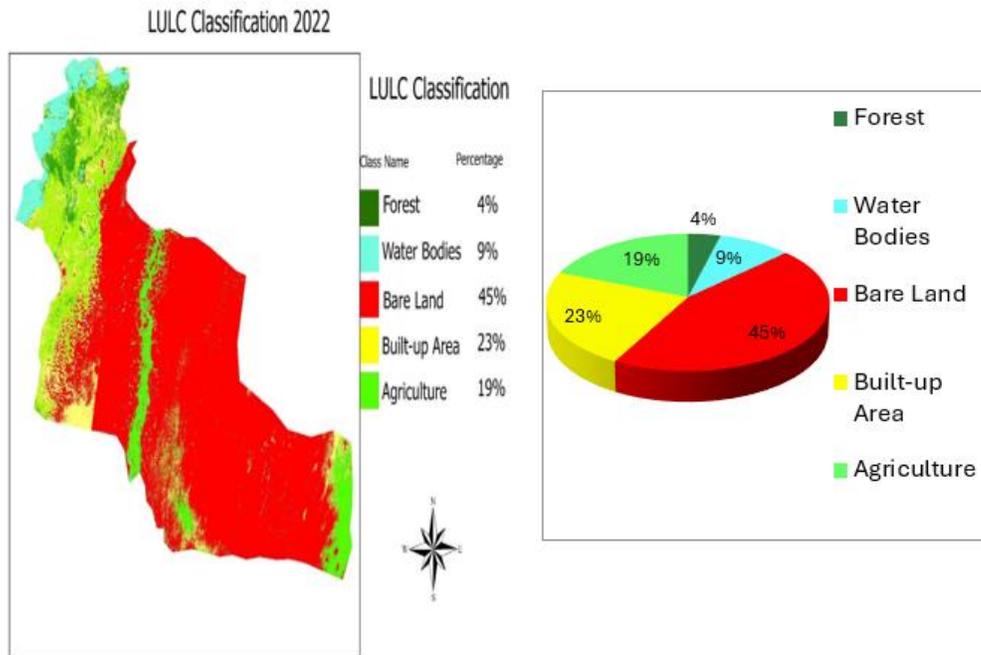
Figure 5: LULC Analysis for the Year 2022

Table 4: LULC Classification /Analysis for the Year 2022

Sr. No	Class Name	Area (km²)	%
01	Forest	636.40	4%
02	Water Bodies	1431.90	9%
03	Bare Land	7,159.50	45%
04	Built-up Area	3659.30	23%
05	Agriculture	3022.90	19%
Total Area		**15,910·00**	**100%**

According to the 2022 LULC analysis, barren land still predominated in District Khairpur Mirs, albeit slightly less so than in prior years. Sustained urban growth was shown by the continued expansion of built-up areas. There was a noticeable rise in water bodies, which could be due to seasonal fluctuations or better surface water supply. There was continued pressure on vegetated regions, as seen by the decrease in agricultural land and the restricted amount of woodland cover. All things considered, the land-use pattern for 2022 shows a dynamic transition characterized by urban growth and shifting natural resources, highlighting the significance of coordinated and sustainable land-use management.

4.2 LULC Prediction

The future prediction was made by the application of TerrSet software and the results for the study area for the year 2030, 2040 and 2050 are given as under:
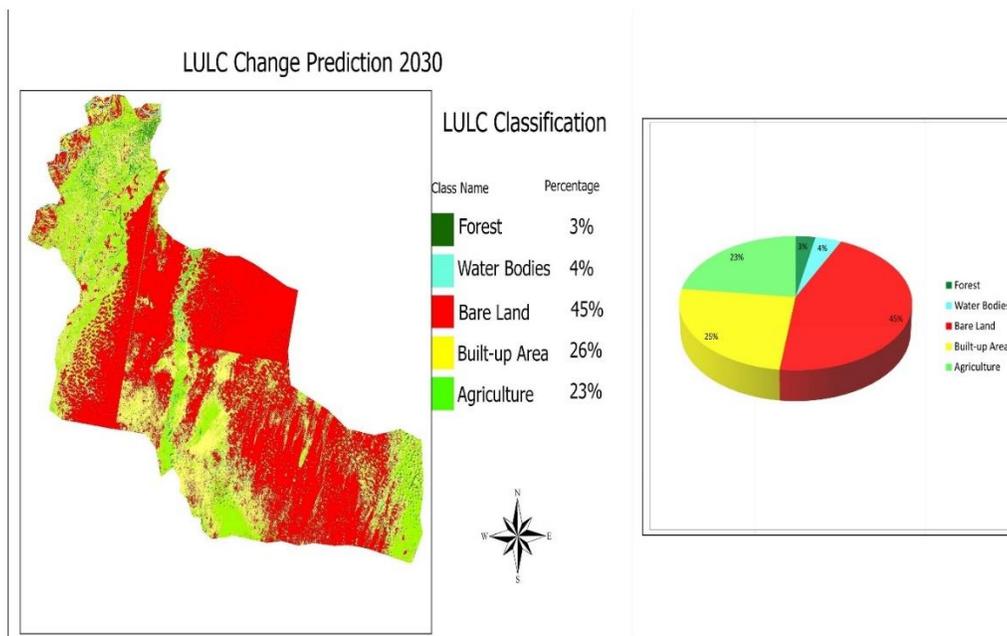
Figure 6: LULC Predictions for the Year 2030

Table 5: LULC Prediction for the Year 2030

Sr. No	Class Name	Area (km²)	%
01	Forest	477.30	3%
02	Water Bodies	636.40	4%
03	Bare Land	7,159.50	45%
04	Built-up Area	4,136.60	26%
05	Agriculture	3,500.20	22%
Total Area		15,910·00	100%

According to the 2030 LULC forecast, built-up areas would continue to develop, indicating District Khairpur Mirs' rapid urbanization. It is anticipated that bare land will continue to be the predominant land cover, albeit gradually decreasing as a result of land conversion. It is anticipated that a significant portion of the land would remain agricultural, sustaining the district's agrarian economy. Conversely, it is anticipated that water bodies and forest cover would continue to be scarce, indicating ongoing stress on natural ecosystems. In general, the 2030 forecast emphasizes the necessity of proactive land-use planning to strike a balance between environmental sustainability and urban expansion.
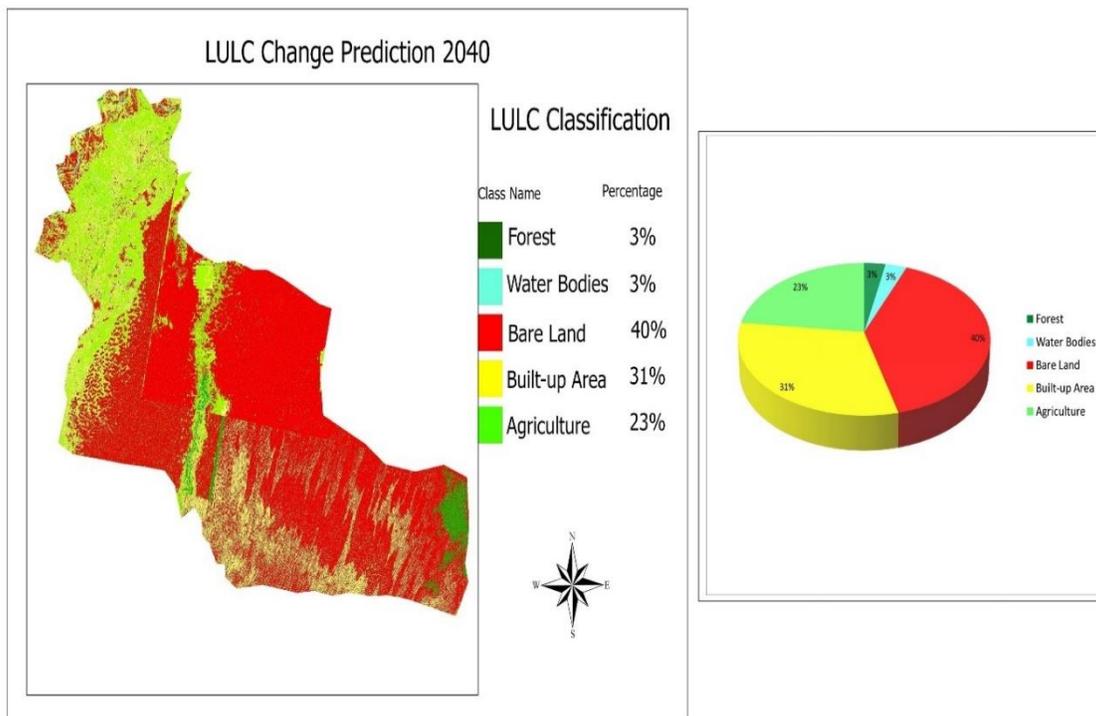
Figure 7: LULC Predictions for the Year 2040

Table 6: LULC Prediction for the Year 2040

Sr. No	Class Name	Area (km²)	%
01	Forest	477.30	3%
02	Water Bodies	477.30	3%
03	Bare Land	6,364.00	40%
04	Built-up Area	4,932.10	31%
05	Agriculture	3,659.30	23%
Total Area		15,910.00	100%

Strong and ongoing urban growth in District Khairpur Mirs is indicated by the 2040 LULC forecast, which shows a noticeable increase in built-up areas. Due to its conversion to agricultural and urban uses, bare land is expected to drastically decrease. It is anticipated that agricultural land would continue to be comparatively stable, retaining its economic significance. In the meanwhile, it is anticipated that water bodies and forest cover will continue to be sparse, underscoring the continued environmental strain. All things considered, the 2040 forecast emphasizes how urgent it is to implement efficient land-use regulations and conservation strategies in order to lessen the effects of fast urbanization.
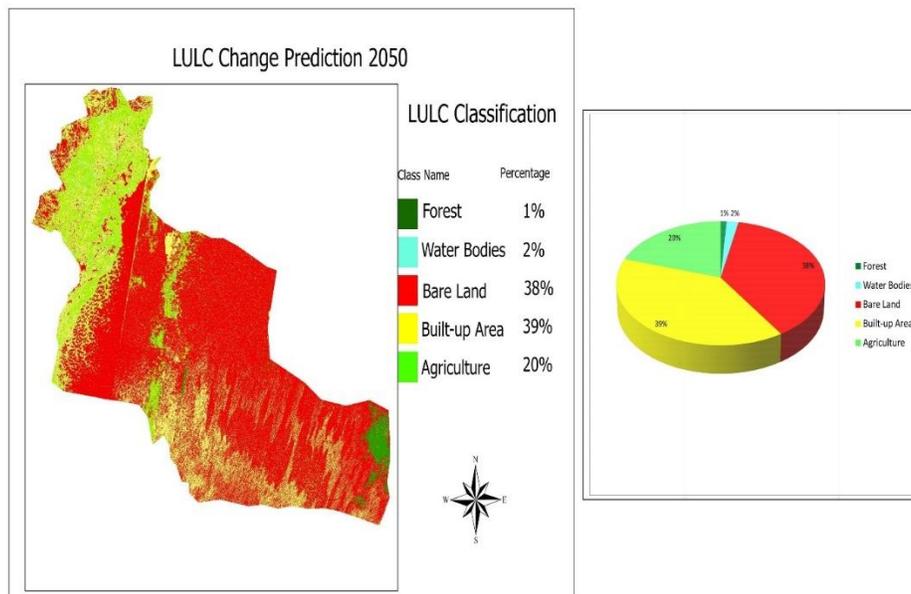
Figure 8: LULC Predictions for the Year 2050

Table 7: LULC Prediction for the Year 2050

Sr. No	Class Name	Area (km²)	%
01	Forest	159.10	1%
02	Water Bodies	318.20	2%
03	Bare Land	6,045.80	38%
04	Built-up Area	6,204.90	39%
05	Agriculture	3,182.00	20%
Total Area		**15,910-00**	**100%**

According to the 2050 LULC forecast, District Khairpur Mirs is predicted to have built-up areas as the predominant land cover due to rapid and uncontrolled urban growth. Large-scale land conversion is predicted to cause bare land to decrease even more, while agricultural land is predicted to decrease somewhat. It is anticipated that water bodies and forest cover will drop to dangerously low levels, indicating extreme ecological stress. In order to stop irreversible environmental degradation, the 2050 prediction emphasizes the critical need for sustainable land-use regulations, stringent environmental protection, and long-term planning.

4.3 Comprative Analysis:
The following Table and Graph shows the land use land cover changes senario of the study area from the year 2010 to the year 2050.

Table : 08: Comprative Analysis and Prediction

Sr. No	LULC Categories	Classiffication-wise by Year			Prediction by Year		
		2010	2020	2022	2030	2040	2050
01	**Forest**	6%	3%	4%	3%	3%	1%
02	**Water Bodies**	10%	4%	9%	4%	3%	2%
03	**Bare Land**	46%	47%	45%	45%	40%	38%

| 04 | Built-up Area | 18% | 22% | 23% | 26% | 31% | 39% |
| 05 | Agricalture | 20% | 24% | 19% | 22% | 23% | 20% |

Comprative Analysis and Prediction Graph

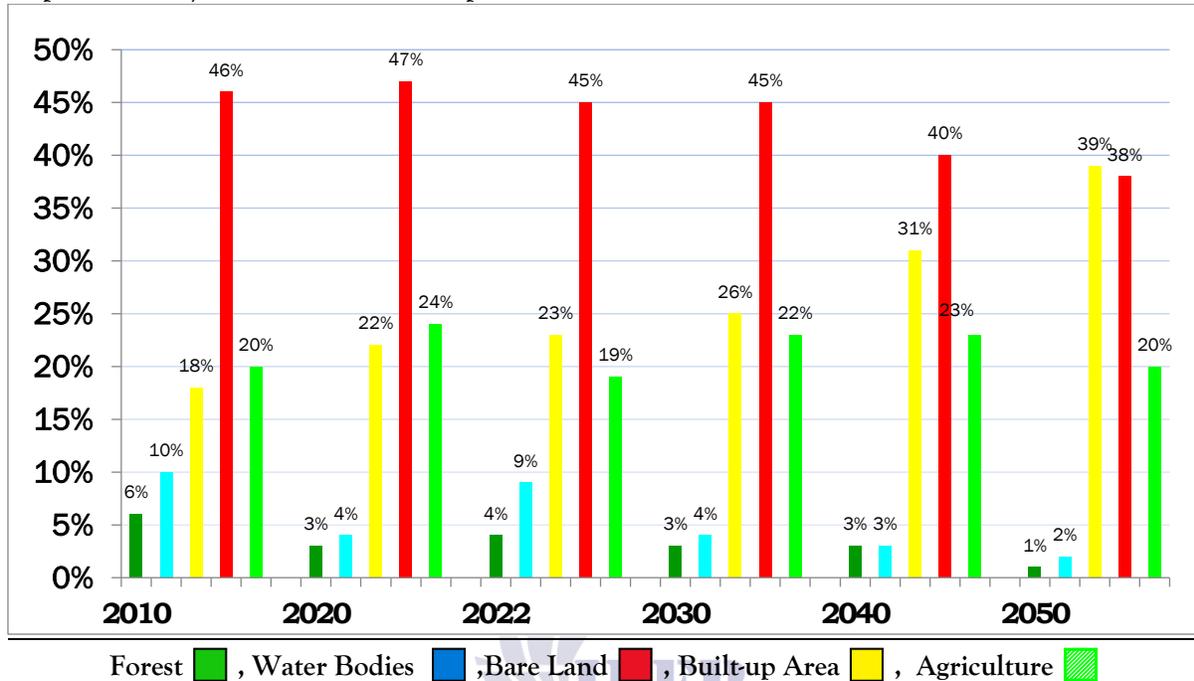Forest █ , Water Bodies █ ,Bare Land █ , Built-up Area █ , Agriculture ▨

Figure 9: LULC Predictions For the year 2050

INTERPRETATION:

- Research on land use and land cover (LULC) in District Khairpur Mirs reveals significant changes between 2010 and 2022, with further significant changes predicted for 2030–2050.

- Forest cover decreased significantly, from 6% to 1% of the total area, even though it remained the most common land-use class during the research period (2010–2050).With water bodies predicted to drop to 2% by 2050, the observed fall in forest cover and water bodies, together with the growth of built-up area from 18% in 2010 to 23% in 2022, illustrates the increasing strain on natural resources.

- Throughout the study period, bare land remained the most common class, making up between 45 and 47 percent of the total area.

- Due to increased urbanization and infrastructural development, built-up area increased steadily between 2010 and 2050, rising from 18% to 39%.

- Despite exhibiting some instability, agricultural land remained a significant land-use type.

Built-up areas are predicted to increase to 26% in 2030, 31% in 2040, and 39% by 2050, according to the anticipated LULC scenarios, suggesting that urban expansion would become more intense in the future. However, it is projected that forest cover and water bodies will continue to decline until they reach dangerously low levels by 2050. The results indicate a gradual shift from natural land covers to built-up areas, underscoring the need for environmental conservation and sustainable land-use planning to reduce adverse ecological effects in District Khairpur Mirs. It is expected that agricultural land will remain relatively stable, highlighting its continued importance in the district.

5. CONCLUSION:

This study evaluated the spatiotemporal dynamics of land use and land cover (LULC) in District Khairpur Mirs and projected future scenarios for 2030, 2040, and 2050 using multi-temporal satellite data for the years 2010, 2020, and 2022. The results demonstrate that while built-up areas have been gradually expanding over time, bare terrain still predominates. Urban growth is accelerating at the expense of water bodies and forest cover, as evidenced by changes between 2010 and 2022. This reflects the increasing strain that humans are placing on natural resources.

This trend is expected to worsen over the next decades, according to the projected LULC scenarios, with built-up areas forecasted to become a substantial land-use class by 2050 and surface water and forest levels predicted to fall to dangerously low levels. Agricultural land shows notable stability despite ongoing land alterations, underscoring its continued importance in the local economy.

Advantage and Dis Advantage of Research Result:

Advantages of the Research Results

1. **Clear Temporal Trends**
The comparative analysis clearly shows year-wise changes in LULC classes, enabling easy identification of long-term land transformation patterns.

2. **Urban Growth Insight**
The steady increase in built-up area (18% in 2010 to 39% in 2050) provides strong evidence of rapid urbanization, which is valuable for urban planning and policy formulation.

3. **Environmental Assessment Support**
The decline in forest cover (6% to 1%) and Water Bodies (10% to 2%) highlights environmental stress, supporting sustainable land-use and conservation strategies.

4. **Predictive Planning Utility**
The inclusion of future prediction years (2030–2050) assists decision-makers in forecasting land-use impacts and preparing mitigation measures.

5. **Quantitative and Comparable**
Percentage-based representation allows straightforward comparison between different years and land-use categories.

Disadvantages / Limitations of the Research Results

1. **Prediction Uncertainty**
Future LULC predictions are model-based and may vary due to unexpected socio-economic, climatic, or policy changes.

2. **Limited Classification Detail**
Broad LULC classes (e.g., built-up or agriculture) may overlook sub-category variations such as residential vs. industrial or irrigated vs. rain-fed agriculture.

3. **Data Resolution Constraints**
Classification accuracy may be influenced by the spatial and temporal resolution of satellite imagery used.

4. **Assumption of Linear Trends**
The prediction assumes continuation of past trends, which may not fully capture abrupt land-use changes or regulatory interventions.

In order to maintain ecological balance and long-term resource sustainability in District Khairpur Mirs, integrated land-use planning, environmental protection, and sustainable development strategies are critically needed. Overall, the results show a clear shift toward urbanization and a decrease in natural land covers.

6. RECOMMENDATIONS

➤ Implement controlled urban growth policies by enforcing zoning regulations, promoting vertical development, and restricting unplanned expansion to manage the rapid growth of built-up areas and prevent uncontrolled land conversion.

➤ Protect and restore forest cover through strict enforcement of land-use laws, prevention of encroachment, and the implementation of large-scale afforestation and reforestation programs involving local communities.

➤ Enhance water resource management by regulating land use near rivers, canals, and wetlands, establishing buffer zones, and promoting conservation measures to safeguard water bodies from further degradation.

➤ Promote sustainable agricultural

practices such as efficient irrigation systems, soil conservation techniques, and crop diversification to minimize land degradation and maintain long-term agricultural productivity.

➢ Integrate GIS-based LULC monitoring systems into regional and local planning frameworks to enable real-time monitoring, early detection of land-use changes, and informed, timely decision-making.

➢ Adopt climate-resilient land-use planning strategies by incorporating future climate projections (2030–2050), reducing vulnerability to environmental hazards, and ensuring sustainable land management under changing climatic conditions.

7. Acknowledgment

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