Jagannath University Journal of Life and Earth Sciences, 10(1) 91-122 pISSN 2414-1402, eISSN 2791-1845

DOI: https://doi.org/10.3329/jnujles.v10i1.85065

JnUJLES

Research Article

DYNAMICS OF LAND USE AND LAND COVER CHANGES IN KERANIGANJ UPAZILA: IMPACTS OF RAPID URBAN EXPANSION NEAR DHAKA CITY

Md. Asraf Uddin*

Department of Geography and Environment, Jagannath University, Dhaka-1100, Bangladesh.

Received:05 February 2025 *Accepted: 25 May 2025*

ABSTRACT

Keraniganj Upazila, adjacent to Dhaka city, has experienced significant land use and land cover (LULC) changes over the past three decades due to rapid urbanization and socio-economic transformation. This study aims to investigate the spatial and temporal dynamics of LULC in Keraniganj from 1989 to 2023 and assess the driving factors and environmental implications of these changes. To achieve this, multi-temporal Landsat imagery, remote sensing (RS), and geographic information systems (GIS) techniques were applied, complemented by socio-economic data. Supervised classification algorithms were used to generate accurate LULC maps, and the results were validated using confusion matrices and Kappa statistics. The analysis covered six major LULC categories: bare land/sand fill, urban settlements, cultivated land, rural settlement/homestead vegetation, water bodies, and wetlands/lowlands. The results reveal a substantial increase of 1,738.62 hectares in urban settlements, particularly between 2009 and 2023, primarily at the expense of cultivated land, rural settlements, and natural ecosystems. During the study period, Keraniganj lost 476.46 hectares of cultivated land, 480.51 hectares of rural settlement areas, 1,087.83 hectares of water bodies, and 166.68 hectares of wetlands. These trends indicate extensive land reclamation, unplanned urban growth, and environmental degradation, driven by the area’s proximity to Dhaka, improved transportation infrastructure, and lower living costs. The findings underscore the urgency of implementing sustainable land use policies and integrated urban planning to address the negative impacts of urban expansion, including habitat destruction, reduced biodiversity, heightened flood risks, and declining agricultural productivity. This research contributes valuable insights into LULC dynamics and provides a replicable framework for monitoring and managing land transformation in rapidly urbanizing regions globally.

Keywords: *land use and land cover (LULC) change, urbanization, remote sensing (RS), geographic information system (GIS), Dhaka City*

***Correspondence:** *masrafuddin.85@gmail.com*

Introduction

Land cover refers to the natural features present on the Earth's surface, while land use pertains to human activities conducted on that land *(*Bununu *et al.,* 2023; Nedd *et al.,* 2021*)*. In recent years, Asia has experienced dynamic land cover changes, with South Asian countries witnessing an imbalance characterized by rapid urban settlement expansion and large-scale deforestation *(*Arshad *et al.,* 2020; Srivastava, R.K., 2020*)*. Urban growth, marked by the transformation of rural areas into urban settlements and commercial land use at the periphery of metropolitan areas, is often seen as an indicator of economic progress *(*Cengiz *et al.,* 2022; Nong *et al.,* 2021; Yuan *et al.,* 2005*)*. However, urbanization is a major contributor to the loss of arable land *(*Junaid *et al.,* 2024; Zhou *et al.,* 2023; *Sumbo,* 2023; Lopez *et al.,* 2001*)*, habitat destruction (James, 2023; Alphan, 2003), and the reduction of natural vegetation *(*Deng *et al.,* 2024; Fayshal *et al.,* 2024; Kisvarga *et al.,* 2023; Zhang *et al.,* 2023; Dewan and Yamaguchi, 2009*)*. These changes lead to critical climatic challenges such as global warming, increased pollution, and natural disasters like flooding *(*Das *et al.,* 2024; Yu *et al.,* 2024; Pakhira *et al.,* 2024; Humbal *et al.,* 2023; Mas *et al.,* 2004; Zhao *et al.,* 2004; Dwivedi *et al.,* 2005*)*. Therefore, understanding land use and land cover (LULC) changes is crucial for effective environmental management and urban planning *(*Ashwini *et al.,* 2024; Gaur and Singh, 2023; Pande *et al.,* 2023; Fan *et al.,* 2007*)*.

Several factors, including rapid urban growth, population pressure, technological advancements, and increasing demand for production, have significantly altered the Earth's LULC patterns *(*Sarif *et al.,* 2024; Ullah, 2024; Kamran *et al.,* 2023*)*. Socioeconomic, demographic, political, cultural, and environmental conditions also play pivotal roles in driving these changes, with high population growth being a particularly influential factor *(*Reimann *et al.,* 2023; Hariram *et al.,* 2023; Muttarak, 2021; Masek *et al.,* 2000*)*. Such pressures often result in unplanned and uncontrolled LULC changes, leading to the mismanagement of agricultural, forest, and urban lands, which in turn causes long-term environmental challenges *(*Sarfo *et al.,* 2024; Desta and Fetene, 2020; Seto *et al.,* 2002*)*.

Bangladesh has undergone rapid urbanization in recent years, significantly impacting other LULC categories *(*Hasan *et al.,* 2023; Rahman, 2022; Rahman and Szabó, 2021*)*. Annually, approximately 809 km² of agricultural land is converted into settlements, roads, and infrastructure, leading to food shortages, unemployment, and landlessness (Islam, 2024; Ghimire *et al.,* 2023; Ahmad, 2005). Dhaka, the capital of Bangladesh and the center of administrative, educational, medical, and economic activities, has seen one of the highest rates of urban growth globally *(*Rahaman *et al.,* 2023; Rashid *et al.,* 2023; Uddin *et al.,* 2022; Islam, 1999*)*. Adjacent to Dhaka, Keraniganj Upazila is experiencing rapid urban growth due to its proximity to the capital, which is projected to become the world's third-largest city by 2020 *(*Miah *et al.,* 2024; Islam, 2024; Datta, 2020*)*. This rapid urban expansion has brought significant transformations to Keraniganj's LULC patterns.

Modern tools like Geographical Information Systems (GIS) and remote sensing provide powerful means to analyze LULC (Land Use Land Cover) dynamics by offering accurate and timely spatial information across various scales *(*Chatrabhuj *et al.,* 2024; Wu *et al.,* 2024; Kanga *et al.,* 2024; Anees*et al.,* 2020; Carlson and Azofeifa, 1999; Rogan and Chen, 2004*)*. These tools enable the assessment of human-induced changes and their impacts on natural resources *(*Xing *et al.,* 2024; Gabriele *et al.,* 2023; Agarwal *et al.,* 2002*)*. GIS provides a flexible platform for collecting, storing, analyzing, and visualizing digital data essential for LULC change detection *(*Patel *et al.,* 2024; Sharma *et al.,* 2024; Yomralıoğlu *et al.*, 2000; Demers, 2005*)*. Remote sensing imagery, particularly from satellites like Landsat, serves as a critical data source for GIS applications *(*Wulder *et al.*, 2022; Hemati *et al.*, 2021*)*.Landsat Thematic Mapper (TM) and Enhanced Thematic Mapper Plus (ETM+) data have been extensively used since 1972 for monitoring forest and agricultural changes due to their rich archive and high spectral resolution *(*Durage and Nandasena, 2023; Bannari and Al, 2020; Campbell, 2007*)*.

The free availability of the entire Landsat archive has greatly enhanced researchers' capabilities to monitor and analyze both environmental and anthropogenic changes *(*Demarquet *et al.*, 2023; Masek *et al.,* 2020; Chander *et al.*, 2009; El Bastawesy, 2014*)*. Accurate change detection depends on rigorous pre-processing steps, including data selection, radiometric calibration, normalization, and co-registration, complemented by robust post-processing methods *(*de Lange, 2023; Kocaman and Seiz, 2023; Okolie and Smit, 2022; Jensen, 2005; Scheidt *et al.*, 2008*)*.

This study examines the spatial-temporal dynamics of LULC changes in Keraniganj Upazila (1989–2023) and evaluates their environmental and socio-economic impacts through the lens of Central Place Theory. To achieve this aim, the study has three key objectives: (1) to classify and quantify major LULC changes using multi-temporal satellite imagery and GIS techniques; (2) to identify the drivers of land transformation—including urban expansion, infrastructure development, and population growth; and (3) to evaluate the ecological and social implications of these changes and propose policy directions for sustainable land-use planning and management.

Materials and methods

Study Area

Keraniganj Upazila, situated in the southern part of Dhaka District, covers an area of 166.87 sq. km *(*BBS, *2022)*. Geographically, it lies between 23°37' and 23°47' north latitudes and 90°13' and 90°29' east longitudes (Figure 1). The Upazila is traversed by three major rivers—Buriganga, Dhaleshwari, and Ichamati—and is bordered by Narayanganj Sadar Upazila to the south, Savar and Singair Upazilas to the north, and Hazaribagh, Kamrangirchar, Lalbagh, Kotwali, Khyampurthanas, and Savar and Narayanganj Sadar Upazilas to the east. The western boundary includes Nawabganj, Singair, and Serajdikhan Upazilas. Keraniganj Upazila is connected to the Dhaka metropolitan area through multiple bridges over the Buriganga River, situated on the northeastern part of the Upazila. It comprises 12 unions, 122 mouzas, 422 villages, and had a population of 1,011,063*(*BBS, 2022*)*.

Due to its connectivity with Dhaka via several bridges, Keraniganj has witnessed rapid urban settlement growth. The increasing urbanization has significantly contributed to population growth, as the expanding economic sector in Dhaka creates ample job opportunities. Many seasonal migrants relocate to Keraniganj due to its lower living costs and efficient transport links with Dhaka. As Dhaka, the economic hub of Bangladesh, continues to expand rapidly, Keraniganj Upazila has also experienced substantial growth, driven by its proximity, affordable living conditions, and ease of transportation.

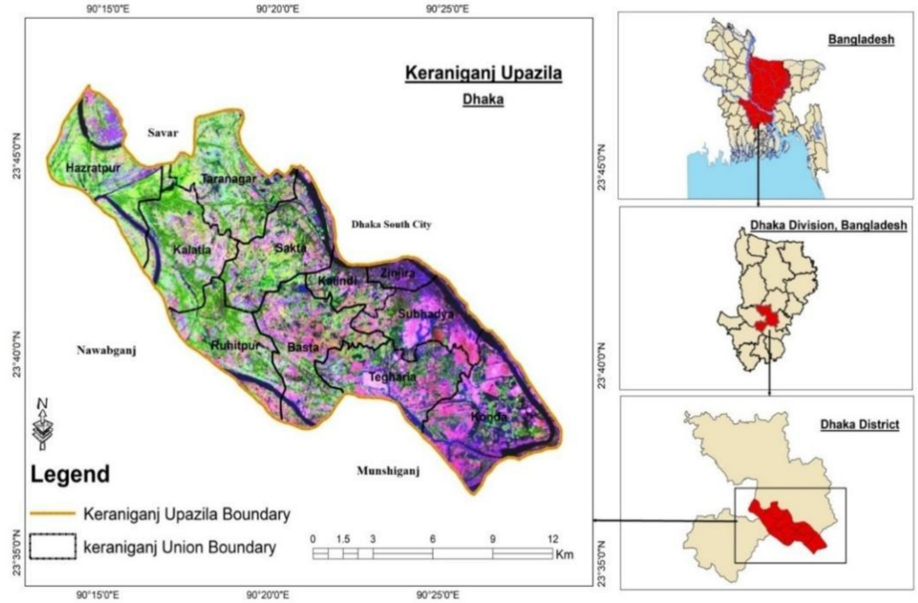


Figure 1: Location of the Study Area (Keraniganj Upazila, Bangladesh), Source: Author, 2024

Keraniganj Upazila, located in the central region of Bangladesh, exhibits minimal variation in elevation. Topographically, the study area is predominantly flat and situated on an alluvial terrace, identified as the Modhupur Terrace from the Pleistocene period (Dewan and Yamaguchi, 2009). The surface elevation of the region ranges from 0 to 28 meters (Figure 2), with the majority of urban settlements observed at elevations between 6 to 8 meters.

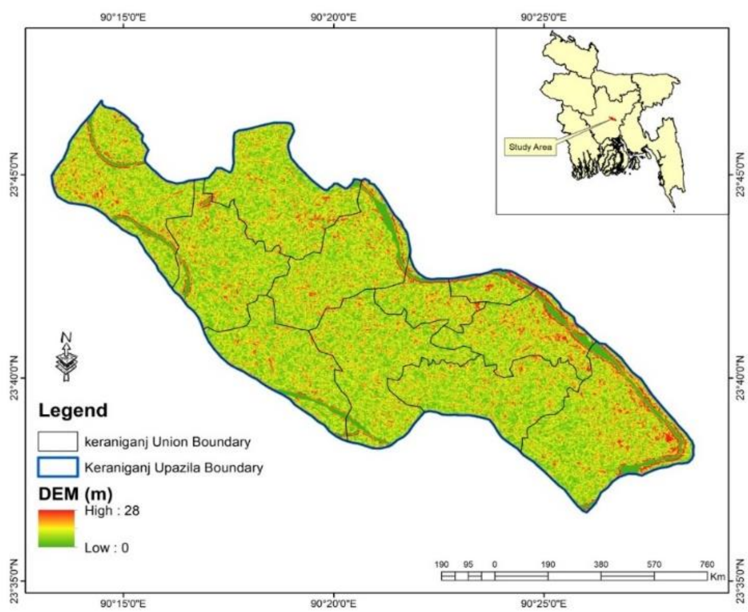


Figure 2: Elevation of the study area from sea level, Source: Author, 2024

Data Source

In this research, two types of geometrically corrected and cloud free temporal Landsat(TM/ETM+) data were used to generate land use land cover classification. Three Landsat data comprised of TM (20 November 1989, 27 November 2009) and ETM+(25 November 2023) (Table 1) were obtained and employed from the Earth Resource observation and science (EROS) through free satellite image provider United State of Geological Survey (USGS) (http://glovis.usgs.gov) Global Visualization Viewer L1T format.

Table 1:Remote sensing data used in the study

Date of acquisition (based on image data availability)	***Time of acquisition***	***Satellite and Sensor***	***Path and Row***	***Spatial Resolution***
11/25/2023	4:27:21	Landsat ETM	137/44	30
11/27/2009	4:15:15	Landsat TM	137/44	30
11/20/1989	3:48:48	Landsat TM	137/44	30

Image Pre-Processing

To ensure consistency, all satellite images were re-projected to the UTM WGS 84N (46 North latitude zone) using the third-order polynomial and nearest-neighbor resampling methods. The spectral information captured by Landsat-5 TM and Landsat-7 ETM+ sensors is stored as 8-bit digital numbers (DN) in the L1T products (Markham *et al.*, 2006). Using sensor-specific calibration parameters from the L1T metadata file, several equations were applied to convert the DN values of each scene into TOA (Top of Atmosphere) spectral radiance following the USGS-provided formula (Eq-1 for TM/ETM+ images) (Chander *et al.*, 2009).

Subsequently, the TOA spectral radiance values for reflective bands were converted into TOA reflectance using standard equations (Eq-2 for TM/ETM+) provided by Roy *et al.* (2010) and USGS. These steps ensured accurate radiometric corrections for further analysis, maintaining consistency across the Landsat datasets (Chowdhury and Islam, 2022).

$$L_\lambda = \left(\frac{L_{max} - L_{min}}{QCAL_{max} - QCAL_{min}}\right) * (QCAL_{max} - QCAL_{min}) + L_{min} \quad (1)$$

$$\rho_\lambda = \frac{\pi * L_\lambda * d^2}{ESUN_\lambda * \cos\theta_s} \quad (2)$$

Where,

L_λ = TOA spectral radiance

L_{max} = Spectral radiances scaled to $QCAL_{max}$

L_{min} = Spectral radiances scaled to $QCAL_{min}$

$QCAL_{max}$ = Maximum and quantized calibrated pixel values

$QCAL_{min}$ = Minimum quantized calibrated pixel values

$ESUN_\lambda$ = solar exoatmospheric irradiances

$\cos\theta_s$ = Solar zenith angle (radians) calculated from the solar elevation angle

ρ_λ = TOA spectral reflectance

All the satellite images used in this study required clear atmospheric conditions. However, atmospheric disturbances such as clouds, water vapor, aerosols, dust particles, and variations in sun angle can influence optical imagery, reducing spectral information and introducing errors. To minimize these effects and enhance image quality, atmospheric correction was applied to all satellite images. The dark object subtraction (DOS) method, a widely-used and advanced image-based correction technique, was employed for TOA reflectance images. This method does not require in situ field measurements and relies solely on image data for corrections (Chavez, 1988). All pre-processing of the images was conducted using ENVI 5.2 software.

The scan-line corrector (SLC) for Landsat ETM+ failed in 2003, causing approximately 20% of the pixels in ETM+ images to remain unscanned (Pringle, Schmidt, and Muir, 2009). This anomaly affects the continuity of image data. To address this limitation, missing pixels were filled using data from overlapping portions of adjacent scenes (lateral overlapping) or subsequent passes over the same scene (O.R. Abd El-Kawy *et al.,* 2011). In this study, for the 2009 Landsat ETM+ image, data from a scene acquired on 25 November 2009 were used to fill gaps in the image from 9 November 2009. This gap-filling approach ensured data consistency and improved the usability of the affected images.

Accuracy Assessment of LULC

Accuracy assessment is essential for evaluating the reliability of classified land cover images (Shao *et al.,* 2021; Islam *et al.,* 2021). In this study, 100 random sampling points were generated using ArcGIS 10.5 tools, and validation was performed with high-resolution Google Earth™ imagery for 1990 and 2022. Confusion matrices were used to calculate user, producer, and overall accuracy (Sim *et al.,* 2024; Ursu *et al.,* 2025). Additionally, the Kappa coefficient was applied to assess classification agreement beyond chance (Rosen field and Fitzpatrick-Lins, 1986), ensuring a robust accuracy evaluation.

Accuracy of Classified Images

The accuracy of the derived land cover maps from satellite data was assessed using error matrices. These matrices summarized the classification accuracy for the two years of land use/cover data. The confusion matrices for individual accuracy assessments of the classified images are presented in Table 6.

Table 6. Confusion matrix for the classified images using Google Earth Pro

LULC Classes	**1989**		**2009**		**2023**	
	User accuracy (%)	**Producer accuracy (%)**	**User accuracy (%)**	**Producer accuracy (%)**	**User accuracy (%)**	**Producer accuracy (%)**
Bare land	80.12	83.23	82.14	82.14	88.89	100
Built-up area	76.87	90.12	78.95	93.75	97.06	94.29

Vegetation	90	96.23	100	87.5	88.24	100
Waterbodies	82.34	89.11	84.38	84.38	100	91.18
Cultivated land	81.34	88.67	87.76	91.23	92.23	94.19
Rural settlement/ Homestead	79.67	82.98	85.11	89.98	90.45	98.11
Overall accuracy	84.65		86.37		93.55	
Kappa coefficient	0.81		0.81		0.93	

*(**Source:** Author, 2024)*

Image Classification and Data Extraction

In this study, six land use and land cover (LULC) classes were defined for the suburban area adjacent to Dhaka: bare land/sand fill, urban settlement, cultivated land, rural settlement/homestead vegetation, water bodies, and wetlands/lowlands. The Area of Interest (AOI) was extracted using ERDAS Imagine, and Landsat imagery was classified using spectral signatures and band composites (e.g., SWIR-NIR-Red) to distinguish LULC types.

Around 40 training samples per class were selected and refined based on statistical parameters. A supervised maximum likelihood classification (MLC) algorithm was applied, though spectral similarity led to misclassifications, particularly between urban settlement and bare land, and among cultivated land, wetlands, and water bodies. These were corrected using the recode method in ERDAS Imagine.

Post-classification refinement and a 3×3 majority filter was applied to reduce noise and improve accuracy. Final classified images from three time points were analyzed in ArcGIS 10.4, producing high-quality LULC maps and change detection matrices for robust land cover assessments.

Table 1: Land Cover classification scheme

Land Cover Types	Description
Bare land/ Sand fill	Exposed soils, landfill sites, and areas of active excavation
Urban Settlement	Residential, commercial and services, industrial, transportation, roads, mixed urban, and other urban
Cultivated Land	Agricultural area, crop fields, fallow lands and vegetable lands
Rural settlement/ Homestead Vegetation	Rural resident, rural commercial, deciduous forest, mixed forest lands, palms, conifer, scrub and others
Water bodies	River, permanent open water, lakes, ponds and reservoirs
Wet lands/ Low lands	Permanent and seasonal wetlands, low-lying areas, marshy land, rills and gully, swamps

Collection of Socio-Economic Background Data

This study primarily focused on the collection and analysis of remote sensing data. Additionally, both primary and secondary data were utilized. Secondary data were sourced from the Bangladesh Population Census reports (1991, 2001, 2011, and 2022) and land use and land cover information from the Bangladesh Agriculture Census (1984, 1996, and 2008) published by the Bangladesh Bureau of Statistics. Primary data were collected through questionnaire surveys**,** field observations**,** and key informant interviews**,** providing essential insights to complement the secondary data.

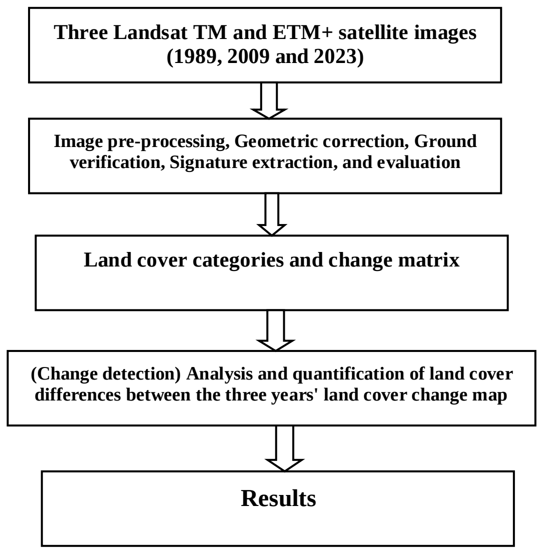


Figure 3: Image classification and data analysis work-flow

Results and Discussion

The spatial patterns of land use and land cover changes (LULCC) in Keraniganj for the years 1989, 2009, and 2023 are illustrated in Figure 4. In 1989, the landscape was predominantly characterized by lowlands, cultivated land, and water bodies, with urban expansion primarily directed southward. By 2009, many low-lying areas near urban centers had been replaced by bare land/sand fill and newly emerging urban settlements. A significant transformation occurred between 2009 and 2023, during which much of the previously filled land was converted into urban settlements (Figure 3).

Several studies indicate that the construction of bridges spanning rivers surrounding Dhaka—completed between 1975 and 1992—substantially improved regional road connectivity. This enhanced access fueled directional urban growth toward the north, south, northwest, and west of the city (Zaman, 2010). During the 1989–2009 period, both cultivated land and water bodies experienced notable declines, with the Buriganga River bridge playing a pivotal role in driving urban expansion toward the southern and northwestern parts of Keraniganj.

The maps also show the spatial distribution of exposed landfills, illustrating the transformation of lowlands into landfills on the outskirts of Keraniganj (Figure 3). Land developments in

Keraniganj are driven by three main sectors: public, private, and individual-household initiatives. The government of Bangladesh has initiated multiple housing projects aimed at developing planned model towns in Keraniganj. At the same time, private developers have rapidly purchased land in the area, often competing for space and driving urban expansion. This has resulted in the conversion of lowlands and cultivated land into landfills or bare land, often without considering environmental costs.

Fieldwork revealed that land speculation has significantly influenced suburban development. Rising land prices and housing demand have led to the rapid conversion of lowlands and cultivated land in fringe areas into urban settlements by both private and public developers. While suburban development is influenced by various factors, including speculation and economic demand, these alone do not fully explain the process in Keraniganj, necessitating further research. Poor coordination among executive agencies has also contributed to the loss of natural resources, underscoring the need for better planning and governance in land-use management.

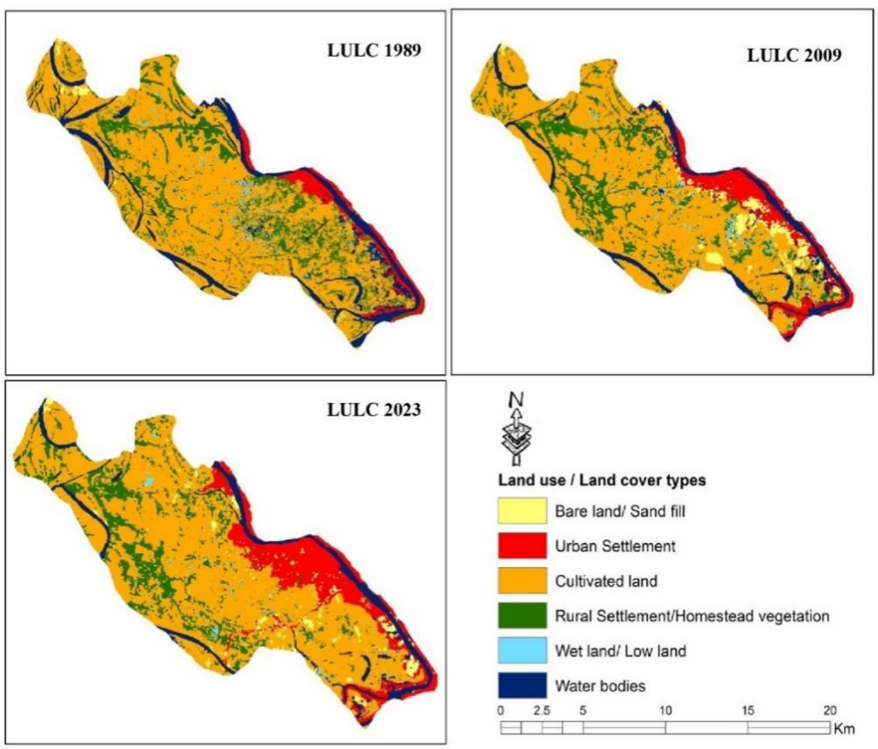


Figure 4: Land cover changes of Keraniganj Upazila (1989-2023), Source: Author, 2024

In 1989, cultivated land was the dominant land-use category, covering 12,113 ha or 64.2% of the total area. Rural settlement/homestead vegetation was the second-largest category, occupying 3,016.8 ha (16%). Urban settlements were minimal, covering only 843.8 ha due to the area's low population. Natural features, including water bodies and wetlands, were largely unaffected, with water bodies covering 2,446.2 ha and wetlands/lowlands accounting for 320.6 ha. Bare land was the least significant, covering only 125.8 ha. By 2009, cultivated land decreased slightly to 11,531 ha but remained the largest category. Rural settlement/homestead vegetation also declined, reaching 2,833.8 ha. Urban settlements expanded significantly to 1,696.9 ha, reflecting rapid urbanization. Bare land increased sharply to 838.4 ha, while wetlands/lowlands reduced to 297.2 ha.

In 2023, urban settlements reached 2,582.4 ha, marking the highest recorded growth. Rural settlement/homestead vegetation declined further to 2,536.3 ha. Wetlands/lowlands experienced the steepest decline, dropping to 153.9 ha. Water bodies also decreased, covering 1,358.4 ha, while bare land reduced to 598.8 ha. These changes reflect the ongoing impact of urbanization on Keraniganj's natural and rural landscapes.

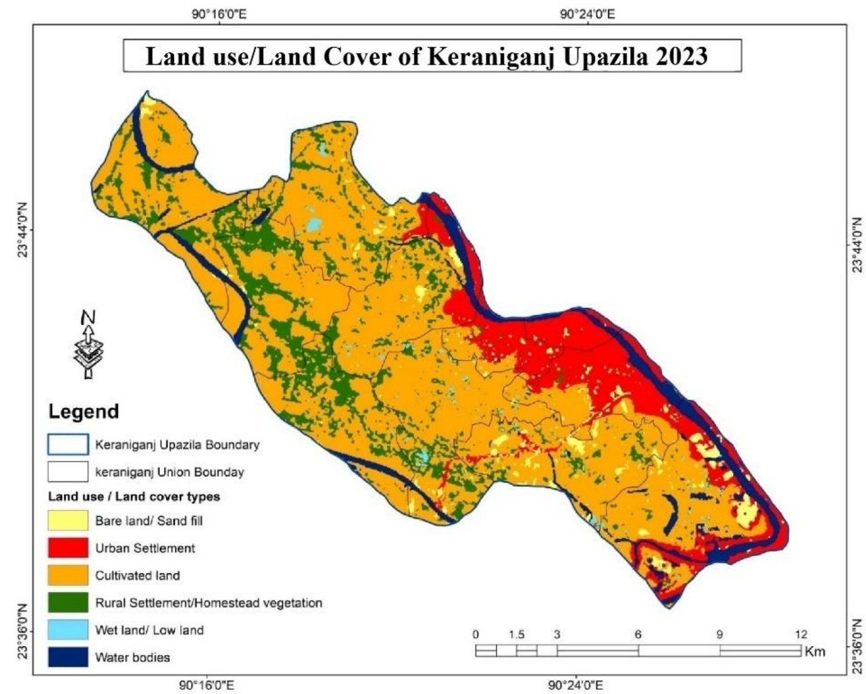


Figure 5: Classified Land Cover Image of Keraniganj Upazila Derived from the 2023 Landsat ETM+ Image, Source: Author, 2024

The map illustrates various land cover types in the upazila, categorizing them into six types: bare land/sand fill, urban settlements, cultivated land, rural settlement/homestead vegetation, wetlands/lowlands, and water bodies. Cultivated land, shown in orange, dominates the central and southern regions, emphasizing the area's agricultural prominence. Urban settlements, marked in red, are concentrated near the northeastern boundary, reflecting significant expansion near Dhaka metropolitan. Bare land/sand fill, represented in yellow, is scattered, particularly near urban settlements, indicating transitional areas under development. Rural settlement/homestead vegetation, depicted in green, is distributed widely but shows a gradual decline due to advancing urbanization. Wetlands/lowlands, shaded light blue, are primarily located in the southern regions but have been significantly reduced over time. Water bodies, marked in dark blue, are concentrated along rivers like the Buriganga and scattered across the upazila, highlighting the role of waterways in shaping the area. The map reveals a clear trend of land conversion, with cultivated land and rural settlements increasingly replaced by urban settlements. This change underscores the growing pressure of urbanization on traditional land use and natural ecosystems. The proximity to Dhaka and increasing development activities contribute significantly to these transformations.

Analysis of the study area indicates a rapid increase in urban settlements over three decades. In 1989, urban settlements covered 843.8 hectares, doubling to 1,696.9 hectares in 2009 and expanding to 2,582.8 hectares by 2023. The highest growth rate occurred between 2009 and 2023, driven by improved transportation, economic growth, and technological advancements. Despite this, cultivated land remained the largest land cover type throughout the study, accounting for 64.2% in 1989, decreasing slightly to 61.1% by 2009, and remaining stable until 2023.

Water bodies consistently declined, covering 2,446.2 hectares in 1989, decreasing to 1,669.3 hectares in 2009, and further to 1,358.4 hectares by 2023. Wetlands/lowlands also declined, dropping from 1.7% in 1989 to 0.8% in 2023. Rural settlements, encompassing katcha and semi-pucca households with planted vegetation, decreased from 3,016.8 hectares in 1989 to 2,833.8 hectares in 2009 and 2,536.3 hectares in 2023. Bare land/sand fill exhibited unstable patterns, expanding from 125.8 hectares in 1989 to 838.4 hectares in 2009 but decreasing to 598.8 hectares by 2023. These changes reflect the dynamic nature of land-use transformation, emphasizing urbanization's impact on natural and rural landscapes. Sustainable planning is essential to balance urban growth with agricultural and ecological conservation.

Table 3:Summary of LULC Statistics

Land Cover Types	1989		2009		2023	
	Area(Ha)	Percentage (%)	Area(Ha)	Percentage (%)	Area(Ha)	Percentage (%)
Bare land/ Sand fill	125.8	0.7	838.4	4.4	598.8	3.2
Urban Settlement	843.8	4.5	1696.9	9.0	2582.4	13.7
Cultivated Land	12113.6	64.2	11531.0	61.1	11637.2	61.7
Rural settlement/ Homestead Vegetation	3016.8	16.0	2833.8	15.0	2536.3	13.4
Water bodies	2446.2	13.0	1669.3	8.8	1358.4	7.2
Wet lands/ Low lands	320.6	1.7	297.2	1.6	153.9	0.8
Total	18866.6	100.0	18866.6	100.0	18866.9	100.0

*(**Source:** Author, 2024)*

The table highlights significant land-use changes in Keraniganj Upazila between 1989, 2009, and 2023. Bare land/sand fill increased from 125.8 ha (0.7%) in 1989 to 838.4 ha (4.4%) in 2009 due to urbanization but declined to 598.8 ha (3.2%) by 2023 as it transitioned into urban areas. Urban settlements expanded rapidly, growing from 843.8 ha (4.5%) in 1989 to 1,696.9 ha (9.0%) in 2009 and 2,582.4 ha (13.7%) by 2023, reflecting intensified development. Cultivated land remained the dominant land cover, declining from 12,113.6 ha (64.2%) in 1989 to 11,531.0 ha (61.1%) in 2009, with a slight increase to 11,637.2 ha (61.7%) in 2023, likely due to conversions. Rural settlements decreased consistently, from 3,016.8 ha (16.0%) in 1989 to 2,833.8 ha (15.0%) in 2009 and 2,536.3 ha (13.4%) in 2023, driven by urban expansion. Water bodies showed a marked reduction, declining from 2,446.2 ha (13.0%) in 1989 to 1,669.3 ha (8.8%) in 2009 and 1,358.4 ha (7.2%) in 2023, largely due to land reclamation. Wetlands/lowlands also decreased, from 320.6 ha (1.7%) in 1989 to 297.2 ha (1.6%) in 2009 and 153.9 ha (0.8%) in 2023, reflecting critical ecological losses. Urban growth came at the expense of natural and rural areas, highlighting the need for sustainable practices to balance development with resource conservation.

Table 2:Land cover change matrix (1989-2009)

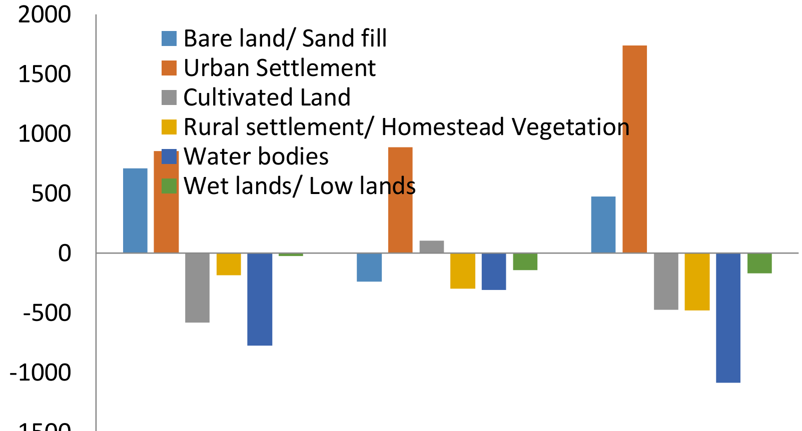
		LULC 2009						
		Bare land/ Sand fill	Urban Settlemen t	cultivated Land	Rural settlement/ Homestead Vegetation	Water bodies	Wet lands/ Low lands	Total
		Area(ha)	Area(ha)	Area(ha)	Area(ha)	Area(ha)	Area(ha)	
LULC 1989	Bare land/ Sand fill	10.8	5.0	93.9	3.7	6.0	0.4	119.9
	Urban Settlement	44.8	742.3	18.1	0.8	36.0	0.5	842.6
	cultivated Land	527.8	489.9	9503.0	1276.0	305.7	133.9	12236.4
	Rural settlement/ Homestead Vegetation	93.0	239.7	1088.8	1392.8	45.8	58.2	2918.3
	Water bodies	131.8	205.8	680.8	98.5	1259.4	54.3	2430.5
	Wet lands/ Low lands	19.9	14.0	188.5	27.8	11.8	39.4	301.3
	Total	828.1	1696.8	11573.1	2799.5	1664.7	286.7	18848.8

Table 5: Land cover change matrix (2009-2023)

		LULC 2023						
		Bare land/ Sand fill	Urban Settlement	cultivated Land	Rural settlement/ Homestead Vegetation	Water bodies	Wet lands/ Low lands	Total
		Area(ha)	Area(ha)	Area(ha)	Area(ha)	Area(ha)	Area(ha)	
LULC 2009	Bare land/ Sand fill	122.2	376.1	319.4	5.5	4.5	0.1	827.9
	Urban Settlement	94.3	1444.5	88.1	4.5	63.4	2.2	1697.0
	Cultivated Land	269.1	560.4	9732.2	795.5	133.3	82.4	11572.9
	Rural settlement/ Homestead Vegetation	15.6	86.0	1030.6	1641.9	11.2	14.5	2799.7
	Water bodies	63.6	100.1	310.1	25.8	1139.0	25.9	1664.5
	Wet lands/ Low lands	12.7	19.6	204.5	23.4	5.6	20.8	286.7
	Total	577.5	2586.6	11684.9	2496.6	1357.1	146.0	18848.7

The Land Cover Change Matrix (1989–2009) reveals significant transformations in land use in Keraniganj Upazila over 20 years. Bare land/sand fill, covering 119.9 ha in 1989, mostly transitioned to cultivated land (93.9 ha), while 10.8 ha remained unchanged. Urban settlements expanded to 842.6 ha by 2009, with contributions from cultivated land (44.8 ha), bare land (18.1 ha), and earlier urban areas (742.3 ha).Cultivated land, the largest category in 1989 at 12,236.4 ha, retained 9,503.0 ha but saw major losses. It contributed 527.8 ha to bare land, 489.9 ha to urban settlements, and 1,276.0 ha to rural settlements, reflecting urbanization trends. Rural settlements increased to 2,799.5 ha, largely gaining land from cultivated areas (1,088.8 ha) while retaining 1,392.8 ha from 1989.Water bodies retained 1,259.4 ha in 2009, gaining contributions from cultivated land (680.8 ha) and rural settlements (98.5 ha). Wetlands remained relatively stable, with 301.3 ha in 2009 compared to 286.7 ha in 1989, although they experienced slight losses to other land uses. Urban settlements experienced the most growth, fueled by conversions from cultivated land and bare areas. Rural settlements expanded significantly, driven by population growth and agricultural land conversions, but this contributed to declining wetlands and water bodies. Cultivated land, while still dominant, faced consistent reductions due to urban and rural expansions. Water bodies and wetlands, although relatively stable, remain at risk, requiring conservation measures.

The Land Cover Change Matrix (2009–2023) highlights similar transformations, with bare land transitioning into urban settlements and cultivated areas. Urban settlements expanded significantly, retaining most of their previous coverage while absorbing land from bare land, cultivated land, and wetlands. Cultivated land saw a decline due to conversions into urban and rural settlements, though much of it remained stable. Water bodies experienced marked reductions as portions were converted into cultivated land and urban settlements. Wetlands also declined significantly, transitioning mainly into cultivated land and urban settlements. Urban settlements demonstrated the most rapid growth, reflecting intensified urbanization. Rural settlements retained much of their coverage but gained additional land from cultivated areas. The data shows that cultivated land continues to dominate but faces consistent pressure from urban expansion. Water bodies and wetlands are increasingly vulnerable to land-use changes, emphasizing the need for conservation. These trends underscore the rapid pace of urbanization and its environmental impacts, with significant losses in agricultural and ecological areas. The findings highlight the importance of sustainable land-use management to balance urban development with resource conservation. Integrated strategies are necessary to ensure ecological stability and sustainable growth in Keraniganj Upazila. The Land Cover Change Matrix (2009–2023) illustrates significant transformations across land-use categories. Bare land/sand fill, totaling 827.9 ha in 2009, saw major transitions, with 376.1 ha converting into urban settlements and 319.4 ha into cultivated land. Urban settlements, initially 1,697.0 ha, retained 1,444.5 ha by 2023 while absorbing portions of bare land and transitioning small areas into cultivated land and water bodies. Cultivated land, the largest category at 11,572.9 ha in 2009, retained 9,732.2 ha but saw losses to urban settlements (560.4 ha) and rural settlements (795.5 ha), with 269.1 ha becoming bare land. Rural settlements, covering 2,799.7 ha in 2009, retained 1,641.9 ha while contributing 1,030.6 ha to cultivated land and a smaller portion (86.0 ha) to urban settlements. Water bodies, initially 1,664.5 ha in 2009, reduced to 1,139.0 ha as 310.1 ha converted to cultivated land and smaller areas transitioned into urban and rural settlements. Wetlands, covering 286.7 ha in 2009, remained relatively stable, retaining 204.5 ha but losing small areas to cultivated land, urban settlements, and water bodies. These shifts underscore the pressures of urbanization and land-use changes on natural and agricultural landscapes. The spatial change analysis of land use over three time periods reveals significant transformations. Figure 6 indicates that urban areas experienced the highest growth. Between 1989 and 2009, approximately 853.11 hectares of urban settlements were added, followed by an additional 885.51 hectares between 2009 and 2023.Conversely, water bodies showed a consistent decline over the study period. Between 1989 and 2009, 776.88 hectares of water bodies were lost, with a further reduction of 310.95 hectares between 2009 and 2023.Over the 34-years period (1989–2023), cultivated land decreased by 476.46 hectares. The reduction in wetlands and rural settlements has been particularly pronounced in recent years, with 297 hectares of rural settlement/homestead vegetation and 143 hectares of wetlands/lowlands lost between 2009 and 2023. These changes highlight the growing pressures of urbanization and land-use transformations in the study area.



	Change area(Ha)(1989-2009)	Change area(Ha)(2009-2023)	Change area(Ha)(1989-2023)
Bare land/ Sand fill	712.62	-239.67	472.95
Urban Settlement	853.11	885.51	1738.62
Cultivated Land	-582.66	106.2	-476.46
Rural settlement/ Homestead Vegetation	-182.97	-297.54	-480.51
Water bodies	-776.88	-310.95	-1087.83
Wet lands/ Low lands	-23.4	-143.28	-166.68

Figure 6: Land cover changes of Keraniganj Upazila from 1989 to 2023 in hectares, Source: Author, 2024

The figure illustrates LULC changes in Keraniganj Upazila from 1989 to 2023, focusing on six categories: Bare Land, Urban Settlement, Cultivated Land, Rural Settlement, Water Bodies, and Wetlands.

Bare Land increased by 712.62 ha between 1989–2009 but decreased by 239.67 ha from 2009–2023, showing a net rise of 472.95 ha over the study period due to urbanization. Urban Settlement grew the most, expanding by 1,738.62 ha from 1989–2023, with rapid increases in both intervals. Cultivated Land declined by 582.66 ha between 1989–2009 but slightly recovered by 106.2 ha after 2009, resulting in a net loss of 476.46 ha due to urban conversion. Rural Settlement decreased consistently, with a total reduction of 480.51 ha by 2023, highlighting urban expansion impacts. Water Bodies saw the largest decline, losing 1,087.83 ha over the period due to sand filling and reclamation. Wetlands decreased by 166.68 ha, primarily during 2009–2023, reflecting their conversion to urban uses. Urban growth dominates LULC changes, while natural and rural areas face significant losses.

Changes in Bare land coverage

The spatial analysis of bare land in Keraniganj Upazila reveals an unstable pattern of change over the years. The highest concentrations of bare lands were observed in Subhadya, Kalindi, Tegharia, and Konda unions (Figure 7), which are located adjacent to Dhaka metropolitan. Between 1989 and 2009, bare land increased significantly by approximately 712 hectares. However, a reduction of 239 hectares was observed between 2009 and 2023. Despite this decline, the total amount of bare land increased by 472 hectares over the entire study period from 1989 to 2023, largely due to urbanization. The transformation of low lands, wetlands, and cultivated land into bare lands is a key factor driving this trend. These bare lands are eventually converted into urban settlements, highlighting the dynamic nature of land-use change in the study area. This pattern underscores the ongoing pressures of urban expansion and the need for sustainable land management strategies to balance development with environmental preservation.

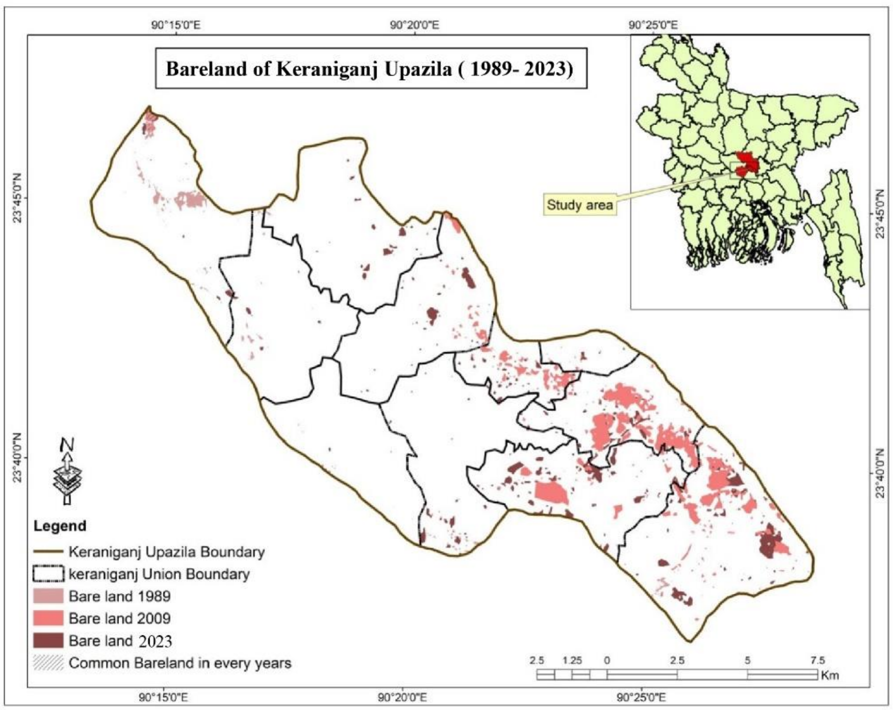


Figure 7: Spatial changes in Bare land coveragein Keraniganj Upazila from 1989 to 2023, Source: Author, 2024

The map "Bare Land of Keraniganj Upazila (1989–2023)" shows changes in bare land over 28 years, highlighting coverage for 1989, 2009, and 2023. Bare land is concentrated in Subhadya, Kalindi, Tegharia, and Konda unions near Dhaka, driven by urbanization and land-use transformations. In 1989, bare land was limited but expanded significantly by 2009, especially near urban areas, before reducing slightly by 2023 while remaining higher than 1989 levels. Between 1989 and 2009, bare land grew by 712 hectares due to the conversion of wetlands and lowlands. From 2009 to 2023, 239 hectares of bare land transitioned into urban settlements, resulting in a net increase of 472 hectares over the study period. Some areas consistently remained bare land, reflecting stable but transitional zones for future development. The expansion of bare land is linked to urban growth and infrastructure development, often acting as a precursor to settlements. This trend highlights the need for sustainable planning to balance development with environmental conservation and minimize impacts on vegetation, biodiversity, and the local climate.

Changes in Cultivated land Coverage

The dominant LULC category in the study area is cultivated land, which is present in all unions of Keraniganj Upazila. However, the extent of cultivated land has been decreasing due to settlement expansion. Spatial analysis reveals a significant reduction in cultivated land across the unions, particularly those near Dhaka metropolitan (Figure 8). Between 1989 and 2009, approximately 582.66 hectares of cultivated land were lost (Figure 6), primarily due to the increasing pressure from urban settlements. Interestingly, the analysis indicates a marginal increase in cultivated land between 2009 and 2023. This increase can be attributed to the conversion of bare lands and homestead vegetation into cultivated land. While settlement expansion remains a challenge, this slight recovery highlights the adaptability of land-use practices in response to population and economic demands.

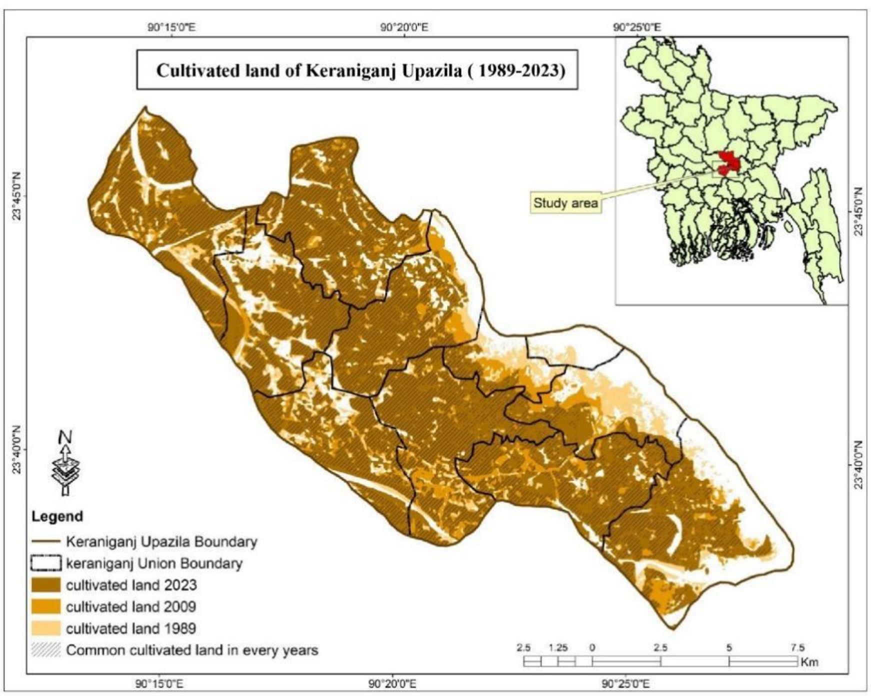


Figure 8: Spatial changes in Cultivated land coveragein Keraniganj Upazila from 1989 to 2023, Source: Author, 2024

The map "Cultivated Land of Keraniganj Upazila (1989–2023)" shows the spatial distribution and changes in cultivated land over 34 years. Cultivated land, the dominant category in 1989, significantly reduced by 2009 due to urban expansion, particularly near Dhaka, but showed a slight recovery by 2023 in southern and central areas. The map uses dark brown to depict the extensive coverage in 1989, medium brown for the reduced coverage in 2009, and light brown for the marginal increase in 2023. Crosshatched areas highlight regions consistently used for cultivation, indicating stable agricultural practices. The primary drivers of change are urban settlement expansion and land conversion for housing and infrastructure. A small recovery of cultivated land from 2009 to 2023 came from converting bare lands and vegetation back into agriculture. The loss of cultivated land affects food production and livelihoods, underscoring the need for sustainable land management. The map highlights the need to balance urban growth with preserving cultivated land to ensure food security and sustainable development. Policies should prioritize protecting high-value agricultural land from urban encroachment while promoting efficient land-use practices. The marginal recovery of cultivated land between 2009 and 2023 demonstrates the potential for adaptive strategies to mitigate urbanization impacts and guide sustainable planning.

Changes in Rural Settlement Coverage

The category of rural settlements primarily includes homestead vegetation. Population growth has driven the need for new settlements, leading to a reduction in homestead vegetation, which has often been converted into cultivated land. Spatial analysis reveals that while rural and homestead vegetation was abundant in 1989, it has significantly declined over a relatively short period. Between 1989 and 2023, approximately 480 hectares of rural settlements or homestead vegetation were lost (Figure 9). Of this, about 182 hectares were lost between 1989 and 2009, and an additional 297 hectares were reduced between 2009 and 2023 (Figure 6).

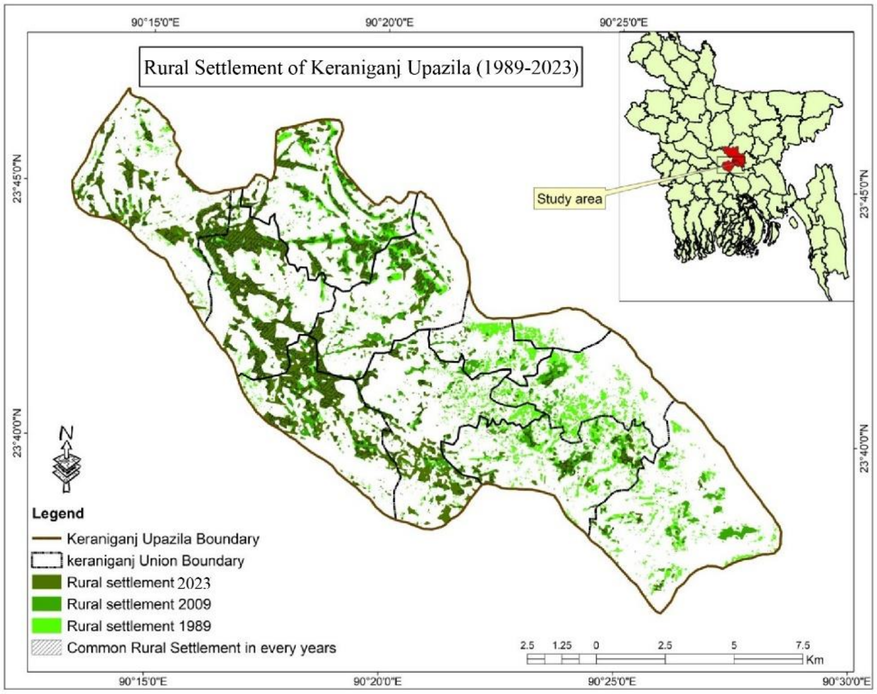


Figure 9: Spatial changes in Rural Settlement coverage in Keraniganj Upazila from 1989 to 2023, Source: Author, 2024

The map titled "Rural Settlement of Keraniganj Upazila (1989–2023)" illustrates the spatial distribution and changes in rural settlements over 34 years, focusing on homestead vegetation. It highlights coverage in 1989, 2009, and 2023, alongside areas where rural settlements persisted throughout the period. In 1989, rural settlements were widespread across central and peripheral areas of Keraniganj. By 2009, a decline became evident, particularly near urbanized zones, and by 2023, coverage had further reduced due to urban expansion and other land-use changes. The map uses dark green to represent extensive rural settlements in 1989, medium green for the reduced coverage in 2009, and light green for the significantly declined areas in 2023.Crosshatched areas indicate regions where rural settlements have persisted, often located in less urbanized or agriculturally dominant zones. The decline is driven by population growth, urbanization, and economic development, with rural settlements transitioning into urban areas or cultivated land. Approximately 480 hectares of rural settlements were lost between 1989 and 2023.This transformation has environmental implications, including reduced green cover, biodiversity loss, and changes in the local microclimate. Socially, it reflects the shift of rural communities adapting to urbanization and economic pressures. The map emphasizes the need for sustainable land-use planning to balance urban growth with rural preservation and maintain ecological and cultural heritage. It serves as a crucial tool for guiding sustainable development in Keraniganj Upazila.

Changes in Urban Settlement Coverage

As Keraniganj Upazila is situated adjacent to Dhaka metropolitan, significant urban settlement expansion has been observed in Zinjira, Kalindi, Subhadya, and Konda unions. Over the 34-year period, a consistent increase in urban settlements has been documented, with the majority of this growth concentrated in Zinjira, Kalindi, and Subhadya (Figure 10). Being close to Dhaka and well-connected via multiple bridges over the Buriganga River, urban expansion in the study area is primarily directed towards the south.

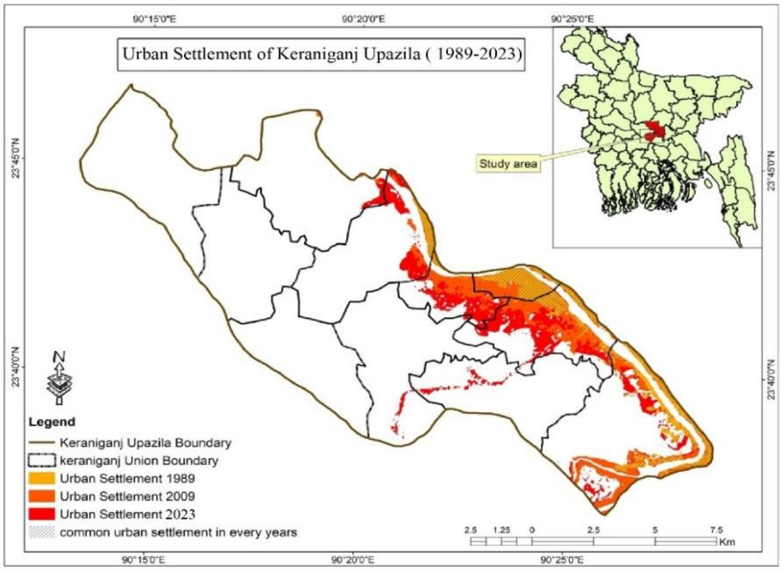


Figure 10: Spatial Changes in Urban Settlement Coverage in Keraniganj Upazila from 1989 to 2023, Source: Author, 2024

Between 1989 and 2023, approximately 472 hectares of new urban settlements were added. The increase in urban settlements was particularly notable during two periods: from 1989 to 2009, 853 hectares were added, while between 2009 and 2023, the expansion rate accelerated significantly, adding 885 hectares (Figure 6). Spatial analysis also revealed the conversion of bare land and rural settlements into urban areas, further illustrating the dynamic transformation of land use in Keraniganj Upazila.

The map titled "Urban Settlement of Keraniganj Upazila (1989–2023)" depicts the spatial expansion of urban areas over 34 years. It shows urban settlement coverage in 1989, 2009, and 2023, along with areas that remained urbanized throughout the study period. Urban settlements were initially concentrated in the northern and northeastern parts near Dhaka metropolitan, with limited coverage in 1989 (orange areas). By 2009 (red areas), significant growth occurred along the northern boundary and the Buriganga River. By 2023 (dark red areas), urban settlements expanded further southward, showing intensified growth across the upazila. Crosshatched areas highlight zones that remained urban settlements throughout, reflecting sustained urbanization near Dhaka and along the Buriganga River. Key drivers of this growth include proximity to Dhaka, economic activities, and infrastructure improvements, such as bridges and better transportation networks. Land-use transformation over the period shows the conversion of rural settlements, bare lands, and agricultural areas into urban settlements, with rapid expansion especially from

2009 to 2023. This urbanization has environmental implications, including loss of agricultural land, reduced water retention, and increased resource pressure.

The map underscores the need for comprehensive urban planning to balance growth with the preservation of ecological resources. It serves as a critical tool for policymakers to guide sustainable urban development and mitigate environmental impacts in Keraniganj Upazila.

Change in waterbodies

The study area is characterized by three main rivers: the Buriganga, Dhaleshwari, and Ichamati. The Buriganga River separates Keraniganj Upazila from Dhaka metropolitan (Figure 11). Among the various LULC categories, water bodies have experienced the most significant reduction. Over the 34-year study period, approximately 1,087 hectares of water bodies have been lost (Figure 6). The primary drivers of this reduction are sand filling and the establishment of new settlements. Between 1989 and 2009, around 776 hectares of water bodies were lost, while an additional 310 hectares were reduced between 2009 and 2023.

The map titled "Water Bodies of Keraniganj Upazila (1989–2023)" illustrates the spatial distribution and changes in water bodies over 34 years. Water bodies are primarily concentrated along the Buriganga, Dhaleshwari, and Ichamati rivers, with smaller scattered water bodies distributed across the upazila. Over time, there has been a significant reduction in water body coverage, particularly in smaller and scattered areas. In 1989, the light blue areas on the map represent extensive water bodies. By 2009, the medium blue areas show noticeable shrinkage, especially in smaller water bodies. The decline continued in 2023, with dark blue areas indicating further reduction. Crosshatched regions highlight water bodies that have remained consistent, mainly along the primary rivers, reflecting their resilience to land-use changes. The reduction in water bodies is driven by sand filling, urban expansion, and the development of new settlements. These activities have transformed many water bodies into land for construction or agriculture. This loss reduces water retention capacity, increases flooding risks, and negatively impacts aquatic ecosystems and groundwater recharge.

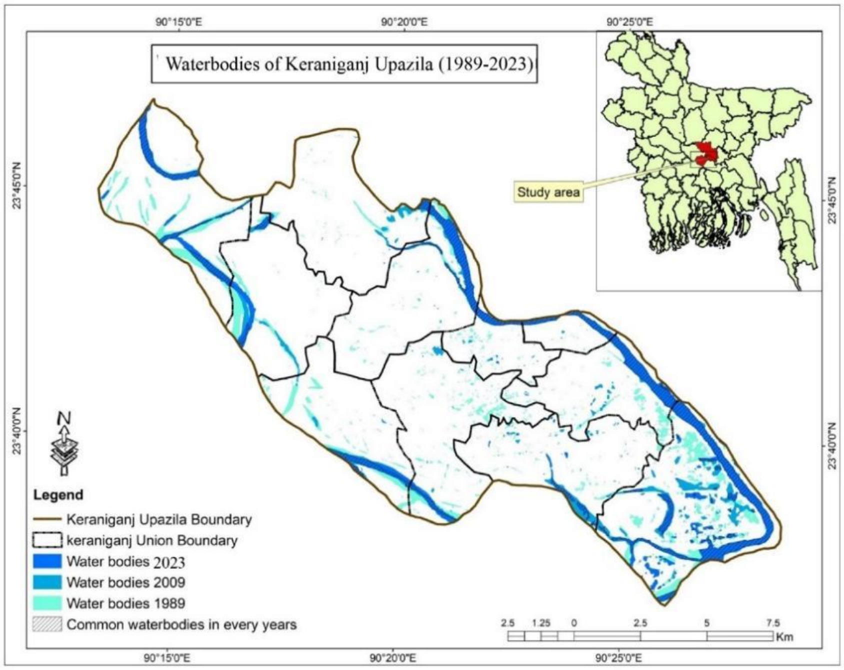


Figure 11: Spatial change in Water bodies cover of Keraniganj Upazila from 1989 to 2023, Source: Author, 2024

The map underscores the need for sustainable water resource management to balance urban growth with ecological conservation. Protecting remaining water bodies, especially along major rivers, is critical for maintaining ecological balance and reducing environmental degradation. It serves as a valuable tool for guiding sustainable planning and addressing the environmental challenges of urbanization in Keraniganj Upazila.

Changes in wetlands

The wetland/lowland category is distributed across all unions of Keraniganj Upazila, as depicted in Figure 12. Analysis reveals a continuous decline in these areas over time. Between 1989 and 2009, approximately 23.4 hectares of wetlands were lost, primarily due to sand filling and the establishment of new settlements. The rate of wetland reduction has significantly accelerated in recent years, with approximately 144 hectares of wetlands/lowlands disappearing between 2009 and 2023 (Figure 6).

The figure illustrates the spatial distribution and changes in wetlands in Keraniganj Upazila from 1989 to 2023, showing a significant decline in wetland coverage over nearly three decades. Wetlands were more widespread in 1989, particularly in certain regions, but by 2023, many had been significantly reduced, with only some areas retaining their original state. Crosshatched zones on the map highlight consistent wetlands, representing ecologically resilient areas or those less affected by human activities. The decline in wetlands is driven by urbanization, population growth, and land reclamation for settlements, agriculture, and infrastructure. Wetland reductions are more prominent near urbanized zones and high-density settlements, while peripheral regions retain more wetlands. This loss has reduced water retention capacity, increasing flooding risks, and has negatively impacted biodiversity, groundwater recharge, and local climate regulation.

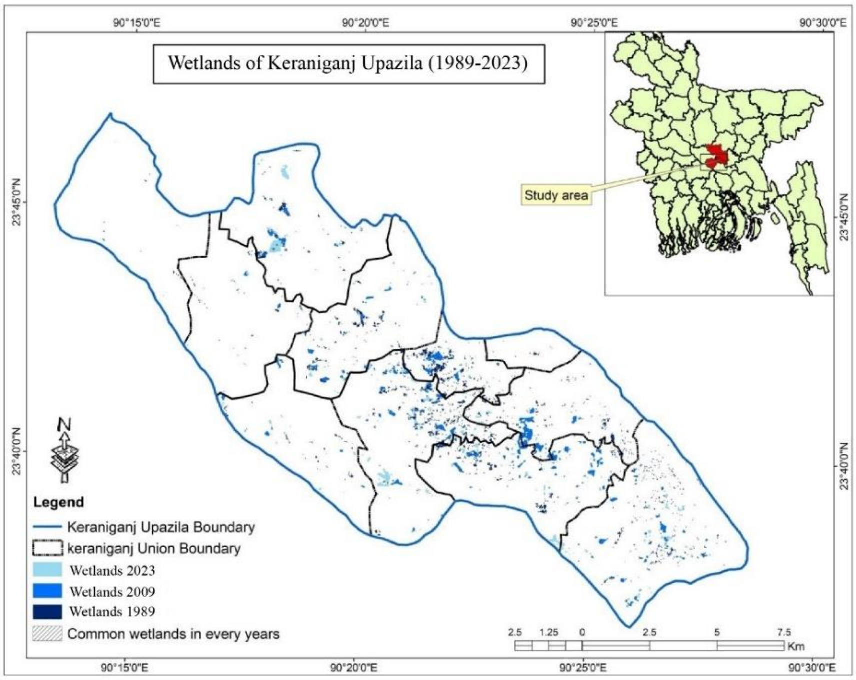


Figure 12: Spatial change in Wet lands cover of Keraniganj Upazila from 1989 to 2023, Source: Author, 2024

To mitigate these impacts, wetland conservation efforts should focus on protecting and restoring remaining areas. Integrated urban planning must prioritize wetland preservation alongside development. Promoting sustainable practices and community engagement is critical to reducing wetland loss and ensuring ecological balance. The map underscores the urgent need for conservation and sustainable planning in Keraniganj Upazila.

Table 3: Households number and population of Keraniganj Upazila in 1991, 2001, 2011 and 2022

	1991		2001		2011		2022	
Union	**Household**	**Population**	**Household**	**Population**	**Household**	**Population**	**household**	**Population**
Basta	4421	27741	5312	28721	7150	34181	10019	38895
Hazratpur	4727	25401	5554	26536	7488	33069	9914	39893
Kalatia	5790	29913	6640	32143	9016	40007	13221	47012
Kalindi	4823	3811	6694	35363	10251	46783	14886	54665
Konda	7942	55666	10063	50074	13887	67204	18104	73932
Ruhitpur	4081	24612	5406	28253	7172	31563	11163	43755

Sakta	6617	38764	8471	43240	12828	58075	22702	90511
Subhadya	26519	134438	32260	146379	52487	225865	79388	288360
Taranagar	5615	31218	6855	33355	9465	42203	14972	59419
Tegharia	4633	28290	6011	31444	7189	32416	14900	70102
Zinjira	19597	106426	18946	88572	25490	109982	33621	124780

Source: Population and Housing Census 1991, 2001, 2011 and 2022of BBS (Community Report, Dhaka)

The table titled "Households Number and Population of Keraniganj Upazila in 1991, 2001, 2011, and 2022" highlights household and population growth trends over four decades. Data from the Population and Housing Census shows a consistent increase in households across all unions, with Subhadya growing from 26,519 households in 1991 to 79,388 in 2022. Smaller unions like Basta and Hazratpur also experienced significant growth, with household numbers nearly doubling during this period. Population growth has mirrored these trends, with Subhadya's population rising from 134,438 in 1991 to 288,360 in 2022, making it the most densely populated union. Other unions, including Zinjira and Konda, also showed notable growth, reaching populations of 124,780 and 73,932, respectively, by 2022. The rapid rise in households and population reflects ongoing urban sprawl, driven by Keraniganj's proximity to Dhaka, lower living costs, and improved connectivity. Unions like Kalindi and Sakta nearly doubled their populations, while smaller unions like Taranagar and Tegharia saw slower but consistent growth. Between 1991 and 2001, growth was steady, but it accelerated between 2001 and 2022, suggesting increased migration and urban development. Urban settlements have expanded significantly over the last two decades, as reflected in the sharp rise in household numbers.

This rapid urbanization underscores the need for urban planning to manage housing, infrastructure, and public services. Environmental considerations are crucial to mitigate the impact of population growth on land use and resources. Sustainable development strategies will be essential to accommodate future growth while preserving local ecosystems. The table provides valuable insights for guiding urban and regional planning in Keraniganj Upazila.

Analysis of LULC Impacts in the Light of Central Place Theory

The land use and land cover (LULC) changes observed in Keraniganj Upazila over the 34-year period (1989–2023) reflect a classic manifestation of Central Place Theory (CPT), which explains the spatial interaction between a dominant urban core and its surrounding hinterlands. Dhaka City, as the central place, has exerted strong functional and spatial *influence* over Keraniganj, leading to significant urban expansion and land transformation in the peripheral areas. Studies show that improved connectivity—particularly through bridge construction and road development between 1975 and 1992—facilitated urban sprawl into neighboring upazilas like Keraniganj, with notable growth spreading northward, southward, northwest, and westward (Moniruzzaman *et al.*, 2021; Zaman, 2010).

Urban settlement in Keraniganj has increased dramatically, growing by approximately 1,738.62 hectares—an estimated 412% increase from its 1989 baseline. This transformation is particularly pronounced between 2009 and 2023, during which 885.51 hectares were added, accounting for 50.9% of the total urban growth. This spatial expansion of urban land is directly aligned with CPT's prediction that higher-order central places (such as Dhaka) attract economic activities and population, thereby inducing land conversion in adjacent lower-order centers. As Keraniganj became more integrated into the metropolitan transport and economic network, land values surged, and natural or rural lands were systematically converted into urban use. One of the most alarming consequences of this urban growth is the extensive loss of agricultural land. Cultivated land declined by 476.46 hectares, representing an estimated 17% reduction relative to its original extent. While a marginal recovery of 106.2 hectares was observed between 2009 and 2023 due to temporary land-use shifts, this does not offset the long-term pressure on agricultural productivity. This aligns with CPT's implication that peripheral areas become increasingly dependent on the central place for both economic sustenance and governance, leading to a loss of self-sufficiency in food production and rural livelihoods.

The most critical ecological losses are evident in the reduction of water bodies and wetlands. Water bodies declined by 1,087.83 hectares—over 60% of the baseline—due to sand filling and unauthorized settlement expansion. Wetlands declined by an additional 166.68 hectares, with nearly 86% of that reduction occurring after 2009. These changes reflect the rapid encroachment of ecological lands under the pressure of real estate development and infrastructural expansion. Central Place Theory accounts for such outcomes by suggesting that as peripheral zones become more integrated with urban cores, environmental trade-offs are increasingly accepted in favor of economic growth. However, the consequences in this case are severe, including increased flooding risks, reduced groundwater recharge, and loss of aquatic biodiversity. The decline of rural settlements and homestead vegetation by 480.51 hectares—61.9% of which occurred post-2009—illustrates the sociocultural impact of LULC changes. As predicted by CPT, smaller rural communities near a dominant urban center become absorbed into the expanding urban structure, resulting in the erosion of traditional livelihoods and rural heritage. Homestead vegetation, which provides ecological stability and social continuity in rural landscapes, has been increasingly replaced by high-density housing and commercial structures, leading to a fragmented and homogenized urban fringe.

Another indicator of transitional instability is the increase in bare land by 472.95 hectares. While such lands initially appear as unused or degraded, spatial analysis reveals they often serve as speculative land banks, temporarily held before being converted to urban infrastructure. The temporal shift—an increase of 712.62 hectares from 1989 to 2009 followed by a decrease of 239.67 hectares from 2009 to 2023—suggests that bare lands are a precursor to eventual urbanization. CPT supports this notion by explaining that the spatial gradient around central places facilitates staggered phases of land development, moving from agricultural to transitional to urban states. In summary, the LULC changes in Keraniganj Upazila illustrate a spatial transformation deeply rooted in the dynamics of Central Place Theory. Dhaka's gravitational pull has restructured land use patterns in Keraniganj, favoring urban development while marginalizing agricultural, ecological, and rural systems. This has resulted in environmental degradation, socio-economic displacement, and a growing imbalance in spatial equity. These findings underscore the urgent need for integrated land-use planning that aligns urban growth with ecological sustainability and rural resilience. Without strategic interventions, the unchecked centralizing influence of Dhaka may continue to undermine the environmental and socio-cultural integrity of its surrounding regions.

Conclusion

This study comprehensively analyzed the dynamics of land use and land cover (LULC) changes in Keraniganj Upazila over a 34-year period (1989–2023) using remote sensing (RS), geographic information systems (GIS), and socio-economic data. The findings revealed significant transformations in LULC patterns, primarily driven by the rapid urban expansion emanating from Dhaka city. Proximity to the metropolitan center, enhanced transportation networks, and lower living costs have catalyzed this urbanization process. Urban settlements exhibited the highest rate of expansion, increasing by 49.07%between 1989 and 2009 and a further 50.93%from 2009 to 2023. This urban growth has largely occurred at the expense of cultivated land, rural homestead vegetation, water bodies, and wetlands, reflecting the pressures of unplanned urbanization. Over the study period, cultivated land and rural settlements decreased by 10.77% and 10.86%, respectively, while water bodies experienced a net loss of 24.59%, and wetlands declined by 3.77%. These changes were primarily driven by the conversion of lowlands and natural features into bare lands, which were subsequently transformed into urban settlements. The study highlights the environmental consequences of rapid urbanization, including biodiversity loss, habitat destruction, reduced agricultural productivity, and potential climate risks such as increased flooding. The widespread filling of lowlands and wetlands has further exacerbated these challenges, leading to disruptions in local ecosystems and water management systems. By employing a combination of GIS and RS technologies alongside socio-economic data, the research effectively captured the spatial and temporal dynamics of LULC changes. This approach provided valuable insights into the drivers of urban expansion, including population growth, rural-urban migration, and economic development. The findings underscore the critical need for sustainable urban planning and management strategies to address the adverse effects of urbanization while accommodating future growth.

To mitigate the environmental and social impacts of LULC changes, policymakers and planners must focus on integrating sustainable practices, preserving agricultural land, and protecting natural resources. Strategic interventions are essential to balance urban expansion with ecological conservation and to ensure resilient and inclusive development in Keraniganj Upazila. The study offers a robust framework for guiding urban planning efforts not only in Bangladesh but also in similar urbanizing regions worldwide, where rapid land-use changes pose significant challenges to sustainability.

References

Abd El-Kawy, O. R., Abou El-Magd, I., Abd El-Ghani, M., and El-Hadidi, H. (2011). Land use and land cover change detection in the western Nile Delta of Egypt using remote sensing data. *Applied Geography,* 31(2), 483–494.

Agarwal, C., Green, G. M., Grove, J. M., Evans, T. P., and Schweik, C. M. (2002). A Review and assessment of land-use change models: Dynamics of Space, time and human choice. Center for the Study of Institutions, Population, and Environmental Change, USDA Forest Service Northeastern Forest Research Station, USA, pp: 1–62.

Ahmad, N. (2005). Determining landlessness in rural Bangladesh. Dhaka: University Press Limited.

Alphan, H. (2003). Land use change and urbanization in Adana, Turkey. Land Degradation and Development, 14(6), 575–586.

Anees, M. M., Mann, D., Sharma, M., Banzhaf, E., and Joshi, P. K. (2020). Assessment of urban dynamics to understand spatiotemporal differentiation at various scales using remote sensing and geospatial tools. *Remote Sensing*, *12*(8), 1306. https://doi.org/10.3390/rs12081306

Ashwini, K., Sil, B. S., Kafy, A. A., Altuwaijri, H. A., Nath, H., and Rahaman, Z. A. (2024). Harnessing Machine Learning Algorithms to Model the Association between Land Use/land cover change and heatwave dynamics for enhanced environmental management. *Land*, *13*(8), 1273. https://doi.org/10.3390/land13081273

Arshad, Z., Robaina, M., Shahbaz, M., and others. (2020). The effects of deforestation and urbanization on sustainable growth in Asian countries. *Environmental Science and Pollution Research, 27*(7), 10065–10086. https://doi.org/10.1007/s11356-019-07507-7

Bangladesh Bureau of Statistics (BBS). (2022). Population and Housing Census: Community Report, Dhaka: Ministry of Planning.

Bannari, A., and Al-Ali, Z. M. (2020). Assessing climate change impact on soil salinity dynamics between 1987–2017 in arid landscape using Landsat TM, ETM+ and OLI data. *Remote Sensing, 12*(17), 2794. https://doi.org/10.3390/rs12172794

Boakye, E., Odai, N., Adjei, A., and Annor, O. (2008). Landsat images for assessment of the impact of land use and land cover changes on the Barekese Catchment in Ghana. European Journal of Scientific Research 22: 269–278.

Bolstad, P. V., and Lillesand, T. D. (1991). Rapid Maximum Likelihood classification. Photogrammetric Engineering and Remote Sensing, 57, 67–74.

Bununu, Y.A., Bello, A., and Ahmed, A. (2023). Land cover, land use, climate change and food security. *Sustain Earth Reviews* 6, 16, https://doi.org/10.1186/s42055-023-00065-4

Campbell, J.B. (2007). Introduction to Remote Sensing, Fourth edition, The Guilford Press, New York, USA.

Carlson,T.N., and Azofeifa, S.G.A. (1999). Satellite remote sensing of land use changes in and around SanJose´, Costa Rica. Remote Sensing of Environment, 70, 247–256.

Cengiz, S., Görmüş, S., and Oğuz, D. (2022). Analysis of the urban growth pattern through spatial metrics: Ankara City. *Land Use Policy, 112*, 105812. https://doi.org/10.1016/j.landusepol.2021.105812

Chander, G., Markham, B. L., and Helder, D. L. (2009). Summary of current radiometric calibration coefficients for Landsat MSS, TM, ETM+, and EO-1 ALI sensors. Remote Sensing of Environment 113: 893–903.

Chatrabhuj, Meshram, K., Mishra, U., and Omar, P. J. (2024). Integration of remote sensing data and GIS technologies in river management system. *Discover Geoscience, 2*, Article 67. https://doi.org/10.1007/s44253-024-00067-8

Chowdhury, T. A., and Islam, M. S. (2022). Assessing and Simulating Impacts of Land Use Land Cover Changes on Land Surface Temperature in Mymensingh City, Bangladesh. *Environment and Natural Resources Journal*, 20(2), 110–128. https://doi.org/10.32526/ennrj/20/202100110

Congalton, R. G., and Green, K. (1999). Assessing the Accuracy of Remotely Sensed Data: Principles and Practices. CRC Press, Taylor and Francis Group, Boca Raton, FL, 159–171.

Datta, U. S. (2020). *Developing a biophilic city through natural land transformation analysis and geodesign: The case of Purbachal New Town, Bangladesh* (Publication No. 28187418) [Doctoral dissertation, West Virginia University]. ProQuest Dissertations and Theses Global.

Das, S., Choudhury, M. R., Chatterjee, B., Das, P., Bagri, S., Paul, D., Bera, M., and Dutta, S. (2024). Unraveling the urban climate crisis: Exploring the nexus of urbanization, climate change, and their impacts on the environment and human well-being – A global perspective. *AIMS Public Health, 11*(3), 963–1001. https://doi.org/10.3934/publichealth.2024050

Demers, M. N. (2005). Fundamentals of Geographic Information Systems, John Wiley and ons, Inc., Newyork, USA,**.**

Desta, H., and Fetene, A. (2020). Land-use and land-cover change in Lake Ziway watershed of the Ethiopian Central Rift Valley Region and its environmental impacts. *Land Use Policy*, *96*, 104682. https://doi.org/10.1016/j.landusepol.2020.104682

Demarquet, Q., Rapinel, S., Dufour, S., and Hubert-Moy, L. (2023). Long-Term Wetland Monitoring Using the Landsat Archive: A Review. *Remote Sensing*, *15*(3), 820. https://doi.org/10.3390/rs15030820

Dewan, M. A., and Yamaguchi, Y. (2009). Land use and land cover change in Greater Dhaka, Bangladesh: Using remote sensing to promote sustainable urbanization. *Applied Geography* 29 (2009) 390–401. doi:10.1016/j.apgeog.2008.12.005

Dewan, M. A., and Yamaguchi, Y. (2009). Using remote sensing and GIS to detect and monitor land use and land cover change in Dhaka Metropolitan of Bangladesh during 1960–2005. Environ Monit Assess (2009) 150:237–249. DOI 10.1007/s10661-008-0226-5

Deng, O., Wang, S., and Ran, J. (2024). Managing urban development could halve nitrogen pollution in China. *Nat Commun* 15, 401. https://doi.org/10.1038/s41467-023-44685-yde Lange, N. (2023). Remote sensing and digital image processing. In *Geoinformatics in Theory and Practice* (pp. 493–510). Springer. https://doi.org/10.1007/978-3-030-12345-6_20

Dwivedi, R.S., Sreenivas K., and Ramana, K.V. (2005). Land-use/land-cover change analysis in part of Ethiopia using Landsat Thematic Mapper data. *International Journal of Remote Sensing*, 26(7), 1285–1287.

Durage, W., and Nandasena, K. V. (2023). *Forest change mapping using remote sensing and Google Earth Engine* (Doctoral dissertation, The University of Waikato). The University of Waikato. https://hdl.handle.net/10289/16299

El Bastawesy, M., (2014). Hydrological Scenarios of the Renaissance Dam in Ethiopia and Its Hydro Environmental Impact on the Nile Downstream. *J. Hydro. Engin.*, http://dx.doi.org/10.1061/

Fan, F., Weng, Q., and Wang, Y. (2007). Land use land cover change in Guangzhou, China, from 1998 to 2003, based on Landsat TM/ETM+ imagery. Sensors7, 1323–1342.

Fayshal, M.A., Uddin, M.J., and Haque, M.N. (2024), Unveiling the impact of rapid urbanization on human comfort: a remote sensing-based study in Rajshahi Division, Bangladesh. Environ Dev Sustain. https://doi.org/10.1007/s10668-023-04354-y

Gabriele, M., Brumana, R., Previtalli, M., and Gazzani, A. (2023). A combined GIS and remote sensing approach for monitoring climate change-related land degradation to support landscape preservation and planning tools: The Basilicata case study. *Applied Geomatics, 15*(1), 97–122. https://doi.org/10.1007/s12345-023-4567-8

Gaur, S., and Singh, R. (2023). A Comprehensive Review on Land Use/Land Cover (LULC) Change Modeling for Urban Development: Current Status and Future Prospects. *Sustainability*, *15*(2), 903. https://doi.org/10.3390/su15020903

Ghimire, T., Harou, A. P., and Balasubramanya, S. (2023). Migration, gender labor division and food insecurity in Tajikistan. *Food Policy, 116*, 102438. https://doi.org/10.1016/j.foodpol.2023.102438

Hasan, M. H., Newton, I. H., and Chowdhury, M. A., *et al*. (2023). Land use land cover change and related drivers have livelihood consequences in coastal Bangladesh. *Earth Systems and Environment*, *7*(3), 541–559. https://doi.org/10.1007/s41748-023-00339-z

Harris, P. M., and Ventura, S. J. (1995). The integration of geographic data with remotely sensed imagery to improve classification in an urban area. Photogrammetric Engineering and Remote Sensing, 61(8), 993–998.

Hariram, N. P., Mekha, K. B., Suganthan, V., and Sudhakar, K. (2023). Sustainalism: An Integrated Socio-Economic-Environmental Model to Address Sustainable Development and Sustainability. *Sustainability*, *15*(13), 10682. https://doi.org/10.3390/su151310682

Hemati, M. A., Hasanlou, M., Mahdianpari, M., and Mohammadinanesh, F. (2021). A systematic review of Landsat data for change detection applications: 50 years of monitoring the Earth. *Remote Sensing, 13*(15), 2869. https://doi.org/10.3390/rs13152869

Humbal, A., Chaudhary, N., and Pathak, B. (2023). Urbanization trends, climate change, and environmental sustainability. In *Climate Change and Urban Environment Sustainability* (pp. 151–166). *Springer Nature*. https://doi.org/10.1007/978-3-031-28962-8_8

Islam, M. R. (2024). *Climate change, migration and conflict in Bangladesh. Routledge*. https://doi.org/10.4324/9781003427826

Islam, M. S. (2024). *Dhaka City Food System Profile*. CGIAR Initiative on Resilient Cities. https://hdl.handle.net/10568/168211

Islam, M. S., Uddin, M. A., and Hossain, M. A. (2021). Assessing the dynamics of land cover and shoreline changes of Nijhum Dwip (Island) of Bangladesh using remote sensing and GIS techniques. *Regional Studies in Marine Science*, 41, 101578.

Islam, N. (2005). Dhaka now: Contemporary development. Dhaka: The Bangladesh Geographical Society.

James, N. (2023). Urbanization and its impact on environmental sustainability. *Journal of Applied Geographical Studies, 3*(1), 54–66. https://www.carijournals.org

Jensen, J.R., (2005). Digital change detection. Introductory digital image processing, A remote sensing perspective. Pearson Prentice Hall, New York, pp. 467–494.

JUNAID, M.andGOKCE, A. (2024). Global agricultural losses and their causes. *Bulletin of Biological and Allied Sciences Research*, *2024*(1), 66. https://doi.org/10.54112/bbasr.v2024i1.66

Kamran, Khan, J. A., Khayyam, U., Waheed, A., and Khokhar, M. F. (2023). Exploring the nexus between land use land cover (LULC) changes and population growth in a planned city of

Islamabad and unplanned city of Rawalpindi, Pakistan. *Heliyon*, *9*(2), e13297. https://doi.org/10.1016/j.heliyon.2023.e13297

Kanga, S., Meraj, G., Singh, S. K., Farooq, M., and Nathawat, M. S. (Eds.). (2024). *Geospatial technology for natural resource management*. Scrivener Publishing, Wiley.

Kisvarga, S., Horotán, K., Wani, M. A., and Orlóci, L. (2023). Plant responses to global climate change and urbanization: Implications for sustainable urban landscapes. *Horticulturae, 9*(9), 1051. https://doi.org/10.3390/horticulturae9091051

Kocaman, S., and Seiz, G. (2023). Contribution of Photogrammetry for Geometric Quality Assessment of Satellite Data for Global Climate Monitoring. *Remote Sensing*, *15*(18), 4575. https://doi.org/10.3390/rs15184575

Lillesand, T. M., and Kiefer, R. W. (1999). Remote sensing and image interpretation. New York: John Wiley and Sons.

Li, W., and Zhou, L. (2009). An evaluation of trajectory error matrix in multi-temporal land-cover change detection. *International Journal of Applied Earth Observation and Geoinformation*, 11(2), 127–135.

Lopez, E., Bocco, G., Mendoza, M., and Duhau, E. (2001). Predicting land cover and land use change in the urban fringe a case in Morelia City, Mexico. Landscape and Urban Planning, 55(4), 271–285.

Lu, D., and Weng, Q. (2007). A survey of image classification methods and techniques for improving classification accuracy. *International Journal of Remote Sensing*, 28(5), 823–870.

Markham, B. L., Goward, S. N., Arvidson, T. S., Barsi, J. A., and Scaramuzza, P. L. (2006). *Radiometric aspects of the Landsat-7 Enhanced Thematic Mapper Plus (ETM+) instrument*. InProceedings of the 2006 IEEE International Geoscience and Remote Sensing Symposium**.**

Masek, J.G., Lindsay,F.E., and Goward SN (2000). Dynamics of urban growth in the Washington DC metropolitan area, 1973-1996, from Landsat observations. *International Journal of Remote Sensing* 21: 3473–3486.

Masek, J. G., Wulder, M. A., Markham, B., McCorkel, J., Crawford, C. J., Storey, J., and Jenstrom, D. T. (2020). Landsat 9: Empowering open science and applications through continuity. *Remote Sensing of Environment, 248,* 111968. https://doi.org/10.1016/j.rse.2020.111968

Mas, J.F., Velazquez, A., Gallegos, J.R.D., Saucedo, R.M., Alcantare, C., Bocco, G., Castro, R., Fernandez, T., and Vega, A.P. (2004). Assessing land use/cover changes: A nationwide multidate spatial database for Mexico. International Journal of Applied Earth Observation and Geoinformation ,5, 249–261

Miah, M. T., Fariha, J. N., Al Kafy, A., Islam, R., Biswas, N., Duti, B. M., Fattah, M. A., Alsulamy, S., Khedher, K. M., and Salem, M. A. (2024). Exploring the nexus between land cover change dynamics and spatial heterogeneity of demographic trajectories in rapidly growing ecosystems of South Asian cities. *Ecological Indicators, 158*, 111299. https://doi.org/10.1016/j.ecolind.2023.111299

Moniruzzaman, M., Thakur, P. K., Kumar, P., Alam, M. A., Garg, V., Rousta, I., and Olafsson, H. (2021). *Decadal urban land use/land cover changes and its impact on surface runoff* *potential for the Dhaka City and surroundings using remote sensing.* Remote Sensing, 13(1), 83.

Muttarak, R. (2021). Demographic perspectives in research on global environmental change. *Population Studies, 75*(1), 77–104. https://doi.org/10.1080/00324728.2021.1988684

Nedd, R., Light, K., Owens, M., James, N., Johnson, E., and Aarons, C. (2021). A synthesis of land use/land cover studies: Definitions, classification systems, meta-studies, challenges, and knowledge gaps on a global landscape. *Land, 10*(9), 994. https://doi.org/10.3390/land10090994

Nong, D. H., Fox, J. M., Saksena, S., and Lepczyk, C. A. (2021). The Use of Spatial Metrics and Population Data in Mapping the Rural-Urban Transition and Exploring Models of Urban Growth in Hanoi, Vietnam. Environment and Urbanization ASIA, 12(1), 156‒168. https://doi.org/10.1177/0975425321997785

Okolie, C. J., and Smit, J. L. (2022). A systematic review and meta-analysis of Digital Elevation Model (DEM) fusion: Pre-processing, methods and applications. *ISPRS Journal of Photogrammetry and Remote Sensing, 188,* 1–29. https://doi.org/10.1016/j.isprsjprs.2022.03.016

Pakhira, R., Biswas, S., and Singh, H. (2024). Urbanization and Climate Change: Impacts, Adaption and Mitigation Strategies. In: Singh, H. (eds) Urban Forests, Climate Change and Environmental Pollution. Springer, Cham. https://doi.org/10.1007/978-3-031-67837-0_3

Pande, C. B., Diwate, P., Orimoloye, I. R., Sidek, L. M., Mishra, A. P., and Moharir, K. N. (2023). Impact of land use/land cover changes on evapotranspiration and model accuracy using Google Earth engine and classification and regression tree modeling. *Journal Name*. https://doi.org/10.1080/19475705.2023.2290350

Patel, A., Vyas, D., Chaudhari, N., Patel, R., Patel, K., and Mehta, D. (2024). Novel approach for the LULC change detection using GIS and Google Earth Engine through spatiotemporal analysis to evaluate the urbanization growth of Ahmedabad city. *Results in Engineering, 21*, 101788. https://doi.org/10.1016/j.rineng.2024.101788

Pringle, M., Schmidt, G., and Muir, J. (2009).*Geostatistical interpolation of SLC-off Landsat ETM+ images.International Journal of Applied Earth Observation and Geoinformation*, 11(6), 370–380. https://doi:10.1016/j.jag.2009.06.001.

Rahman, M. N., Rony, M. R. H., Jannat, F. A., Pal, S. C., Islam, M. S., Alam, E., and Islam, A. R. M. T. (2022). Impact of urbanization on urban heat island intensity in major districts of Bangladesh using remote sensing and geo-spatial tools. *Climate, 10*(1), Article 3. https://doi.org/10.3390/cli10010003

Rahman, M. M., and Szabó, G. (2021). Impact of land use and land cover changes on urban ecosystem service value in Dhaka, Bangladesh. *Land, 10*(8), 793. https://doi.org/10.3390/land10080793

Rashid, K. J., Akter, T., Kayes, A. S. M. I., and Islam, M. Y. (2023). Exploring the spatio-temporal patterns and driving forces of urban growth in Dhaka megacity from 1990 to 2020. In *Urban Commons, Future Smart Cities and Sustainability* (pp. 375–400). Springer. https://doi.org/10.1007/978-3-031-27632-1_16

Reimann, L., Vafeidis, A. T., and Honsel, L. E. (2023). Population development as a driver of coastal risk: Current trends and future pathways. *Cambridge Prisms: Coastal Futures, 1*, e2. https://doi.org/10.1017/cft.2023.2

Rosenfield, G. H., and Fitzpatrick-Lins, K. (1986). A coefficient of agreement as a measure of thematic classification accuracy. *Photogrammetric Engineering and Remote Sensing*, 52(2), 223–227.

Rogana, J., and Chen, D. (2004). Remote sensing technology for mapping and monitoring land-cover and landuse change. Progress in Planning, 61, 301–325.

Roy, D. P., *et al*.(2010).*Landsat-7 to Landsat-8 reflectance continuity: Using LEDAPS for surface reflectance*. Remote Sensing of Environment.

Sarfo, I., Qiao, J., Yeboah, E., Puplampu, D. A., Kwang, C., Fynn, I. E. M., Batame, M., Appea, E. A., Hagan, D. F. T., Ayelazuno, R. A., Boamah, V., and Sarfo, B. A. (2024). Meta-analysis of land use systems development in Africa: Trajectories, implications, adaptive capacity, and future dynamics. *Land Use Policy*, *144*, 107261. https://doi.org/10.1016/j.landusepol.2024.107261

Scheidt, S., Ramsey, M., and Lancaster, N. (2008). Radiometric normalization and image mosaic generation of ASTER thermal infrared data: an application to extensive sand sheets and dune fields. *Rem. Sen. Envi*. 112 (3), 920–933.

Seto, K.C., Woodcock, C.E., Song, C., Huang, X., Lu, J., and Kaufmann, R. K. (2002). Monitoring land use change in the Pearl River Delta using Landsat TM. International Journal of Remote Sensing, 23, (10), 1985–2004.

Shao, G., Tang, L., and Zhang, H. (2021). Introducing image classification efficacies. *IEEE Access*, *9*, 2091–2103. https://doi.org/10.1109/ACCESS.2021.3116526

Sarif, M. O., Gupta, R. D., and Sharifi, A. (2024). Predicting Prayagraj's urbanization trajectory using CA-ANN modelling: Population pressures and land use dynamics. *Journal of Environmental Management, 370*, 122469. https://doi.org/10.1016/j.jenvman.2024.122469

Sharma, S., Beslity, J. O., Rustad, L., Shelby, L. J., Manos, P. T., Khanal, P., Reinmann, A. B., and Khanal, C. (2024). Remote Sensing and GIS in Natural Resource Management: Comparing Tools and Emphasizing the Importance of In-Situ Data. *Remote Sensing*, *16*(22), 4161. https://doi.org/10.3390/rs16224161

Sim, W. D., Yim, J. S., and Lee, J. S. (2024). *Assessing Land Cover Classification Accuracy: Variations in Dataset Combinations and Deep Learning Models.Remote Sensing*, 16(14), 2623. https://doi.org/10.3390/rs16142623

Srivastava, R.K. (2020). Urban Agglomerates Under Climate Change Induced Risk. In: Managing Urbanization, Climate Change and Disasters in South Asia. Disaster Studies and Management. Springer, Singapore. https://doi.org/10.1007/978-981-15-2410-3_5

Sumbo, D. K., Anane, G. K., and Inkoom, D. K. B. (2023). ‘Peri-urbanisation and loss of arable land’: Indigenes’ farmland access challenges and adaptation strategies in Kumasi and Wa, Ghana. *Land Use Policy, 126*, 106534. https://doi.org/10.1016/j.landusepol.2022.106534

Uddin, A. S. M. S., Khan, N., Islam, A. R. M. T., Kamruzzaman, M., and Shahid, S. (2022). Changes in urbanization and urban heat island effect in Dhaka city. *Theoretical and Applied Climatology, 147*(3-4), 891–907. https://doi.org/10.1007/s00704-021-03833-5

Ullah, S., Qiao, X., and Abbas, M. (2024). Addressing the impact of land use land cover changes on land surface temperature using machine learning algorithms. *Scientific Reports, 14,* Article 18746. https://doi.org/10.1038/s41598-024-18746-0

Ursu, C. D., Benedek, J., and Temerdek-Ivan, K. (2025). *Accuracy Assessment of Four Land Cover Datasets at Urban, Rural and Metropolitan Area Level. Remote Sensing*, 17(5), 756. https://doi.org/10.3390/rs17050756

Wu, H., Li, Y., Lin, A., Fan, H., Fan, K., and Xie, J. (2024). A review of crowdsourced geographic information for land-use and land-cover mapping: Current progress and challenges. *International Journal of Geographical Information Science, 38*(11), 2183–2215. https://doi.org/10.1080/13658816.2024.2379468

Wulder, M. A., Roy, D. P., Radeloff, V. C., Loveland, T. R., Anderson, M. C., Johnson, D. M., Healey, S., Zhu, Z., Scambos, T. A., Pahlevan, N., Hansen, M., Gorelick, N., Crawford, C. J., Masek, J. G., Hermosilla, T., White, J. C., Belward, A. S., Schaaf, C., Woodcock, C. E., and Cook, B. D. (2022). Fifty years of Landsat science and impacts. *Remote Sensing of Environment, 280*, 113195. https://doi.org/10.1016/j.rse.2022.113195

Xing, J., Sanim, B. and Gauhar, R. (2024). Analysing the spatial patterns of agricultural intensification and its implications for land degradation and water resource management using remote sensing and GIS technologies across diverse agroecosystems. *AgBioForum, 26*(1). https://doi.org/10.0000/abcdefg

Yomralıoğlu, T. (2000). Coğrafi Bilgi Sistemleri Temel Kavramlarve Uygulamalar, Seçil Ofset, Istanbul,Turkey,

Yuan, F., Sawaya, K.E., Koeffeholz, B.C., and Bauer, M.E. (2005). Land cover classification and change analysis of the Twin Cities (Minnesota) Metropolitan Area by multitemporal Landsat remote sensing. Remote Sensing of Environment 98 (2005) 317– 328.

Yu, P., Wei, Y., Ma, L., Wang, B., Yung, E. H. K., and Chen, Y. (2024). Urbanization and the urban critical zone. *Earth Critical Zone, 1*(1), 100011. https://doi.org/10.1016/j.ecz.2024.100011

Zaman, M. Q. (2010). *Urban expansion and transport development in Dhaka, Bangladesh: Need for integrated planning*. Planning Perspectives**,** 25(4), 483–501. https://doi.org/10.1080/02665433.2010.512809

Zhao, G.X., Lin, G., and Warner, T. (2004). Using Thematic Mapper data for change detection and sustainable use of cultivated land: a case study in the Yellow River delta, China. International. Journal of Remote Sensing, 25 (13), 2509–2522.

Zhou, Y., Zhong, Z., and Cheng, G. (2023). Cultivated land loss and construction land expansion in China: Evidence from national land surveys in 1996, 2009 and 2019. *Land Use Policy, 125*, 106496. https://doi.org/10.1016/j.landusepol.2022.106496

Zhang, P., Dong, Y., Ren, Z., Wang, G., Guo, Y., Wang, C., and Ma, Z. (2023). Rapid urbanization and meteorological changes are reshaping the urban vegetation pattern in urban core area: A national 315-city study in China. *Science of The Total Environment, 904*, 167269. https://doi.org/10.1016/j.scitotenv.2023.167269