World Journal of Advanced Research and Reviews
eISSN: 2581-9615 CODEN (USA): WJARAI
Cross Ref DOI: 10.30574/wjarr
Journal homepage: https://wjarr.com/

(REVIEW ARTICLE)

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Spatiotemporal analysis of land use and land cover dynamics using multi-temporal remote sensed imagery and quantifying landscape fragmentation: A case study of Chandannagar Municipal Corporation (CMC), West Bengal, India

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World Journal of Advanced Research and Reviews, 2024, 23(03), 966–995

Publication history: Received on 22 July 2024; revised on 30 August 2024; accepted on 02 September 2024

Article DOI: https://doi.org/10.30574/wjarr.2024.23.3.2664

Abstract

The rapid population growth in developing countries has resulted in increasing pressure on land resources in both urban and rural areas. The growth of the urban population has been one of the major driving forces of change in the urban environment, leading to the development of suburban areas. This has resulted in the loss of other land uses, such as agricultural land and forests at the urban fringes, reducing ecosystem services' availability. Land use/ Land cover (LULC) dynamics and landscape fragmentation are critical aspects of studying the complex interactions between human activities and the environment. This study focuses on Chandannagar Municipal Corporation, characterized by diverse land uses due to its abundant agricultural resources, rapid urbanization. Employing Remote Sensing and Geographic Information System (GIS) techniques, we analyze multi-temporal satellite imagery and land cover data. Through LULC change detection analysis, we identify and quantify spatial and temporal patterns of land use transformation. Landscape metrics are employed to evaluate fragmentation, offering quantitative insights into the spatial arrangement and connectivity of various land cover types. This research provides valuable insights into LULC dynamics and landscape fragmentation in Chandannagar Municipal Corporation. The results highlight the extent and rate of land use changes, including the conversion of agricultural lands, expansion of urban areas, and changes in vegetation cover. The assessment of landscape fragmentation reveals the degree of spatial heterogeneity and connectivity within the landscape, indicating areas of high fragmentation and potential ecological consequences. The outcomes of this research contribute to the existing knowledge base on land use planning, resource management, and sustainable development in Chandannagar.

Keywords: LULC; Land use/cover dynamics; Change detection; Built-up area; Spatio-temporal analysis; Spatial metrics; Landscape fragmentation

1. Introduction

The land is a vital natural resource for human survival and the base for all terrestrial ecosystem services *(Gebeyehu, Getachew, & Ewunetu, 2021).* It is the platform on which human activities take place and also the source of material needed for these activities i.e., the natural asses which provide social, economic, and ecological functions to sustain the livelihood of the inhabitants *(Briassoulis, 2000).* However, Land is becoming a limited resource subject to competing demands and its various functions and services are seriously compromised by the problem of human induced land degradation *(Awoke, Bewket, & Brauning, 2014)***.** One of the prime prerequisites for better use and management of land resources is information on existing land use/cover patterns and changes in land use/cover through time *(Anderson et*

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*al., 1976)***.** The spatial and temporal status of the land use/cover of a given region is an important parameter in understanding the interactions of human activities with the environment *(N.C. Anil et al., 2011).* Land use and land cover patterns change in keeping with demands for natural resources *(Anderson et al., 1976)***.** Studies have shown that although the shreds of evidence of land use/cover changes date back many 1000 years, the recent rates, extents, and intensities of human pressure on land and its scarce resources are more rapid and extensive than in any comparable period *(Petit & Lambin, 2002).* This unprecedented human and environment interactions have been verifies by LULC changes *(Yesuph & Dagnew, 2019).* To understand the evolution of various land use systems, to analyze dramatic changes in land use/land cover at global, continental, and local levels, and further to explore the extent of future changes, the current geospatial information on patterns and trends in land use/land cover is already playing an important role *(Yesserie, 2009).* Remotely sensed imageries provide an efficient means of obtaining information on temporal trends and spatial distribution of urban areas needed for understanding, modeling, and projecting land changes *(Elvidge, Sutton, & Wagner, 2001)*

Growing concerns over the recent urban and rural developmental activities, changing landscape scenario, and the loss of biodiversity have made it imperative for land managers to seek for better ways of managing the landscape and to be able to analyze positive and negative factors that influence the land use and land cover change pattern and its change dynamics. Land use and land cover is a continuous process that is altered in several ways concerning time and space *(Singh et al., 2014).* The natural and socio-economic factors and man's utilization have greatly affected historical land use and land cover patterns. Therefore, the accurate information pertinent to land use land cover is essential for the selection, planning, and implementation of land use programs which can be used to meet the increasing demands for basic human needs and welfare *(Zubair, 2006).* Urban growth is a global phenomenon and one of the most important reforming processes affecting both the natural and human environment through many ecological and socio-economic processes *(Mandelas et al., 2007).* Currently, communities worldwide need spatial data to compensate for and adapt to current urban growth while planning for expected future change and its impacts on infrastructure, as well as the surrounding environment *(Yesserie, 2009).* Rapid population increment and industrial sprawl have made land a scarce resource, mainly in urban and urbanizing areas which are undergoing large-scale land transformation changes that alter the natural ecosystem in different ways at temporal and spatial scales *(Morley & Karr, 2002).* Since the Second World War, this phenomenon of urbanization has shown no sign of slowing and is likely to continue at an accelerated rate throughout the twenty-first century *(Dutta & Guchhait, 2022).* More than 53% of the earth's population nowadays lives in urban areas and is predicted to be more than 60% by 2030 *(Demographia, 2017).* So, there is a great chance of an increase in pace of urbanization in the future due to the rapid urban spreading out and the emergence of large urban agglomerations particularly in developing countries *(Dutta & Guchhait, 2022)***.** Nevertheless, these contentious arguments often overlook the importance of incorporating geospatial data for informed decision-making and effectively monitoring transformation in rapidly evolving landscapes, thus hindering the achievement of sustainable urban development.

Change in land use land cover also aggravates soil erosion, creates strong environmental impacts, affects agricultural production, infrastructure, and water quality *(Lal, 1998).* The productive agricultural land and essential forest, neither of which can resist nor deflect the overwhelming land use and land cover but accelerate its change and alteration based on necessity and sustainable development. This growth is an indicator of socioeconomic development and generally has a negative environmental impact on the region *(Singh et al., 2014)*. Agricultural practices, forest cutting, urban and industrial expansion, road development, military training, alteration of waterways, and other human activities have a significant impact on land cover *(Dale et al., 1998).* Now today, one of the greatest challenges in front of human lies in the question of 'how to minimize the negative impacts of land use land cover change by applying both appropriate and cost-effective technology respectively?'. The landscape metrics is a special feature that provide the ability of quantifying land use land cover pattern distribution. There are a variety of landscape metrics to allow quantitative assessment of a landscape and its level of fragmentation *(McGarigal & Marks, 1995).*

The analysis of landscape-level and class-level metrics *(Szabo et al., 2012)* has provided a strong conceptual and theoretical basis for understanding landscape structure, function, and change. The landscape metrics mainly focus on the three characteristics of landscape *(Forman & Gordon, 1986)* (1) Structure: the spatial relationships among the distinctive ecosystems or elements present specifically, the distribution of energy, materials, and species concerning the sizes, shapes, numbers, kinds, and configurations of the ecosystems. (2) Function: the interactions among the spatial elements, that is, the flow of energy, materials, and species among the component of ecosystem. (3) Change: the alteration in the structure and function of the 'Ecological Mosaic' over time. The landscape level metrics is a special feature of land use that provide significant ability to quantify the landscape patterns and the interactions among patch density, number of patches, total areas, and large patch index within a landscape mosaic and also represent the patterns and interactions change over time. The class level metrics comprise different metrics viz. core areas, number of patches, patch density, percentage of landscape, and largest patch index, some of these metrics quantify the landscape composition and while others quantify landscape configuration. It is also known that composition and configuration can affect ecological processes independently and interactively region *(Singh et al., 2014).*

Landscape fragmentation, Land use land cover information, along with its temporal changes, play a crucial role in environment assessment and informed decision-making. The availability of this information in digital maps enhances its value and utility for integration with other geographic data, enabling geospatial analysis and monitoring. The advancement of geospatial technologies, specifically GIS software and multispectral satellite data, has greatly facilitated the characterization of landscapes and the quantification of their structural changes. Particularly in the past three and a half decades, remote sensing has proven to be an efficient tool for monitoring and detecting land use/land cover changes in urban areas and their surroundings. These outcomes of such studies help quantify patterns of land cover change and highlight the potential of multi-temporal satellite data in accurately and economically mapping and analyzing land cover changes within a spatio-temporal framework. These findings serve as valuable inputs for land management and policy decisions about various themes closely linked to space, including urbanization, water management, deforestation, land degradation, and more.

1.1. Problem Statement

The city of Chandannagar has undergone significant land use and land cover changes in recent years due to rapid urbanization, industrialization, and agricultural expansion. The problem statement of the research topic *"Spatiotemporal Analysis of Land Use and Land Cover Dynamics using Multi-Temporal Remote Sensed Imagery and Quantifying Landscape Fragmentation: A Case Study of Chandannagar Municipal Corporation (CMC), West Bengal, India"* is to understand the current state and changes over time of land use and land cover in Chandannagar Municipal Corporation, and to quantify the level of landscape fragmentation in the region. The rapid expansion of urban areas and other human activities have led to significant changes in the natural landscape of Chandannagar which could have adverse effects on the ecosystem and biodiversity. Therefore, the study aims to use geospatial techniques to analyses satellite imagery and spatial data to identify and map land use land cover changes, asses their impact on the environment, and quantify the degree of fragmentation of the landscape. The results of this research could help in developing effective land management strategies and policies to promote sustainable development and conservation of natural resources in Chandannagar.

1.2. Research objectives

The following are the main objectives of the current research:

To develop a comprehensive spatiotemporal model for analyzing Land Use - Land Cover changes in Chandannagar Municipal Corporation;

- To identify the key drivers and factors influencing Land Use – Land Cover changes in Chandannagar Municipal Corporation;
- Analyse and examine the effects of rapid urbanization on land use/land cover dynamics and;
- Analyse the spatio-temporal land use/land cover change patterns and Landscape fragmentation using spatial metrics.

1.3. Research questions

The following questions have been chosen for this study:

- What are the historical spatio-temporal patterns of Land Use – Land Cover changes in Chandannagar Municipal Corporation?
- What are the key drivers and factors that have influenced Land Use – Land Cover changes in Chandannagar Municipal Corporation?
- What are the impacts of the changing land use and land cover patterns due to rapid urbanization on the local climate and ecosystem service?
- What is the spatial and temporal land use/land cover change patterns, fragmentation, and structural changes in the land cover units?

The goal of this research was to fill the research gap using multi-temporal imageries on a GIS platform to analyze the landscape structure and identify changes. The findings of this study can be used to develop a spatial-temporal map of land use change in the area to estimate the volume and type of development change. It would encourage learning about the entire environment and encourage planning organizations to develop smart and sustainable land use practices.

1.4. The study area: geographical and environmental characteristics of Chandannagar Municipal Corporation

Chandannagar Municipal Corporation is a historically significant city located in the Hooghly district of the Indian state of West Bengal, situated along the banks of the Hooghly River, Chandannagar is renowned for its cultural heritage, architectural beauty, and diverse ecological surroundings. Chandannagar is strategically located at the confluence of the Hooghly River and the Ganges River, making it an essential maritime and trade hub historically. It is positioned at approximately 22.86°N latitude and 88.37°E longitude, providing easy access to Kolkata, the capital of West Bengal, and other major cities in the region. The city located near Kolkata Metropolitan Area, which plays a vital role in the state's economic and cultural landscape. The topography of Chandannagar is characterized by its flat terrain, typical of the Gangetic plains. The elevation is relatively low, which makes the area susceptible to flooding during monsoons and high tides. The landscape is adorned with lush greenery and water bodies, creating a picture square environment. The Hooghly River and its distributaries, along with several small lakes and ponds, contribute to the natural beauty of the region.

Chandannagar experiences a tropical wet and dry climate, influenced by the monsoon winds. Summers are hot and humid, with temperatures often exceeding 30°C, while winters are mild and pleasant. The monsoon season, from June to September, brings heavy rainfall, contributing significantly to the region's water resources.

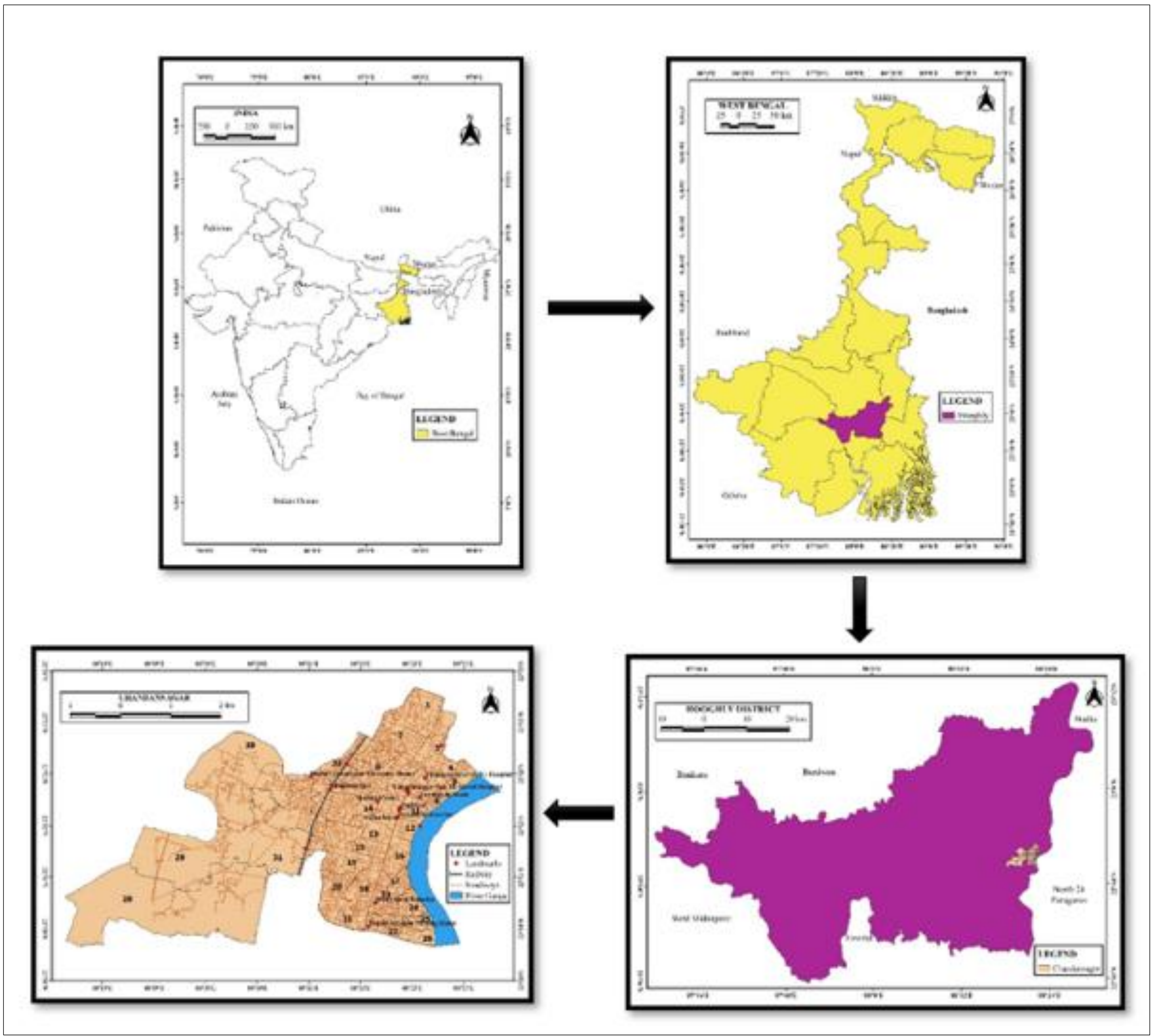

Figure 1 Location map of Chandannagar Municipal Corporation (CMC)

2. Review of literature

The land is a vital natural resource for human survival and the base for all terrestrial ecosystem services. LULC changes play a significant role in spatiotemporal environmental stability since it has a linkage with local, regional, and global climate conditions, carbon cycle, biodiversity stability, clean water, agriculture, and food security *(Yesserie, 2009).* Through the application of Remote Sensing and GIS combined with a survey of the local community's awareness of LULC patterns and causes in the Gubalafto district, North-eastern Ethiopia, this study examined the status of LULC changes and significant drivers of change for the last thirty years. The study identified various drivers of LULC changes in the Gubalafto district. Population growth was identified as one of the significant drivers of LULC change, which resulted in increased pressure on land resources. These research paper emphasizes the need for controlling the root causes of LULC changes and sustainable resource use is essential to prevent the loss of natural resource bases, which can no longer contribute to sustainable ecosystem services. The study also aims to recommend policy interventions that promote sustainable land use practices, secure land tenure, and provide economic opportunities for local communities.

Land resources, which are an integral component of the watershed ecosystem, are essential natural assets that provide social, economic, and ecological functions to sustain the livelihood of the inhabitants. Land use/cover (LULC) change is a dynamic and complex process that can be caused by many interacting processes ranging from various natural factors to socioeconomic dynamics *(Yesuph & Dagnew, 2019)*. It significantly impacts landscape structure, functions, and dynamics. Monitoring and mapping LULC dynamics are vital to environmental assessment and effective resource management. This study focused in quantifying spatio-temporal LULC dynamics in the Geladas watershed of the Blue Nile Basin, Ethiopia, using satellite imagery and local perceptions. The study employed supervised image classification and image differencing techniques to detect and quantify LULC transitions.

The spatial-temporal change of LULC alters landscape patterns and affects the ecosystem. Change in the composition of LULC is a dynamic, widespread, and accelerating process mainly driven by natural phenomena and anthropogenic activities. Over the last few decades, urbanization has emerged as one of the most dominant factors of the losing arable land, devastating habits, and the decline in natural vegetation cover. As a result, rural areas have been converted into urban land ultimately affect the natural functioning of the ecosystem *(Gabril, Denis, Nath, Paul, & Kumar, 2019).* This paper focuses on the spatial and temporal changes in land use and land cover in Prayagraj using satellite data and Fragstats analysis. Landsat images from 1990, 2007, and 2017 were classified, and the resulting maps were used to calculate landscape indices. The findings indicate an increase in agricultural land, settlement, barren land, and salt-affected areas, while forest and water bodies exhibited a decreasing trend. The use of landscape metrics enables the assessment of spatial patchiness trends over the study period.

Most parts of countries in the world are currently experiencing wide-ranging changes in land use and land cover. These LULC changes have mostly been associated with the interaction between humans and the environment. The resulting impacts on ecosystems and human well-being, which include erosion, increased run-off, flooding, loss of water resources, degrading water quality, and other negative impacts, have brought these changes to the attention of the world *(Gondwe et al., 2021).* This research paper utilized Remote Sensing (RS) and supervised classification with an Artificial Neutral Network (ANN) to detect and quantify land use and land cover (LULC) changes in Blantyre City over twenty years. The results showed a significant increase in built-up and agricultural land, while bare land, forest land, herbaceous land, and waterbody decreased. These changes were attributed to urbanization, population growth, social-economic factors, and climate change. The findings provide valuable information for Blantyre City authorities to develop sustainable development plans.

Over 70% of the population in developed countries lives in urbanized areas. Remote sensing technology has great potential for the acquisition of detailed and accurate land-use information for management and planning of urban regions. Population growth, regional migration, and increasing ecological problems require advanced methods for city planners, economists, ecologists, and resource managers to support sustainable development in these rapidly changing regions *(Herold et al., 2002).* This research presents an innovative approach that utilizes spatial characteristics of images and landscape metrics to effectively depict the structures of urban land use and the changes in land cover caused by urban expansion. The study highlights the significance of spatial measurements as secondary image data, which can greatly enhance the precision of urban area mapping and lead to a more precise understanding of spatial patterns in urban growth.

Landscape fragmentation and its potential impact on problems such as global change, biochemical cycles, land use dynamics, and biodiversity have become central issues in Earth System Science. As a consequence, new ecological theories, modern methods to study spatial dynamics and new applications to natural resources planning and monitoring have taken place. Deforestation processes in the Brazilian Amazon have attracted a great amount of attention *(Batistella,* *Brondizio, & Moran, 2000)*. These research paper examines the impact of colonization incentive policies on deforestation processes in the Brazilian Amazon. Focusing on two settlements in Rondônia, Vale do Anari and Machadinho d'Oeste, the study analyses the influence of different architectures on landscape fragmentation. Using landscape ecology and remote sensing techniques, the researchers calculate landscape structure indices based on a LANDSAT TM image from July 1998. The findings reveal distinct fragmentation patterns in the two settlements, highlighting the potential environmental impacts of colonization projects in the Amazon.

Land use/land cover (LULC) change is becoming one of the major global environmental problems in the present-day world due to its diverse impact on the environment and natural landscape. Land cover denotes the physical and biotic attributes, conditions, and characteristics of the earth's surface, while land use describes how humans use the land for various activities. Hence, LULC studies have emerged over the past few decades as one of the key topics for addressing and resolving global environmental change and sustainability issues *(Somendro, 2015)*. This paper focuses on the identification and analysis of land use and land cover (LULC) dynamics in the Jaintia Hills of Meghalaya, India. The study aims to explore the rate of changes in forest cover dynamics and provide updated information and baseline data for understanding LULC changes in the region. This information is crucial for the research community and local planners in formulating conservation and management strategies for natural resources and the environment.

Rapid urban expansion due to large-scale land use/cover change, particularly in developing countries becomes a matter of concern since urbanization drives environmental change at multiple scales. Land use/cover change is one of the most important indicators in understanding the interactions between human activities and the environment *(Dewan et al., 2012).* This paper aimed to comprehensively record the spatiotemporal patterns of land use/cover transformations and measure the landscape structures in the Dhaka Metropolitan area of Bangladesh. Leveraging a combination of multi-temporal remotely sensed data and GIS techniques, the paper analyzed the dynamics of land use/cover changes, calculated a transition matrix, and examined the rate and pattern of these changes.

2.1. Geospatial Technologies-GIS & Remote Sensing

The modern usage of the term "Remote Sensing" has more to do with the technical ways of collecting airborne and spaceborne information. Earth observation from airborne platform has a hundred- and fifty-years-old history although the majority of the innovation and development has taken place in the past three and half decades. The first Earth observation using a balloon in the 1960s is regarded as an important benchmark in the history of remote sensing. Since then platforms have evolved into space stations, sensors have evolved from cameras to sophisticated scanning devices and the user base has grown from specialized cartographers to all-rounded disciplines. It was the launch of the first civilian remote sensing satellite in the date July 1972 that paved the way for modern remote sensing applications in many fields including natural resources management *(Lillesand et al., 2004).*

Today the increased dissemination and utilization of geographic data is the result of an unprecedented growth on the geospatial technologies-referring the three sciences- Global Positioning System (GPS), remote sensing and Geographic Information System (GIS). These technologies allowed users to easily access geographic information and to deal with geospatial data in a variety of activities with different levels of complexity *(Bossler, 2002).* Geographic Information System graphically provide information layers in creative ways to show linkages, patterns, and trends. Software like ESRI, ERDAS, ArcGIS, QGIS offer the features and resources required to store, analyze, and display location-related data. A computer-based tool called A Geographic Information System (GIS) is used to map and analyse aspects of events that occur on Earth. GIS maintains location-based data and enables tools for the visualization and study of various statistics. To generate dynamic presentations and significant interrelations, it is possible to integrate databases and maps. Remote Sensing, on the other hand, is the science of making measurements of Earth using sensors on airplanes or satellites. These sensors collect data in the form of images and provide specialized capacities for manipulating, analyzing, and visualizing those images *(Nicholas, 2008).* As a result, mapping and monitoring land use and land cover dynamics are made accessible by remote sensing in conjunction with GIS. Land use/land cover analysis is an important tool to assess global change at various spatial-temporal scales *(Lambin, 1997).* Similar to this, remotely sensed earth data can be examined to extract essential thematic information, about the environment, including urban, agricultural, forest, wetland, or water surfaces.

2.2. Land Use/Land Cover: Concepts & Definitions

Examining the terminologies and concepts it is helpful and useful to obtain a sense of land cover dynamics. The human modification of the earth's surface is referred to as "land use" or "land cover change". Although humans have been modifying land to obtain food and other essentials for thousands of years, current rates, extents, and intensities of land use/land cover change are far greater than ever in human history, driving unprecedented changes in ecosystem and environmental processes at local, regional and global scales *(Yesserie, 2009).* Today, land use/land cover changes encompass the greatest environmental concerns of the human population including climate change, biodiversity depletion, and pollution of water, soil, and air. Currently, monitoring and mediating the adverse consequences of Land use/land cover change while sustaining the production of essential resources has become a major of researchers and policymakers around the world *(Erle & Pontius, 2018).*

In studying the land use/land cover dynamics, it is quite useful to have an overview of the concepts and working definition of these terms. Hence, land cover refers to the "physical and biological cover of the surface of earth, including water, vegetation, bare soil, and/or artificial structures". Land use is a more complicated term that can be defined in terms of disorders of human activities on the natural environment such as agriculture, forestry, and building construction. These activities alter land surface process including biochemistry, hydrology, and biodiversity processes. Social scientists and land managers define land use more broadly to include the social and economic purposes and contexts for and within which lands are managed (or left unmanaged) such as subsidence versus commercial agriculture, rented versus owned, or private versus public land *(Turner, 2002).*

In the meantime, land use change models are tools to enable the understanding of the causes and effects of land use dynamics. According to *(Verburg, Schot, Dijist, & Veldkamp, 2004),* scenario analysis with land use models can support land use planning and policy. To date, numerous land use models are available that are developed from different disciplinary backgrounds. Models of land use change are tools to support the analysis of the causes and consequences of land use/land cover changes in order to better understand and functioning of land use system and to support land use planning and policy. Models are useful to disentangle the complex suite of socio-economic and biophysical forces that influence the rates and spatial pattern of land use and land cover change and for estimating and predicting the impacts of land use changes. Furthermore, models can support the exploration of future land use changes under different scenario conditions. Summarizing land use models are useful to analyze land use changes and to make more informed decisions *(Costanza & Ruth, 1998).*

2.3. Land Use Land Cover Change Studies

Changes in land cover and the way people use the land have become recognized since the mid-1980s as important global environmental changes in their own right *(Lepers, Lambin, & Janetos, 2005)*. Scientific research community called for the substantive study of land use changes during 1972 Stockholm Conference on the Human Environment, and again 20 years later, at the 1992 United Nations Conference on Environment and Development (UNCED). At the same time, the International Geo-sphere and Biosphere Programme (IGBP) and International Human Dimension Programme (IHDP) co-organized a working group to set up research agenda and promote research activity for land use/land cover changes. The working group suggested three core subjects for land use/land cover change research, such as situation assessment, modelling and projecting and conceptual scaling. The ultimate goal of global change study was to assess the impacts under each possible scenario and suggest preventive actions against the adverse environmental consequences. The focus was the adverse impact of these regional and global changes on society and the environment. Empirical studies by researchers from diverse disciplines found that land use /land cover and its change had become key to many diverse applications such as environment, forestry, hydrology, agriculture *(Li & Yeh, 2004),* geology and ecology *(Weng, 2001).* These applications referred to urban expansion, deforestation, cropland loss, water quality change, soil degradation, etc. At the same time, in the past decades, according to *(Lambin, 1997),* a major international initiative to study land use change, the land use and land cover project had gained great impetus in its efforts to understand the driving forces of land use change (mainly through comparative case studies)., developed diagnostic models of land use change and produce regionally and globally integrated land use models. These endeavors have sparked the curiosity of researchers, prompting them to employ diverse methods for identifying and comprehending environmental dynamics across various scales, encompassing local, regional, and global levels.

Various studies have examined the historical transformations in land use categories, encompassing urban sprawl, agricultural land decline, and alterations in forest cover. *(Houghton, 1994)* pointed out; the major reason for land use change was to increase the local capacity of lands to support human enterprise. In the present era, the cumulative effects of localized changes across the globe have resulted in significant repercussions. Hence, it can be contended that even slight alterations in land utilization carry unintended outcomes. Therefore, it is imperative to examine the ramifications of land use changes on society, the environment, and the economy, with the aim of fostering a sustainable future.

The techniques of GIS and satellite remote sensing have been widely applied on detecting land use /land cover changes especially urban expansion *(Prenzel, 2004),* urban planning *(Li & Yeh, 1998)*, and cropland loss *(Li & Yeh, 2004)*. There are various ways of approaching the use of satellite imagery for determining land use change in urban environments. *(Yuan & Elvidge, 1988)* divide the methods for change detection and classification into pre-classification and post-classification techniques. The pre-classification techniques apply various algorithms including image differencing and image rationing to single or multiple spectral bands, vegetation indices (NDVI), or principal components, directly to multiple dates of satellite imageries to generate “change” vs. “no-change” maps. These techniques locate changes but do not provide information on the nature of change *(Ridd & Liu, 1998).* On the other hand, post-classification comparison methods use separate classifications of images acquired at different times to produce different maps from which “from-to” change information can be generated *(Jensen, 2004).*

Change detection is the process of identifying differences in the state of an object or phenomenon by observing it at different time series *(Singh, 1989).* Detecting changes is a crucial undertaking in the surveillance and administration of natural resources and urban progress as it offers a quantitative examination of the spatial characteristics and their spatial arrangement. *(Macleod & Congalton, 1998)* list four aspects of change detection that are important when monitoring natural resources:

- Detecting the changes that have occurred
- Identifying the nature of the change
- Measuring the area extent of the change
- Assessing the spatial pattern of the change

The foundation of utilizing remote sensing data for change detection lies in the correlation between alterations in land cover and corresponding shifts in measurement values that can be effectively captured through remote sensing techniques. Over time, the multitude of techniques developed to perform change detection using satellite imagery has expanded considerably due to advancements in digital data manipulation and the exponential growth in computing power. The primary objective of change detection studies employing GIS and remote sensing is to furnish comprehensive insights regarding the extent, spatial distribution, and specific characteristics of land use and land cover changes that have taken place.

3. Data source and methodology

Advancements in geospatial applications have brought about substantial progress in spatial modeling, leading to enhanced capabilities in analyzing land use dynamics and identifying various physical parameters within urban areas. This includes the study of urban expansion and its related dynamics. To accomplish the designed objectives and to answer the research question stated, this part discusses the data and procedures that were used in data collection, processing, presentation, and analysis. This made it feasible for us to analyse change and draw conclusions about the spatio-temporal dynamics of land use/land cover in the region being examined. The research data, methods, and analyses were organized effectively in the flow chart shown in Fig. 3.

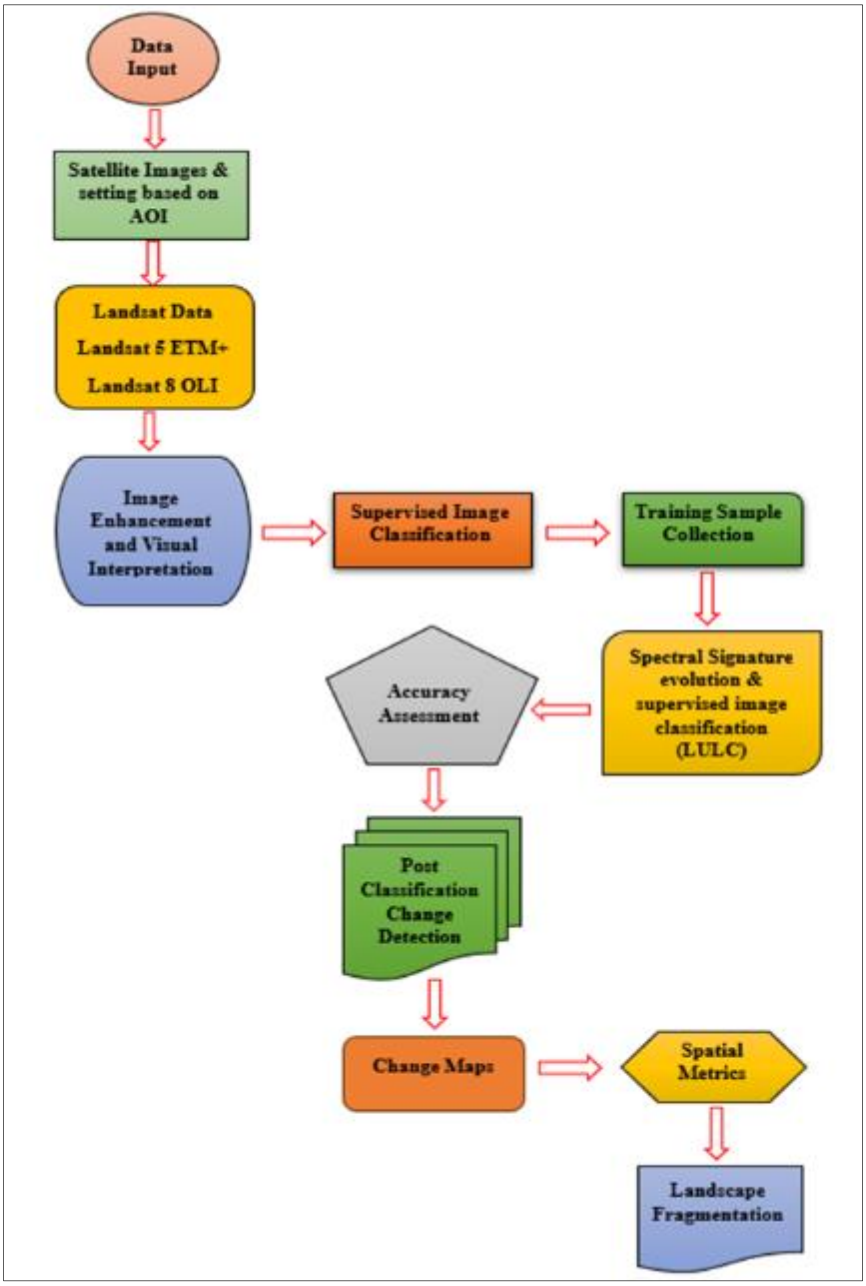

Figure 2 The flow chart of the research data and methodology

3.1. Data Sources

To detect the spatio-temporal changes in various land use parameters, the current study evaluated the Supervised classification based on Landsat satellite images of three different periods. With the help of three Landsat images of three different periods, the spatio-temporal change in LULC has been evaluated. Landsat 8(OLI) image of 2021, the Landsat Enhanced Thematic Mapper of 2001, and the sensor under the Landsat series of 2011 were included as the main sources of information for evaluating the land use types and their spatial mosaic. The process of carefully selecting satellite images that capture different temporal aspects while being devoid of cloud cover holds significant importance in identifying and analyzing various Land Use characteristics. Satellite imagery presents an extensive and cohesive collection of data, enabling precise examination and longitudinal comparisons with high accuracy. However, Landsat-5 is a well-established satellite sensor known for its moderate-resolution imagery, making it suitable for land use analysis and urban growth studies. Further, Landsat-8 is an advanced satellite sensor that provides high-quality imagery with improved spectral and spatial resolution, enabling more precise analysis of land use and land cover changes (Kalaburagi City, Sanjit Sarkar). A comprehensive elaboration of the satellite images is documented in Table 1. Which provides a detailed account of the information captured by these aerial observations.

Table 1 Description of Landsat Data image used in the study

No.	Satellite Images	Data Acquired	Path/Row	Spatial Resolution	Co-ordinate System
1.	Landsat 5	13-02-2001	138/044	30 m	UGS 84/UTM
2.	Landsat 5	09-02-2011	138/044	30 m	UGS 84/UTM
3.	Landsat 8 OLI	04-02-2021	138/044	30 m	UGS 84/UTM

3.2. Tools

ArcGIS 10.8, QGIS 3.14 and Google Earth Engine software were used to extract information about land use land cover, and to perform further research of relationships, patterns, and trends using a multi-temporal approach. FRAGSATS 4.2, a statistical tool was used to calculate spatial metrics and identify changes and fragmentation of land covers. Additionally, Microsoft Windows, specifically MS EXCEL was used for tabulations and graphical representations and to present, describe, and analyze the dynamics and trends of changes in land use-land cover that were made over two periods.

3.3. Image Classification and Land Use Land Cover Analysis

The Supervised Classification technique was used to classify the three satellite images for the land use land cover classifications shown in Table. Supervised classification technique is a process of using samples of known identity to classify pixels of unknown identity. Samples of known identity are those pixels located within training areas defined by the analyst. Signatures for various land use and land cover classes were assigned to facilitate classification. A maximum likelihood algorithm was employed that classifies each pixel in an image based on associated spectral signature *(Singh & Sharma, 2016).* The properties of the training data are used in this process to assess the likelihood that each of the unclassified pixels belongs to each of the training data, and the probabilities are then used to assign pixels to the classes that are considered most likely.

A set of five primary Land Use classifications has been chosen for Land Use and Land Cover (LULC) interpretation. These categories encompass Agricultural Land, Shrublands, Built-Up Area, Vegetation Cover, and Water bodies.

The following analyses of the changes in land use land cover are based on the classes listed below:

Table 2 Land Use - Land Cover types used in the study area

Land Use – Land Cover Class	Description
Water bodies	Area with permanent and seasonal natural and artificial water bodies like river, lakes, pond, open water, etc.
Built-Up Areas	The land that is primarily covered by buildings, including the central urban area as well as its periphery, as well as places used for transportation (roads, railway stations), as well as exposed soil regions brought about by both natural and human activities.
Vegetation Cover	Sparse and mixed tree/vegetation cover
Agricultural Land	The region that is specifically used for the cultivation of crops
Shrublands	Sparse woody vegetation ecosystem.

3.4. Accuracy Assessment

Accuracy assessment is a primary method for evaluating the precision and correctness of a Land Use Land Cover (LULC) Classification (Manna et al., 2023). It allows for assessing the classified map's quality and reliability, ensuring they suit their intended purpose (Manna et al., 2023). Using the Supervised (Maximum Likelihood) Image Classification technique, the land use/land cover classification of the study's landscape was prepared in ArcGIS software (version 10.8). Based on several representative reference points retrieved from Google Earth images, the Kappa Coefficient (KC) is calculated for the classed images of 2001 and 2022 respectively for the accuracy assessment. The Kappa Coefficient is one of the advanced measures for a better understanding of interclass discrimination rather than the overall accuracy level of classification *(Foody, 1992).* In this research, the accuracy assessment of Land Use Land Cover (LULC) classification was conducted through the utilization of the Kappa coefficient method. A total of 120 points were randomly selected within the study to perform this evaluation. To ensure accuracy, Ground Control Points (GCP) were acquired from Google Earth Pro software for analysis. The Kappa coefficient, which measures the agreement between the classification map and the referenced data, was calculated as per *(Bishop & Fienberg, 2007):*

$$K = \frac{N \sum_{i=1}^{r} x_{ii} - \sum_{i=1}^{r} (x_{i+})(x_{+i})}{N^2 - \sum_{i=1}^{r} (x_{i+})(x_{+i})}$$

Where *K* is the Kappa coefficient, *r* is the number of rows in the matrix, *xii* is the number of observations in row *i* and column *i* (the diagonal elements), *xi+* are the marginal totals of row *i, xi+* are the marginal totals column *i*, and *N* is the total number of observations.

3.5. Land Transformation Matrix

It provides crucial information about how one class transitions into another and quantifies each class's gains and losses. *(Manna et al., 2023).* For the areal changes of land transformation, we have prepared the land transformations map (2001-2022) and calculated the area of different land classes using the attributes table in ArcGIS. After that, the attributes table was exported into an Excel sheet and a pivot table for land transformation using an equation

[Where Pij denotes the area of land transformation from I type of land use in the previous year (t time) to j type of land use in last year (t+1 time).]

3.6. Fragmentation Analysis

A spatial pattern analysis program i.e., FRAGSTAT 4.2 offers a comprehensive choice of landscape metrics and has been used to quantify landscape structure. It is implemented by decision maker and ecologists to analyze landscape fragmentation and to describe the characteristics and components of the landscapes. These statistics facilitates the comparison of landscapes and the evaluation of processes. The advantage of FRAGSTATS is that the calculations are implemented in a fully integrated fashion in a GIS and consequently easy to apply to digital map.

Table 3 Spatial Metrics used for this study (McGarigal et al., 2002)

Class Metrics	Abbreviation	Description
Total Area/Class Area	CA/TA	CA measures the total areas of classes (built and non-built) areas in the landscapes.
Number of Patches	NP	Np is the total number of patches in the landscapes.
Patch Density	PD	PD equals the number of patches in the landscapes divided by total landscape areas, multiplied by 10,000 and 100 (to convert to 100 hectares).
Mean Patch Size	MPS	MPS is the average area of (m2) of all patch in the landscape (unit: ha).
Percentage of Landscape	PLAND	PLAND equals the percentage of the landscape comprising the corresponding patch type.
Largest Patch Index	LPI	LPI percentage of the landscape comprised by the largest patch.

4. Results and Discussions

4.1. Dynamics of Land Use Land Cover Changes

To analyze the dynamics of Land use land cover changes in the study landscapes, we conducted a change analysis of three major land use and land cover (LULC) types using maps spanning from 2001 to 2022 (as depicted in Fig.14). The study area's land use and land cover status were classified into five broad categories: Waterbody, Built-Up, Vegetation, Agricultural Land and Shrublands, which are the primary classes in the study area.

The analysis of land use/ Land cover changes in the study landscapes from 2001 to 2022 shows substantial changes in the areal coverage of each land use land cover, as shown in Table.4

Table 4 Area statistics and Percentage of Land use/ Land cover units from 2001-2022

Area statistics and Percentage of the land use/cover units in 2001-2022				
Class	**Area (Sq.km)**	**Area (%)**	**Area (Sq. km)**	**Area (%)**
Built-Up Area	3.984719	18.0398079	7.829591	35.42831015
Vegetation Cover	6.765293	30.62815374	8.968493	40.581756
Cultivated Land	5.753691	26.04838142	3.364504	15.22412744
Shrublands	3.191845	14.45027131	0.956869	4.329760226
Waterbodies	2.39293	10.83338562	0.980358	4.436046184

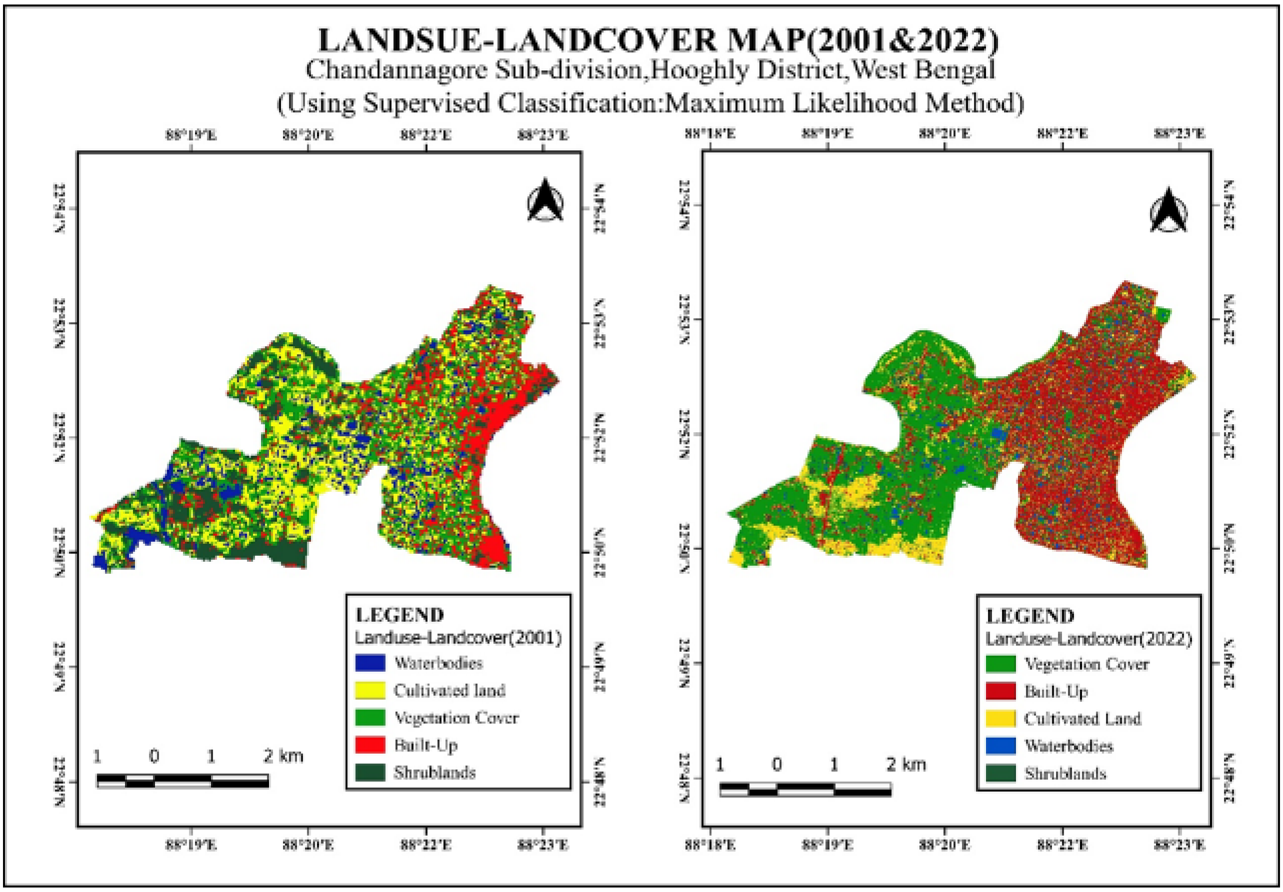

Figure 3 Land use Land cover classification for years 2001 and 2022

The study conducted to assess land use/land cover changes in the landscapes between 2001-2022 reveals that there has been a significant shift in the area coverage of different land use/land cover types (as demonstrated in Table 4). The dominant land cover type in 2001 was vegetation, accounting for 6.765 sq. km of the total area, followed by Cultivated Land (26.04%), Built-Up (18.03%), and Waterbodies (10.83%). However, during the study period, the land cover types underwent a major transformation, with Built-Up area becoming the most dominant (35.42%), followed by Vegetation (40.58%), Cultivated land (-10.82%), and Waterbodies (-6.39%). The data reveals that the Built-Up area witnessed the highest increase (17.39%) i.e., increased by 3.84 Sq. Km, while Cultivated Land experienced the most significant decrease (--10.82 %) from 2001 to 2022. Throughout the study period, the Built-Up area increased significantly from 3.987 sq. km in 2001 to 7.829591 sq. km in 2022, while the Vegetation Cover increased slightly from 6.765293 Sq.km to 8.968493 Sq.km, showing an increase of 2.2032 Sq. km. This rapid expansion of Built-Up area can be attributed to the decrease in Agricultural land and Shrublands, as compared to their areal coverage in 2001 to 2022 as shown in Table.4

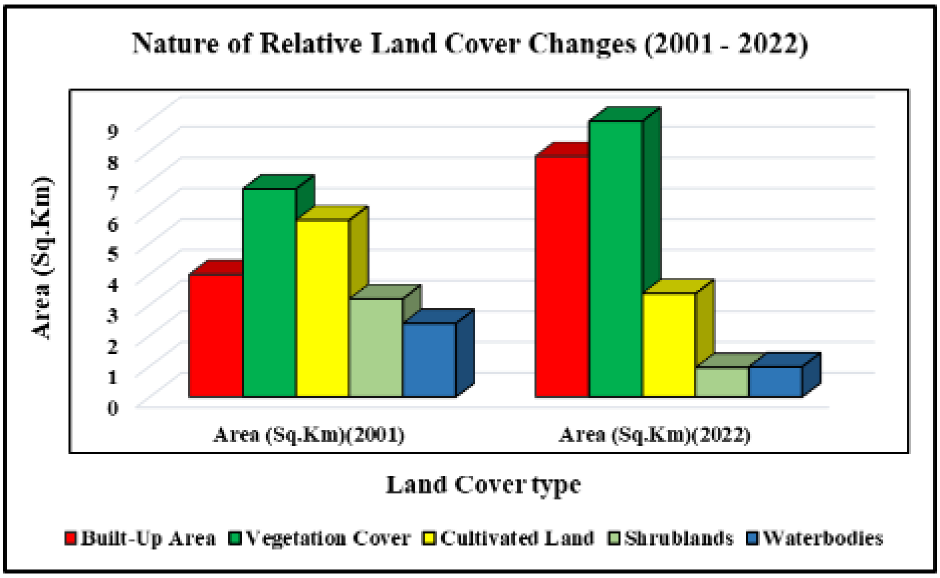

Figure 4 Nature of relative land cover changes (2001-2022)

4.2. Accuracy Assessment of LULC Classification

The classification accuracy evaluations yielded distinct results for the classified images of different years. The 2001 and 2021 images achieved overall classification accuracies of 80.9%, and 83.15% respectively. Furthermore, the calculated Kappa coefficients for the years 2001, 2011, and 2022 were found to be 0.80 and 0.81 respectively. The results showed a good agreement for each of the three classified images *(Lea & Curtis, 2010).*

4.3. Extent, Rate & Trends of Land Use/Land Cover Changes

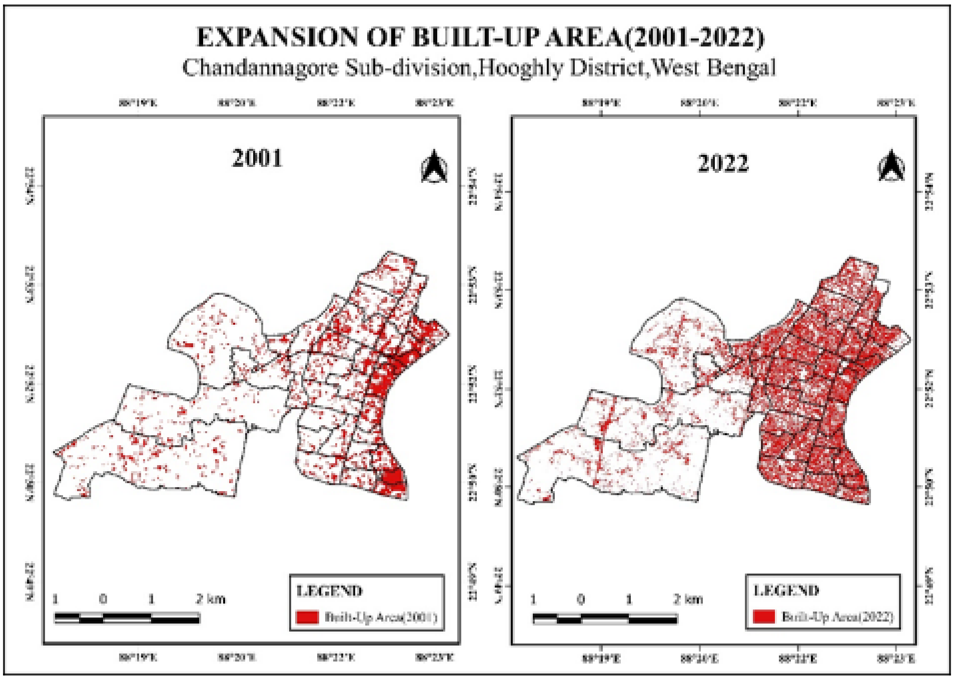

Figure 5 Expansion of Built-Up Area

The methodology utilized in this study involved generating land cover maps for three distinct years (Fig 2) and calculating the area estimates and its change statistics. To determine the extent and rate of changes in each land use/land cover (LULC) category during the research periods of 2001 and 2022, various approaches were adopted. To quantify the land cover change results, multiple methods can be employed. One of the fundamental techniques is to create a table illustrating the total and land cover changes for each LULC type and analyze the change trends between the years. The investigation revealed significant changes in the primary LULC types throughout the periods examined.

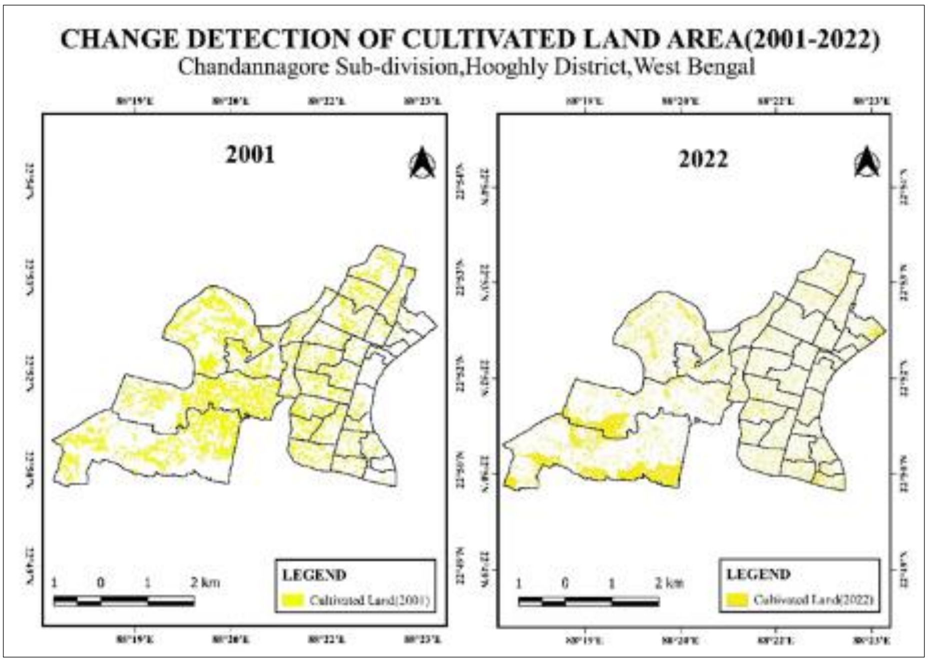

Figure 6 Change in Cultivated Land

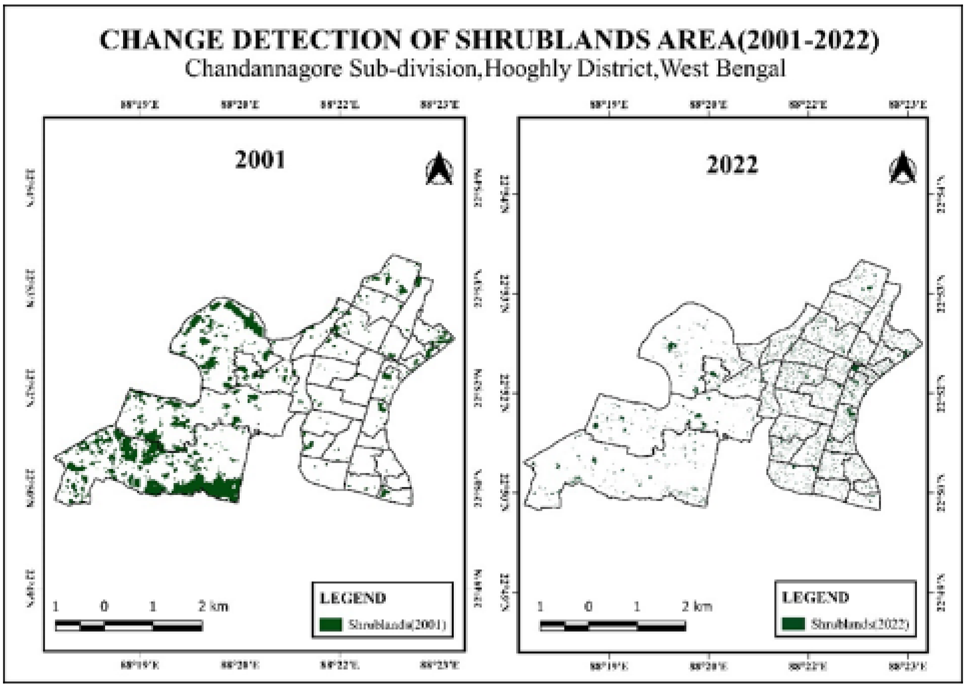

Figure 7 Change in Shrublands

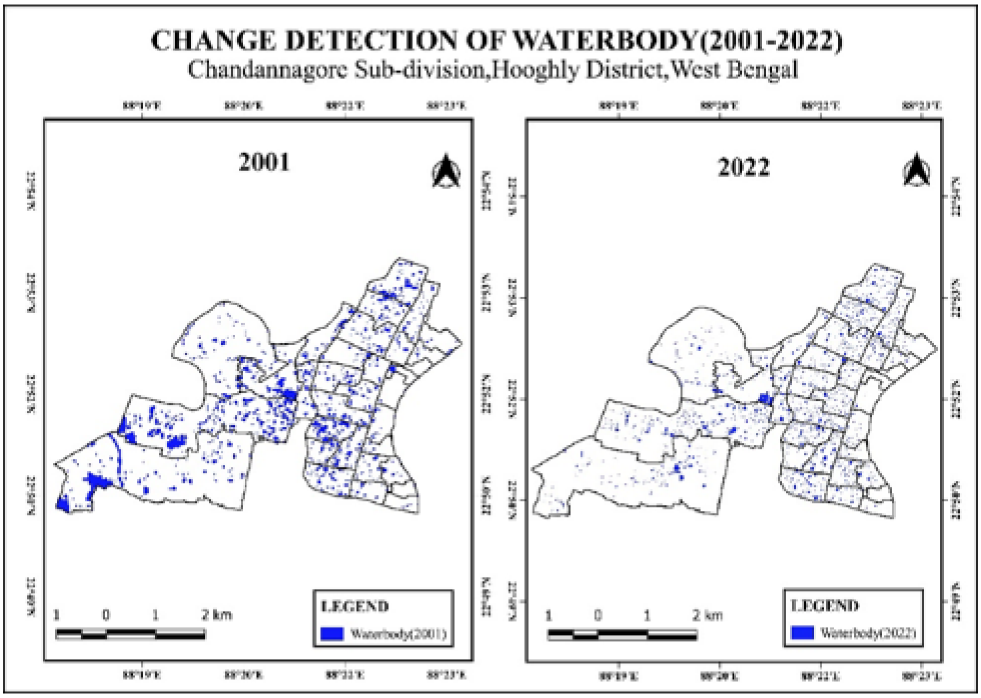

Figure 8 Change in Waterbodies

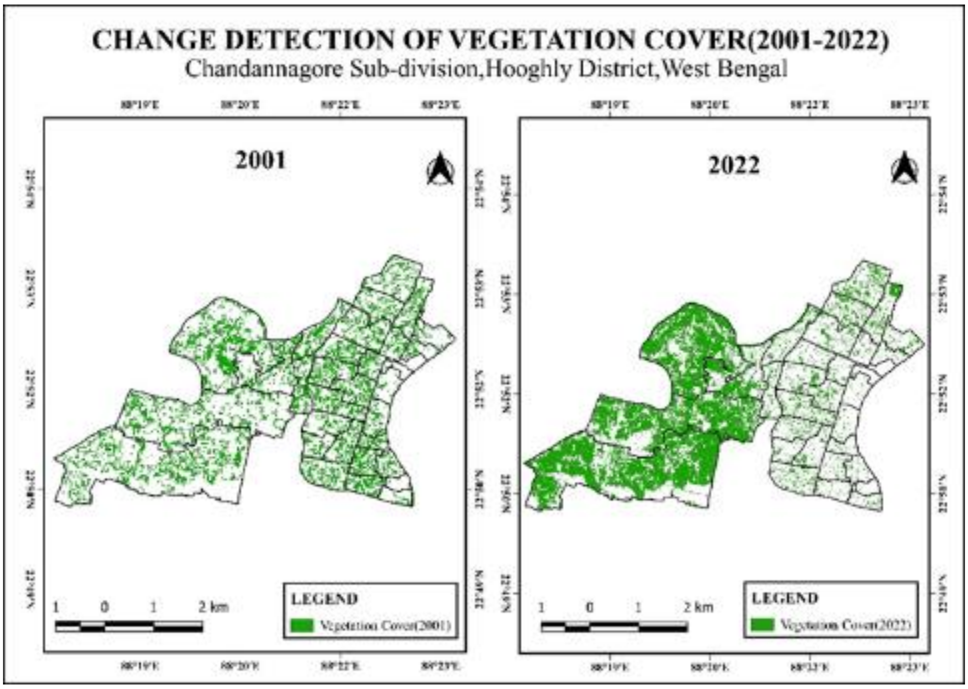

Figure 9 Change in Vegetation Cover

Fig. 5,6,7,8, and 9 show changes of corresponding land use/land cover types from 2001 – to 2022 (Built-Up; Cultivated Land; Shrublands; Waterbodies, Vegetation Cover)

The study aims to evaluate the land cover dynamics in the region and determine the degree and pace of change. For this purpose, several key variables have been devised and computed, including:

- **Total Area (Ta):** This refers to the overall land area within the study region.

- **Changed Area (Ca):** This variable indicates the extent of change in land cover between two specified periods, t1 and t2. It is calculated by subtracting Ta(t1) from Ta(t2).
- **Change Extent (Ce):** This variable quantifies the percentage of the total area that has changed during the study period. It is derived by dividing Ca by Ta(t1). Therefore, the formulas for these variables can be expressed as follows:

$$Ca = Ta(t2) - Ta(t1); \quad Ce = (Ca / Ta(t1)) \times 100\%$$

Table 5 Changed Area and Change Extent rate of Land cover change (2001-2022)

Changed Area and Extent rate of Land Cover Change (2001 - 2022)		
Land Cover Type	**2000 - 2022**	
	Change Area (Sq.km)	**Change Extent (%)**
Built-Up Area	3.844872	17.3977565
Vegetation Cover	2.2032	9.969314223
Cultivated Land	-2.389187	-10.8108914
Shrublands	-2.234976	-10.11309823
Waterbodies	-1.412572	-6.391782013

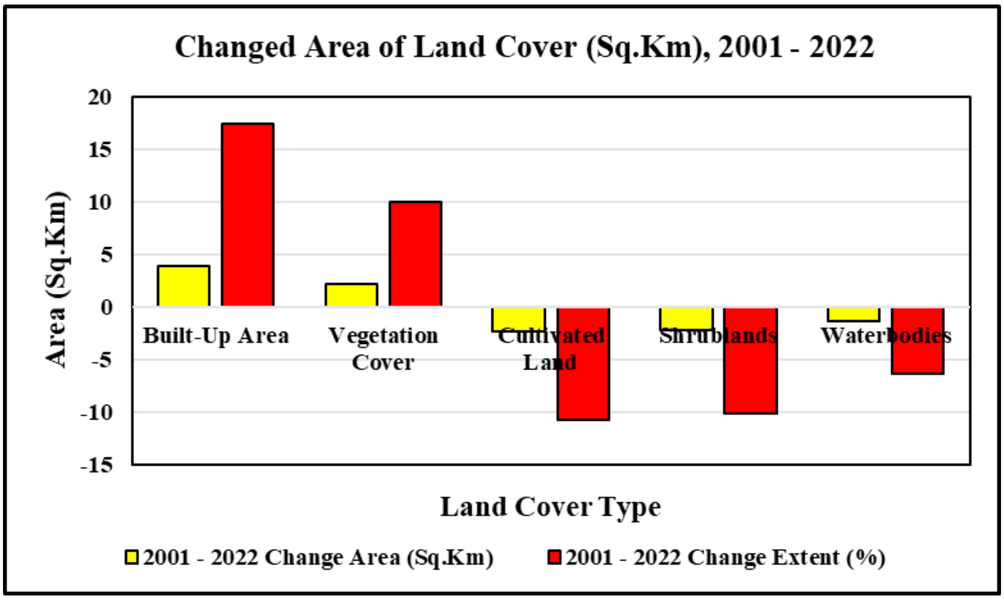

Figure 10 Changed Area of Land Cover (sq. km), 2001-2022

4.4. Analysis of Land Transformation between 2001 to 2022

The spatial pattern of land use/cover change in the study area for 2001 and 2022 is shown in Fig. 5, 6, 7, 8, 9. It is revealed that cultivated lands and vegetation were the dominant cover in 2001 and the direction of urban development (collectively termed 'built-up') confined to the eastern part of the CMC. However, in 2022, built-up land cover replaced most of the water bodies and vegetation within the CMC area and also the cultivated lands. The propensity of urban development extended to further south-east, eastern part, and central direction between 2001 to 2022. The current map shows that the built-up category is fast becoming the dominant cover while rural lands started to disappear concurrently since the demand for urban land dramatically increased in recent years. The land transformation matrix and land transformation map depict changes in land use over time, particularly the gains and losses of Agricultural Land, Vegetation cover, and Shrubland. These changes were largely driven by the expansion of Built-Up area between 2001-2022, resulting from increased human activity in secondary sectors as opposed to primary activities. This led to employment opportunities and rapid population growth in the eastern and central parts of the study area. To evaluate the results of land use/cover conversion, a land use transition matrix was calculated and shown in Table 12 and Table 13. These results indicated that an increase in urban areas mainly resulted from cultivated land, vegetation covers, and water bodies during 2001–2022. The analysis of the land use conversion matrix revealed that 36.935 ha of water bodies and 131.569 ha cultivated land was converted to urban built-up category between 2001 and 2022.

Table 6 Land Transformation Matrix of LULC during 2001-2011

Lulc classes	Built up area	Cultivated land	Shrublands	Vegetation cover	Waterbodies	Grand total
BUILT UP AREA	261.2876439	52.23605282	24.29782395	55.17483686	3.461090035	396.4574476
CULTIVATED LAND	131.5691774	40.75386137	12.01029001	364.9145262	24.74484162	573.9926965
SHRUBLANDS	47.631369955	123.1096025	17.90496699	124.519313	3.485492135	316.6507442
VEGETATION COVER	302.1095449	74.75438335	24.72734279	258.1189326	13.66732121	673.3775248
WATERBODIES	36.93511763	42.85683413	15.8926454	89.05125193	52.570324	237.3061731
GRAND TOTAL	779.5328534	333.7107341	94.83306913	891.7788606	97.92906899	2197.784586

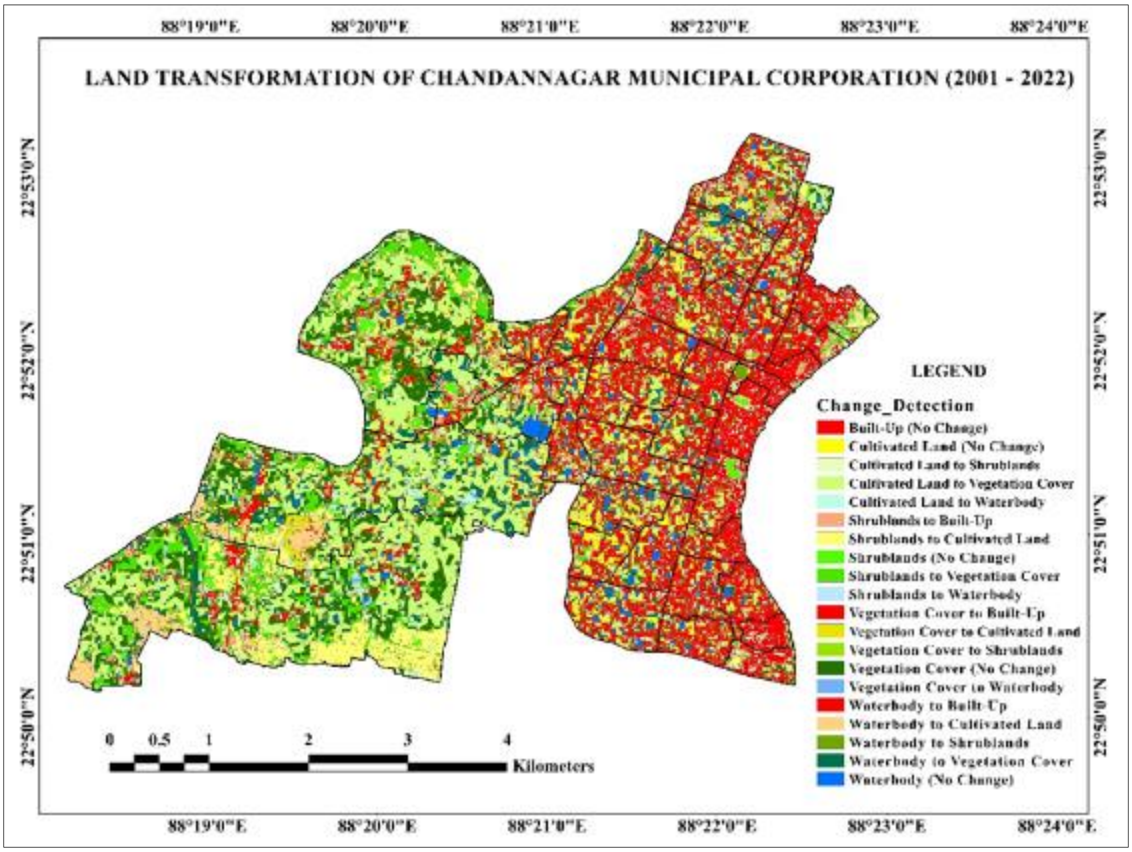

Figure 11 Land Transformation during 2001-2022

Over the last two decades (2001-2022), a comprehensive examination of land use and cover changes has revealed a disheartening trend: a significant decline in natural lands accompanied by a corresponding increase in urban areas. The detailed analysis of these transformations uncovered some striking statistics. Between 2001 and 2022, built-up areas expanded by a staggering 261.287 hectares. Further examination of the nature of these changes revealed distressing alterations in other land categories. Water bodies experienced a decrease of 139.377 hectares, while shrublands shrank by 221.817 hectares. Additionally, cultivated land saw a reduction of 240.281 hectares from 2001 to 2022. However, the most significant and alarming change emerged as the spectacular expansion of built-up areas between 2001 and 2022. This exponential growth in the human landscape and the subsequent reduction of the natural landscape underscores the magnitude of anthropogenic activities and their profound impact on our environment.

4.5. Implications of observed LULC dynamics on resource degradation and the requirement for SLM Planning

LULC change may entail unintended implications and far-reaching long-term effects on ecological processes that potentially compromise the basic functioning of ecosystems. Therefore, understanding the implication of the past and the present patterns of human-environment interaction is increasingly imperative for sustainable land management planning *(Turner et al., 2007).* Changes in LULC are an inevitable and complex phenomenon with multifaced socioeconomic and biophysical implications *(Yesuph & Dagnew, 2019).*

The LULC changes observed in Chandannagar indicate a rapid transformation of land for various purposes. Agricultural land and vegetation cover have been consistently converted into urban and industrial areas to accommodate the growing population and increasing industrial activities. This conversion has led to the loss of fertile soil, reduced agricultural productivity, increased pressure on limited nutrient depletion, and reduced water availability. Additionally, the expansion of urban areas has led to the encroachment on natural habitats and ecosystems, resulting in the loss of biodiversity and disruption of ecological processes. Wetlands, forests, and other natural areas, which provide crucial ecosystem services like water purification, flood regulation, and carbon sequestration, are being rapidly degraded or destroyed. This not only threatens the survival of numerous plant and animal species but also compromises the resilience of the region to climate change impacts. The observed LULC dynamics also have implications for water resources in CMC. The conversion of agricultural land to urban areas and the excessive extraction of groundwater for industrial and domestic purposes have resulted in declining water tables and increased water stress. The depletion of groundwater reserves and the pollution of surface water bodies further exacerbate the problem, leading to water scarcity and compromising the livelihoods of communities dependent on agriculture and fisheries.

To address these challenges and mitigate resource degradation, there is an urgent need for SLM (Sustainable Land Management) planning in Chandannagar Municipal Corporation. SLM focuses on promoting sustainable and equitable use of land resources, minimizing land degradation, and enhancing ecosystem services. It involves the adoption of practices such as agroforestry, conservation agriculture, watershed management, and urban planning that prioritize sustainable land use and natural resource management. By prioritizing conservation, sustainable agriculture, and integrated land use planning, CMC can strive towards a more resilient and resource-efficient future.

4.6. Spatial Transition of Land Use/Land Cover Change Analysis Using Spatial Metrics

The spatial dynamics of land cover refers to the temporal change in the size, number, shape, adjacency, and the proximity of patches in a landscape. A change in urban land cover changes can be well described using information from spatial metrics. A set of spatial metrics can be used in a detailed analysis of growth patterns mapped from the remote sensing data and extended to interpret and analyze the change in spatial structure of urban growth *(Herold, Goldstein, & Clarke, 2003).* Spatial metrics have to be selected, interpreted, analyzed and evaluated according to the context of the study, given the thematic classification and the inherent processes of change *(Gustafson, 1998).*

The spatial metrics in this study were computed using FRAGSTATS version 4.2. This involved analyzing thematic maps that classified the landscape into distinct spatial patches belonging to various patch classes. The resulting metrics provided quantitative measures of the landscapes' spatial structure and composition.

After the initial classifications have been completed, now it is important to conduct further analysis on the landscape patterns. These are done by examining the six classes of land cover maps as well as the reclassified built and non-built maps. At each class level, several metrics can be calculated, including the total class area, mean patch size, number of patches, percentage of landscape, and largest patch index. By examining these for each class, we can gain a better understanding of the landscape pattern in concern of areas of interest.

4.7. Land Fragmented Class Analysis

Figure 11, 12, 13, 14, 15, and 16 illustrates the changes in landscape fragmentation patterns both spatially and temporally over the course of two decades. The vertical axis represents the class value, while the horizontal axis displays the names of land cover type. CA refers to the overall area undergoing various land use changes. In comparison to the previous two decades, the CA value of the land fragmented class has decreased and transformed into multiple land use classes based on the extent of human interference.

The analysis of spatial metrics reveals notable changes in land cover patterns in the study area from 2001 to 2022. The urban cover has exhibited a significant increase, expanding from 3.984 sq. km (18.039% of the total area) to 7.829 sq. km (35.428% of the total area). Conversely, the cultivated land has experienced a considerable decline, decreasing from 5.753 sq. km (26.048% of the total area) to 3.364 (15.224% of the total area). Water bodies have witnessed a reduction from 10.833% to 4.436% and there has been a decrease in shrublands from 14.45% to 4.329%. Interestingly, the vegetation cover class has exhibited insignificant cumulative change throughout the mentioned periods. The outcomes also indicate a decrease in the number of patches (NP) within the urban built-up class, indicating the integration of fragmented built-up patches with neighboring built-up areas. This phenomenon suggests the contagion effect, wherein adjacent built-up areas merge and consolidate over time, resulting in a reduction in the number of individual patches.

Table 7 Change in Landscape Pattern in Chandannagar Municipal Corporation using Spatial Metrics (2001)

Change in Landscape Pattern in Chandannagar Municipal Corporation using Spatial Metrics (2001)						
Land cover type	Class Area (CA)	Number of Patches	Patch Density (PD)	Mean Patch Size	Percentage of Landscape (PLAND%)	Largest Patch Index (LPI%)
Built up Area	3997800	628	134996	6365.92356	18.08484651	2.59381
Vegetation Cover	6738200	563`	120997	11970.15985	30.48611677	2.33849
Cultivated land	5703300	572	122931	9970.80419	25.80001629	3.45647
Waterbody	2464200	560	120352	4400.35714	11.14730071	0.32108
Shrublands	3201300	361	7758435	8867.86703	14.48171973	1.30754

Table 8 Change in Landscape Pattern in Chandannagar Municipal Corporation using Spatial Metrics (2022)

Change in Landscape Pattern in Chandannagar Municipal Corporation using Spatial Metrics(2022)						
Land cover type	Class Area (CA)	Number of Patches	Patch Density (PD)	Mean Patch Size	Percentage of Landscape (PLAND%)	Largest Patch Index (LPI%)
Built up Area	7560000	1709	7.73047	4423.6395	34.196849	28.4792
Vegetation Cover	8891300	2393	0.000108	3715.5453	40.21884174	25.0623
Cultivated land	3569700	7026	0.00031	508.07	16.14715501	1.4465
Waterbody	1023500	1402	6.3417	730.0285	4.629692455	0.1343
Shrublands	1062800	3064	0.00013	346.8668	4.807461789	0.0954

The number of urban-built up patches exhibited a significant increase over time, rising from 628 hectares further to 1709 in 2022. This upward trend indicated the growth of individual development cores and the aggregation of spatially proximate built-up surfaces within the metropolitan area. Moreover, the expansion extended beyond the core urban regions, encompassing the outskirts. The Largest Patch Index (LPI) experienced changes between 2001 and 2022, with a relatively higher increase observed for built-up areas, from 2.593% to 28.479%. The consistent growth of urban built-up areas from 2001 to 2022 contributed to the progressive increase in the LPI value. Consequently, the LPI metric provided compelling evidence of substantial urban expansion in the region. This upward trend in the LPI also indicated the spatial growth of urban areas surrounding existing urban cores, with minimal fragmentation of urban fabrics and other artificial surfaces.

MPS (Mean Patch Size), which is a critical measure of habitat fragmentation *(McGarigal & Marks, 1995)* showed striking feature. The dynamics of various land covers in a specific region have undergone significant changes over time, primarily due to a human activity. Notably, the waterbody category experienced a notable decline, with the total area decreasing from 2.392 sq.km in 2001 to 0.980 sq.km in 2022. This decline indicates a considerable degradation of waterbodies, likely due to ongoing human pressure and its associated impacts. Similarly, cultivated land witnessed a substantial transformation, with a larger mean patch size (MPS) of 9970.804 hectares observed in 2001. However, by 2022, this MPS decreased significantly to 508.07 hectares, indicating a fragmentation of cultivated areas over time. This fragmentation is further supported by the larger proportional dimension (PD) and smaller landscape patchiness index (LPI) values, suggesting that the once contiguous cultivated land has become heavily fragmented due to continuous human activities. Vegetation cover, another crucial land category, was also heavily influenced by anthropogenic factors. The MPS of vegetation cover decreased from 11970.159 hectares in 2001 to 3715.545 hectares in 2022, indicating a significant reduction in the overall size of vegetation patches. This decrease in MPS was accompanied by a similar trend in LPI, suggesting that gradual urban encroachment has further fragmented the vegetation cover.

The landscape of shrubland areas displays a significant amount of variation, as evidenced by the highly fluctuating values of NP and PD. Between 2001 and 2022, the NP (No. of Patches) for barren land increased from 361 to 3064. This can be attributed to the ongoing urban development encroaching upon barren land, resulting in the reduction of its overall areas and consequently yielding variable NP and PD scores. Similarly, waterbodies also experienced an increase in NP and PD (Patch Density), leading to consistently smaller MPS values, indicating a fragmented landscape mosaic. An analysis of land use change revealed that natural landscapes in CMC have been swiftly replaced by built-up cover, as supported by the rise in NP and PLAND. The number of patches in 2001 was 628, which escalated to 1709 by 2022. As urban development became very rapid between 2001 and 2022, this might have resulted in the largest NP *(Seto & Fragkias, 2005).* PD exhibited a similar trend, in line with the NP values. The increased NP score in 2022 suggests a greater aggregation of built-up patches. Sharp and consistent increase in LPI values reflected that the study area gradually became urban-dominated as the intensity of urbanization in the fringe as well as densification within already urbanized area increased tremendously, leading to the dominance of urban landscape (Herold et al., 2002). High PD values indicate a fragmented landscape (Fig. of Bar diagram of Patch Density), which can be directly or indirectly influenced by topographical or anthropogenic activities. The observed changes in PD suggest a positive correlation with the degree of commercial transportation (such as road construction) and residential expansions. Temporally, PD has increased in most land cover types over time, indicating a growing fragmentation of the land fragmented class. A higher number of patches in a particular landscape signifies greater fragmentation. Therefore, NP carries valuable information about current land use practices. Overall, the analysis of two decades of five land use/land cover types reveals a frequent increase in Number of Patches values in recent years. This increase signifies explicit information regarding landscape fragmentation due to human intervention and developmental activities. The findings indicate a correlation between the decrease in patches, PLAND, and LPI and the transformation of non-built-up areas, particularly the previously dominant agricultural patches. These agricultural patches, which previously constituted the highest percentage of land cover in terms of landscape (PLAND) and area (CA), have been increasingly replaced by built-up surfaces. The majority of urban expansion has taken place in close proximity to the existing metropolitan regions, resulting in less fragmentation and fewer suburbs within the central urban areas.

To gain insights into the phenomenon of habitat fragmentation on a landscape scale, we employed several spatial indicators: NP, LPI, and MPS. These indicators were utilized to characterize the patterns of landscape change, offering a comprehensive understanding of the impact of human activities and subsequent alterations in landscape structure. Our analysis presents noteworthy findings, indicating the magnitude of fragmentation within the landscape. Specifically, the results demonstrate a strong correlation between smaller MPS and LPI values, alongside larger NP values, signifying a high degree of landscape fragmentation. In summary, the analysis of spatial metrics reveals a spatio-temporal pattern of urban development characterized by fast growth in proximity to the historical urban core. This growth exhibits lower levels of fragmentation and sprawl. The urban expansion predominantly follows the existing urban boundary, resulting in a decline in spatial complexity and limited signs of fragmentation. This trend is driven by the rising development pressure, economic growth, and tourism in the region. However, it is important to note that the increasing expansion of urban areas poses significant environmental challenges. The expansion leads to soil desiccation and the consumption of fertile agricultural land, which has detrimental effects on the environment. This implies that as human actions intensify, the landscape undergoes a finer-grained fragmentation process. Notably, since 2001, we observed a considerable decrease in MPS in shrublands, cultivated lands, and vegetation cover. This decline can be attributed to the aggregation of built-up areas, primarily driven by rapid urbanization. As a consequence, the landscape has experienced heightened fragmentation, particularly in these affected areas. The result of this study is consistent with studies carried out in other developing nations, where intense human activities are primarily accountable for sharp landscape fragmentation, including widespread urban sprawling and ecological change *(Yu & Ng, 2006).*

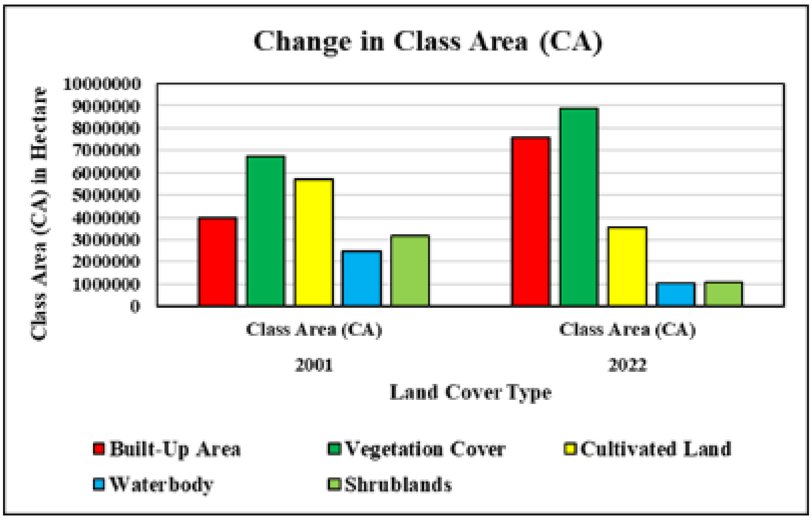

Figure 11 Change in Class Area of Landscape Fragmentation in CMC

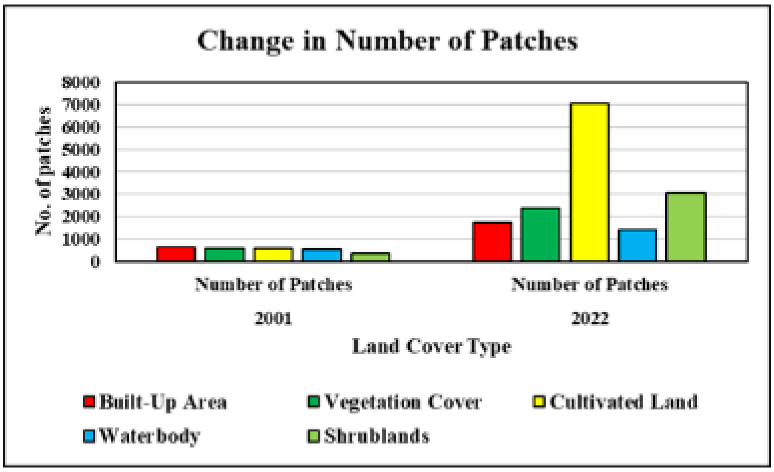

Figure 12 Change in No. of Patches of Landscape Fragmentation in CMC

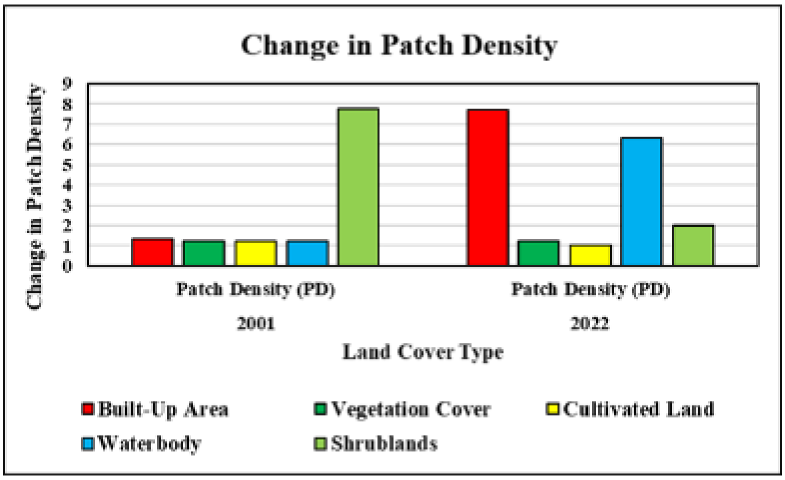

Figure 13 Change in Patch Density of Landscape Fragmentation in CMC

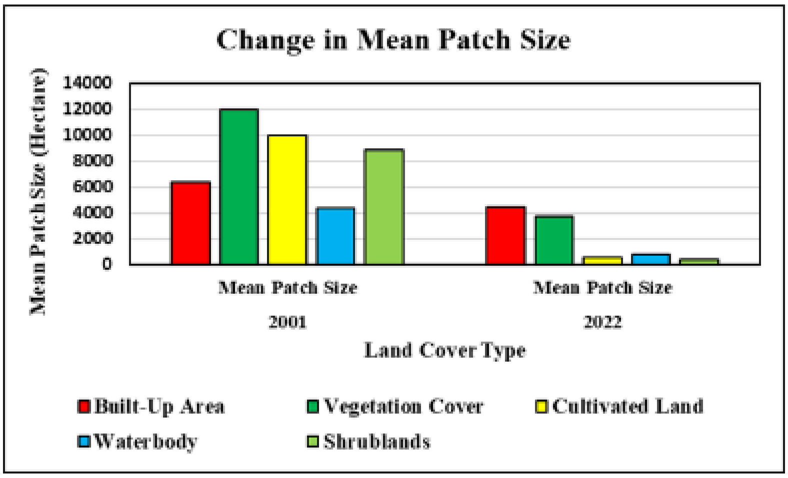

Figure 14 Change in Mean Patch Size of Landscape Fragmentation in CMC

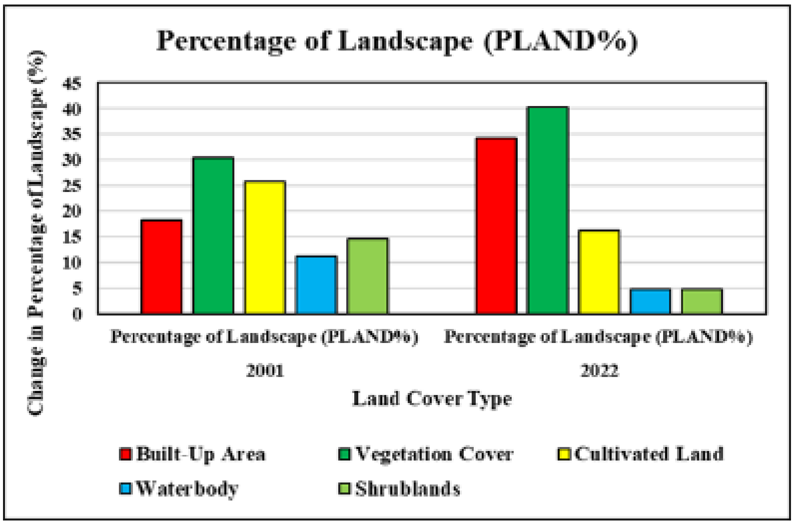

Figure 15 Change in Percentage of Landscape of Landscape Fragmentation in CMC

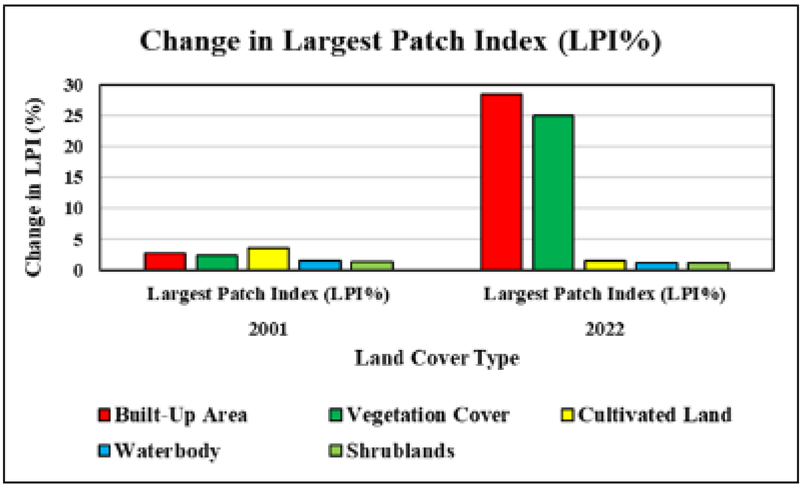

Figure 16 Change in Largest Patch Index of Landscape Fragmentation in CMC

4.8. Temporal Patterns of Land Use / Land Cover Changes

The classifications of Chandannagar Municipal Corporation's land use land cover and their relative changes from 2001 to 2022 are shown in the Table 9, 10, 11. The analysis of spatial patterns of land cover demonstrates that the rise and expansion of Built-Up surfaces followed certain trends, principally affected by new land management initiatives, highway construction, and population expansion. Built-up regions experienced an enormous increase (17.397%) between 2001 to 2022, while other non-built-up areas witnessed a significant decrease. Particularly in locations adjacent to existing urban boundaries, there was a constant transition from non-built-up areas to built-up environments, illustrating the temporal dynamics of urbanization.

Based on the image classification carried out in 2022, it has been observed that there has been a significant transformation in land cover, characterized by the rapid conversion of agricultural land and shrublands to urban built-up surfaces and other artificial surfaces. The expansion of urbanization had been widespread, extending from the already established built-up areas and moving towards the direction of the port. The growth and expansion of the urban area have been substantial, resulting in the consumption of fertile cultivated fields that are situated in close proximity to the city boundaries. This phenomenon is of great concern as it poses a threat to the agricultural productivity of the region, in addition to the potential ecological and environmental impacts of such rapid urban expansion.

The analysis of the temporal trends in land use and land cover changes indicates a substantial increase in built-up areas over time. Specifically, the area covered by built-up surfaces in 2001 was 3.984 sq. km, which gradually increased to 7.829 sq. km in 2022, reflecting a growth of 17.397% within 20 years. This trend highlights the significant transformation of land cover in the built-up areas, particularly agricultural lands and vegetation cover. Such changes in land use and land cover could have severe implications for the ecological health and sustainability of the region, calling for urgent attention to mitigate their impact.

The investigation of spatial metrics has highlighted that temporal changes have led to alterations in landscape structures. Specifically, changes have been observed in the class area, number of patches, mean patch size, percentage of landscape, largest patch index, and area-weighted fractal dimension index over time. Therefore, the careful application of spatial metrics can be useful in interpreting land use and land cover dynamics in time series data. It is important to note that monitoring these changes requires the use of high-quality geographic data with temporal consistency to avoid any distortion in the results due to data-related issues.

Based on the empirical results obtained, it is evident that there is a pressing need for an integrated approach to assess the dynamics of Land Use Land Cover (LULC) changes, and to develop effective spatial and temporal models to manage urban growth and expanding impervious surfaces. This task requires the use of a range of techniques, including remote sensing, spatial metrics, and socio-economic data to provide a comprehensive understanding of the factors driving LULC changes. By integrating these approaches, it will be possible to develop effective strategies manage the impacts of urbanization of the environment, particularly on soil and water quality, which are continuously affected by urban growth and expanding impervious surfaces. It is essential to address the associated issues of water pollution and stress, soil desiccation, and degradation in the region to ensure sustainable development and environmental management. Therefore, it is necessary to prioritize research efforts in this area to develop effective land-use planning policies and strategies that consider the social, economic, and environmental impacts of urbanization.

4.9. Recommendations for Sustainable Land Use and Land Cover Planning

Rapid urban growth in Indian cities poses a variety of major environmental issues. Cities in India are frequently experiencing environmental deterioration as a result of the country's fast urbanization, leading to the need for the urgent implementation of policies that would promote efficient land use planning and development. To address these pressing issues, its crucial to develop a comprehensive and sustainable land use and land cover planning strategy for West Bengal. This recommendation provides a roadmap for implementing effective measures that promote sustainable development, conserve natural resources, and enhance the well-being of communities in the state. Effective land use planning and policies should be adopted by the state government, such as:

- **Integrated Land Use Planning:** Implement an integrated land use planning approach that takes into account the ecological, economic, and social aspects of land use. This approach should involve the participation of all stakeholders, including local communities, government agencies, and environmental experts. The planning process should consider factors such as soil fertility, water availability, biodiversity, and the needs of local communities to ensure sustainable land use practices.
- **Effective management of urban greenery:** The rapid growth of the urban population in West Bengal has a significant impact on the environment. The state's urban areas are characterized by high levels of air and water

pollution, which have contributed to a range of health problems for residents. The challenge for urban planners and managers is to develop and implement strategies to promote environmental sustainability while accommodating population growth. One of the key implications of these findings for urban planning and management in CMC is the need to focus on the development of green infrastructure. As vegetation act as a natural cooling mechanism, it promotes evapotranspiration and that energy is released more through latent heating than sensible heating. It may also function as a sink for $CO2$. The respective government departments and agencies should provide the households in the region with guidance regarding the most suitable vegetables to cultivate and the various inputs to employ. Investing in green spaces, such as parks and gardens, to improve air quality and provide residents with recreational opportunities. It also involves investing in waste management systems, such as recycling and composting, to reduce of waste that is sent to landfills.

- **Sustainable Agriculture:** Promote sustainable agricultural practices that optimize land productivity while minimizing environmental impacts. Encourage the adoption of organic farming techniques, agroforestry, and integrated pest management to reduce the reliance on chemical inputs and enhance soil fertility. Support farmers through capacity-building programs, access to credit facilities, and incentives for adopting sustainable practices. Facilitate the establishment of farmers' cooperatives and promote market linkages for organic produce.
- **Preservation and Restoration of Forests:** Recognize the critical role of forests in maintaining ecological balance, conserving biodiversity, and mitigating climate change. Develop strategies to protect and restore forest cover in West Bengal, including strict enforcement of existing forest protection laws, promotion of afforestation and reforestation initiatives, and integration of community-based forest management approaches. Strengthen forest governance and ensure effective monitoring to prevent illegal logging and encroachments.
- **Urban Planning and Land Management:** address the challenges of rapid urbanization by implementing sustainable urban planning strategies. Encourage compact and mixed-use development patterns to minimize land consumption. Allocate land for green spaces, parks, and recreational areas within urban centres to enhance the quality of life and promote biodiversity. Improve waste management systems, including recycling and composting, to minimize landfill usage and reduce pollution.
- **Water Resource Management:** Develop comprehensive water resource management plans that prioritize the sustainable use of water for agriculture, industries, and domestic purposes. Implement rainwater harvesting techniques, promote efficient irrigation practices, and encourage the reuse of treated wastewater. Protect water bodies from pollution and encroachments through strict enforcement of regulations. Ensure equitable distribution of water resources, considering the needs of both rural and urban areas.
- **Climate Change Adaption:** Integrate climate change considerations into land use planning by identifying vulnerable areas and implementing appropriate adaption measures. Develop climate-resilient infrastructure such as flood-resistant buildings and drainage systems, to reduce the impacts of extreme weather events. Promote the use of renewable energy sources, such as solar and wind power, to reduce greenhouse gas emissions and foster sustainable development.

5. Conclusion

Land plays a crucial role as a natural resource essential for our livelihoods. Monitoring changes in land use and land cover (LULC) is vital to develop effective planning and implementation strategies to conserve land cover. A recent study has demonstrated the significance of integrating information from satellite remote sensing with Geographic Information System (GIS) to gain a comprehensive understanding of the magnitude and patterns of LULC changes. Utilizing software tools such as ArcGIS and QGIS, various techniques were employed to quantify and calculate the extent of land cover change in West Bengal between 2001 to 2021. This research incorporates change detection analysis alongside spatial metrics to facilitate the continuous monitoring of LULC changes both in time and space. The analytical findings yield valuable insights into the nature and scope of transformations that have occurred in West Bengal over the specified period, laying a strong foundation for future studies aimed at modeling and predicting future changes.

By leveraging the power of a GIS platform, we have successfully analyzed multi-temporal satellite images from 2001 and 2022 to identify the dynamics of land use/land cover change patterns. Our quantitative analysis has provided compelling evidence of the significant growth in artificial surfaces. However, this expansion of urban areas harmed both the society and the environment in the study area. The rapid development of urban areas has led to a scarcity of agricultural land, vegetation, and forests. As a result, we have observed a decrease in agricultural, vegetation, and forested areas, primarily due to the increasing expansion of residential areas. This shift in land use has consequently impacted the livelihood patterns of the local population. Farmers and fishermen have had to adapt to these changes by engaging in small businesses, auto-rickshaw driving, and other alternative jobs. To increase their productivity, farmers have resorted to using hybrid seeds and pesticides, leading to environmental pollution. Additionally, overpopulation and developmental activities have caused the transformation of water bodies and forests into urban areas. Water bodies have been filled up for cultivation and urbanization purposes, while trees have failed to meet the demands of infrastructure development and fuel consumption. The processing and analysis of the data were conducted using GIS and remote sensing techniques, culminating in the creation of a comprehensive map. The most prominent land cover change observed was the conversion of agricultural land into urban areas. The rate of change for built-up surfaces was particularly high at 1.8% annually, while agricultural lands were being converted at a rate of 1% per year. Considering the current trend of rapid infrastructure development, the tourism economy, and population growth, it is likely that the extent and pace of urban changes will continue in the future.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest is to be disclosed.

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