

RESEARCH ARTICLE

Open Access



# Cultural heritage and urban morphology: land use transformation in 'Kumbh Mela' of Prayagraj, India

Divyata Yadav<sup>1</sup>, Susanta Mahato<sup>2\*</sup> , Akshita Choudhary<sup>1,3</sup> and P. K. Joshi<sup>1,2\*</sup>

## Abstract

A Hindu pilgrimage site where millions of people gather to seek solutions to problems related to everyday life, the "Kumbh Mela" is recognised as one of India's intangible cultural heritages. The site of the observance rotates between four cities, Haridwar, Ujjain, Nashik and Prayagraj. The infrastructure and services in the city that is hosting such a gathering undergo numerous changes as a result of the sizeable gathering. The goal of the study is to monitor the changes in Land Use and Land Cover (LULC) in the city of Prayagraj before and after the "Kumbh Mela" and to evaluate the effect on infrastructure changes in the city. Analyzing the changes that such pilgrimages and events bring about in cities are fascinating. In 2019, the city of Prayagraj hosted the "Kumbh", hence, Pre-Kumbh (2016), Kumbh (2019), and Post-Kumbh (2022) phases were taken under consideration for LULC change assessment. Supervised classification was conducted using Maximum Likelihood Classifier to prepare LULC maps. It was observed that urbanisation has significantly increased at the expense of vegetation, fallow land, and agricultural land. The success of the local agroforestry policy and plantation drive is demonstrated by the interesting increase in vegetation that has been observed. The construction of a civil airport, the widening of existing roads, the installation of new railroad tracks, and the adornment of roundabouts on existing roads are the major infrastructure changes. The findings offer fresh insights of increasing urban infrastructure from a cultural perspective. The findings will aid in better planning and policy development for the resilient and sustainable infrastructure, as well as in the development of a long-term strategy for the temporary habitation in the "Kumbh" area of such cities.

**Keywords** 'Kumbh', Land use land cover (LULC), Urbanization, City infrastructure, Cultural perspective

## 1 Introduction

In India, the word "pilgrimage" is occasionally interchanged with the term "tirtha-yatra," which means "travel to river fords" (Bhardwaj, 1973). It is believed that participation in the tirtha-yatra will result in

self-transformation, the "reward of purification of the soul, and attainment of objectives related to the problems of mundane existence" (Bhardwaj, 1973). Hindu pilgrimages frequently take place in India in natural settings like mountains, hills, caves, river banks, and ocean coasts (Ruback et al. 2008). India's holy sites have undergone numerous changes as a result of pilgrimage and religious tourism. These types of activities diversify the social and cultural identities of these places and create a wealth of opportunities for economic growth (Chadha & Onkar, 2016). By bringing up the alteration in the natural environment, religious tourism has an impact on these pilgrimage sites. Physical effects of pilgrimage events include overcrowding, stampedes, traffic jams,

\*Correspondence:

Susanta Mahato  
mahatosusanta2011@gmail.com

P. K. Joshi  
pkjoshi27@hotmail.com

<sup>1</sup> School of Environmental Sciences, Jawaharlal Nehru University, New Delhi 110067, India

<sup>2</sup> Special Centre for Disaster Research, Jawaharlal Nehru University, New Delhi 110067, India

<sup>3</sup> Land Use and Governance, Leibniz Centre for Agricultural Landscape Research (ZALF), Munchenberg, Germany



© The Author(s) 2024. **Open Access** This article is licensed under a Creative Commons Attribution 4.0 International License, which permits use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons licence, and indicate if changes were made. The images or other third party material in this article are included in the article's Creative Commons licence, unless indicated otherwise in a credit line to the material. If material is not included in the article's Creative Commons licence and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder. To view a copy of this licence, visit <http://creativecommons.org/licenses/by/4.0/>.

short-term stress on environmental resources, high levels of pollution (air, water, and soil), large amounts of waste, and clearing land for temporary housing (Table 1) (Shinde, 2012). The introduction of new modes of transportation (cars, buses, and trains) may result in new visitor flows, and those flows may call for different types of spaces (bus stops, parking lots, etc.). When new locations are added, the physical environment is changed. Cities with a tourism industry thus face urban planning difficulties.

Combining the idea of socio-spatial dialectic (Brace et al. 2006) with the historical geography approach facilitates an understanding of how contemporary environmental concerns constitute one point in a protracted trajectory of environmental change related to the creation and maintenance of a sacred place. With a physical, economic, institutional, and cultural setting, this viewpoint helps to explain pilgrimage sites as dynamic and developing entities (Shinde, 2012). A pilgrimage is a planned journey focused on a particular goal that is chosen by the heart and carried out with the help of the feet. Hindu mythology refers to one such pilgrimage event as the “Kumbh Mela,” which occurs in the cities of Haridwar, Ujjain, Nashik and Prayagraj (Memish et al. 2019, Raghav et al. 2020). At each of the four locations, the Kumbh is held every 3 years (<https://www.britannica.com/topic/Kumbh-Mela>). The riverbank and access to the water are essential to the framework of the “Kumbh” in these locations. In addition to being the biggest congregation on the planet, it was added to UNESCO’s Representative List of the Intangible Cultural Heritage of Humanity in 2017. The Sanskrit words “Kumbha” and “Mela,” which both mean “fair” or “gathering,” are the origins of the phrase “Kumbh Mela” (David and Roy, 2016). Hindu mythology claims that gods and demons were at odds over the concoction that gives life, and that this conflict resulted in the tilting of urns, which fell upon the four locations of Prayagraj, Nashik, Haridwar, and Ujjain (<http://kumbh.gov.in/en>). Since the Gupta era, the “Kumbh Mela” has taken place in Prayagraj (<https://www.britannica.com/topic/Kumbh-Mela>). The first event was

recorded sometime between 629 and 645 by the Chinese Buddhist monk Hsuan Tsang, who had travelled to India in search of Buddhist sacred texts (<https://www.britannica.com/topic/Kumbh-Mela>).

According to their timing within a 144-year cycle and the various planetary alignments that take place during this time, the various “Melas” themselves are divided into categories. There are four different kinds of Melas. The most recent “Maha Kumbh” which takes place once every 144 years, was held in Prayagraj in 2001. Every 6 years and 12 years, Prayagraj hosts the “Ardh Kumbh” and “Purna Kumbh”, respectively (<http://kumbh.gov.in/en>).

The effective operation of the “Kumbh” festival depends on the transportation infrastructure of roads, railways, and highways, and these large pilgrimage fairs offer the opportunity for a focused effort to develop the transportation infrastructure (Greenough, 2013). The enormous temporary encampments necessary for the “Kumbh” must also be considered in each city’s urban plan (Buzinde et al. 2014). As a result, the city interacts with a sparsely populated area nearby those doubles as both a farm and a temporary settlement. The temporary city’s density and dynamism as well as the extensive stretches of relatively tranquil agricultural landscapes in between can both be supported by this fertile and usable soil.

The ability of the Mela to accommodate the tens of millions of visitors is facilitated by wide roadways, pontoon bridges, pedestrian traffic control, vehicular restrictions, surveillance cameras, and a sizeable, noticeable police presence (Yamin, 2019). This township provides access to all governmental and administrative services, including food, clean water, sanitation, garbage and sewage disposal, safety, counselling and personal assistance, and medical care (Quadri and Padala, 2021).

Thus the mass pilgrim gatherings have an effect on the LULC as the city provides facilities for pilgrims, tourists, and locals. Infrastructure development is the main driver of such changes. For example, recently, government increased temporary settlement area from 1600 ha to 3200 ha in order to make the 2019 “Kumbh” the largest temporary settlement in history. The extent of the

**Table 1** The environmental issues faced by ‘Kumbh’ cities

Environmental issue	Examples of academic sources
Water Pollution	Patil et al. 2020; Bhadula et al. 2012; Bhutiani et al. 2016; Kanaujiya & Tiwari, 2023; Matta et al. 2017, b; Varma et al. 2022; Yadav K Bhatia, 2020
Solid waste disposal	Bamb Nikita and Bahade, 2024; Bisht et al. 2022; Kanaujiya & Tiwari, 2022
Sanitation	Holman & Shayegan, 2014
Congestion /Health issues	Aggrawal et al. 2020; Goel et al. 2020; Mishra et al. 2020; Sharma et al. 2023
Lack of governance	Kala & Chaubey, 2023; Mishra et al. 2020

area and the intensity of land use are two examples of how LULC changes occur both spatially and temporally (Houghton, 1994; Matlhodi et al. 2019). In general, natural and anthropogenic factors are the causes of LULC changes (Lambin et al. 2001; Veldkamp and Lambin, 2001; Sewnet, 2015; Matlhodi et al. 2019). The impact of these factors on the terrestrial environment is unprecedented. While LULC is one of the main contributors to global warming and climate change, this does not necessarily mean that it only contributes to the degradation of lands and forests (Lambin, 1999). Land use has a significant impact on the operation of socioeconomic and environmental systems, leading to crucial trade-offs in terms of sustainability, food security, biodiversity, and the socioeconomic vulnerability of people and ecosystems (Lambin et al. 2003; Mishra et al. 2020; Petit et al. 2001; Verburg et al. 1999). Growing concerns over the environmental impacts of pilgrimage have spurred the formation of organizations dedicated to promoting sustainable pilgrimage practices. Notable examples include the Green Pilgrimage Network in Europe, which advocates for eco-friendly approaches to pilgrimage (Project et al. 2012), and the Green Kumbh Foundation in India, which undertakes various “green campaigns” during the Kumbh Melas. In Kerala, India, the state government has launched the “Mission Green Sabarimala” initiative to exchange eco-friendly cloth bags for plastic bottles and distribute postcards reminding pilgrims to protect the environment. Similarly, religious and government groups organising the 2013 Kumbh Mela at Haridwar adopted the moniker “Green Kumbh – Clean Kumbh,” highlighting their commitment to environmental sustainability. Additionally, the organization Green Ganga focuses on cleaning the Ganga River during and after pilgrimages along its various sections. While these efforts demonstrate a growing awareness of environmental responsibility within the pilgrimage context, the effectiveness of these organizations remains a subject of debate (Singh et al. 2021).

The city hosted the “Kumbh” festivities from January 15 to March 9 in the year 2019 (Table 2), and various infrastructural changes were made in order to accommodate and attract thousands of devotees. For this research, the entire study period was divided into three segments: Pre-Kumbh (2016), Kumbh (2019), and Post-Kumbh (2022), respectively. To create supervised LULC classification, Sentinel-2 satellite images were used. Unplanned changes in land use are currently the main issue. The two main factors causing land-use changes are a lack of clear, logical planning and disregard for environmental impact. During the celebrations, temporary communities encroached on both sides of the riverbank. Additionally, many improvised river crossings were built. Kumbh had

**Table 2** The schedule of ‘Kumbh’ 2019

The itinerary of ‘Kumbh’ 2019	Date
1. Makar Sankranti (1st Shahi Snan)	15 January 2019
2. Paush Poonnima	21 January 2019
3. Mauni Amavasya (2nd Shahi Snan)	04 February 2019
4. Basant Panchami (3rd Shahi Snan)	10 February 2019
5. Maghi Poonnima	19 February 2019
6. Maha Shivratri	04 March 2019

a big impact on Prayagraj’s infrastructure and accessibility of urban amenities. Hence, the present study intends to monitor the changes in LULC in the city of Prayagraj before and after the “Kumbh Mela” and to evaluate the effect on infrastructure changes in the city. This paper investigates how pilgrimage cities undergo urban transition, focusing on planning concepts like land use change, real estate development, infrastructure, and the planning tools that manage these aspects. The goal is to understand how these cities can transform sustainably and inclusively. The concentration of people at religious tourism destinations during peak seasons intensifies the environmental impact compared to less crowded periods (Shinde, 2021). Eco-development programs have emerged to safeguard the planet and foster a deeper sense of environmental responsibility among individuals. Organizations like the Green Pilgrimage Network (GPN) have played a pivotal role in facilitating this shift towards environmentally conscious pilgrimage. This study will explore the challenges faced and help to develop policies for the urban planning of religious cities incorporating smart city parameters. The effective solid waste management, beautification of cities, broadening and electrification of roads, development of traffic junctions, parks and green zone in the city ROBs (road over bridges) and RUBs (roads under bridges), sanitation facilities and adequate amount of drinking water supply to all the identified places. Also, to analyze the changes that such pilgrimages and events enrich cultural ecosystem services.

## 2 Literature review and research gap

Pilgrimage gatherings and festivals are integral to cultural and spiritual practices globally, yet the impacts of these events on land use remain a relatively understudied area within academic discourse. A comprehensive review (Table 3) outlining the changes in land use associated with pilgrim gatherings or pilgrimage festivals is essential to position contemporary studies within the broader context of urban revitalization and intangible cultural heritage. This study seeks to contribute to this gap by understanding the intricate relationship between

**Table 3** Key findings and research implications in pilgrimage tourism and urban sustainability studies

Author/Date	Theoretical Framework	Study Area	Objectives	Results	Implications for future research
Shinde & Olsen, 2023	Reframing the Intersections of Pilgrimage, Religious Tourism, and Sustainability.	Pilgrimage cities	To understand the concept of sustainability in pilgrimage tourism	<ol style="list-style-type: none"> <li>1) Validated the 'Tourism Area Life Cycle' and 'Carrying Capacity' tourism environmental models.</li> <li>2) A conceptual model was developed to analyze the impacts of tourism on pilgrimage towns.</li> </ol>	A holistic approach is needed to understand the sustainability concept and issues in the pilgrimage towns.
Kumar Dutta, 2022	Sustainable Development of Tourism in Haridwar, Uttarakhand.	Haridwar	<ol style="list-style-type: none"> <li>1) mainly focused on conflicts between tourism and the conservation of natural resources in the city.</li> <li>2) to assess the sustainability of tourism in terms of economy, ecology, culture and local community with scientific methods including modern techniques.</li> </ol>	Tourism appears in sustainable form in terms of economy and culture but from the point of ecological value and local or community level amenities, the tourism industry of the area is in very vulnerable condition.	The master plan prepared by the City Development Authority for coming years (2006-2025), should be reviewed properly from the ecological perspectives of the area. The entire tourism activities should be guided according to "the carrying capacity of the city.
V.S. & Firoz, 2022	Benchmarking sustainability of pilgrimage cities: a case of three cities in Tamil Nadu, India.	Thanjavur, Tiruchirappalli, Madurai	To develop a comprehensive method that includes more dimensions to assess sustainability by adding variables from diverse domains.	<ol style="list-style-type: none"> <li>1) A well-established solid waste management system in Thanjavur helps achieve good environmental sustainability.</li> <li>2) The less per capita open space and utilization of large area for tourism facilities lead to low performance of land use.</li> <li>3) All three cities lack open space compared to the national standards. Hence, the immediate focus areas of Thanjavur and Madurai is the land use category and of Tiruchirappalli is waste management.</li> <li>4) The hidden crisis traced by this method enables planners and policymakers to decide whom to benchmark against, and which targets are most appropriate to their development status.</li> <li>5) Using the benchmarking method, an assessment procedure (PCS) is developed to measure the sustainability level of three prominent South Indian pilgrimage cities.</li> </ol>	<ol style="list-style-type: none"> <li>1) The method adopted in this study can be applied to cities with similar challenges in India or abroad with little or no modifications.</li> <li>2) Future studies can collect the time-series data for a vertical comparison with previous years. Also, using the same variables, the study can be attempted using alternate methods such as TOPSIS or AHP.</li> </ol>



**Table 3** (continued)

Author/Date	Theoretical Framework	Study Area	Objectives	Results	Implications for future research
Shinde, 2017	Planning for urbanization in religious tourism destinations: insights from Shirdi, India.	Shirdi	To examine urban transformation in religious tourism destinations using planning vocabulary that includes concepts of land use, real estate and infrastructure development and the planning mechanisms.	It is found that planning mechanisms including the conventional master plan approach have been ineffective in adequately responding to issues such as the proliferation of unauthorized commercial establishments, hotels, lodging and boarding houses; strained infrastructure; and environmental pollution that characterize urbanization in religious tourism destinations.	The need for articulating better planning mechanisms in religious tourism destinations. The sacred and religious must be sustained in the wake of the rapid urbanization of religious tourism destinations.
Chadha & Onkar, 2016	Changing Cities in the Perspective of Religious Tourism – A case of Allahabad.	Prayagraj	To explore reasons behind urban planning problems in tourist potential city.	Temporary plotting, permanent plotting, ecology of site and conservation are the land management challenges. The biggest challenge is the construction of makeshift shelters on floodplains of rivers. Above all, these have to be built, used and then dissembled in a matter of few months. Once crowds are dispersed, banks of rivers are clogged with garbage, mainly flowers, food and plastic bottles. Preservation and protection of monuments and other buildings of historical importance is also to be taken care of.	The need of the hour for urban planners and designers is to be prepared for changes, thus converting these challenges into appropriate development proposals for "changing cities".
Chandan & Kumar, 2019	Challenges for Urban Conservation of core area in pilgrim cities of India.	India	To explore the urban conservation challenges and issues in the core pilgrimage cities.	The insurmountable visitation and the resulting economic opportunities shape the sociological, economic and cultural environment through direct impacts of the magnitude of visitors, and indirect pressures of pilgrimage induced urbanization.	strengthening the capacities of planning agencies and local stakeholders to be able to integrate heritage in a strategic vision.

**Table 3** (continued)

Author/Date	Theoretical Framework	Study Area	Objectives	Results	Implications for future research
Forouhar & Hasankhani, 2018	Urban Renewal Mega Projects and Residents' Quality of Life: Evidence from the Historical Religious Center of Mashhad Metropolis.	Mashhad, Iran	To assess the impact of renewal mega projects on residents' subjective quality of life.	1) Samen Renewal Project had a serious deviation from the initial goals of renovation towards the goals of investors. 2) lack of strategic planning for sustainable financing of the project by the Samen Renewal Organization.	1) to recognize the political economy of space in the historical religious cities.
Nicu & Stoleriu, 2019	Land use changes and dynamics over the last century around churches of Moldavia, Bukovina, Northern Romania – Challenges and future perspectives.	Bukovina	To fill the gap and to depict the spatial fragmentation degree and land use dynamics for almost a century for the UNESCO Churches of Moldavia.	In the buffer zone of 1 km for the eight areas of interest, it is observed that the spatial dynamics of the land use categories are governed on the one hand by natural phenomena (floods, lateral erosion, variability of the water flow within the catchments and reforestation) and on the other by anthropogenic ones (land use changes, retro migration, migration, industrialization, household construction, tourism and construction).	1) the UNESCO directives are not respected, and this may have short- and long-term consequences in what concerns the specificity of the place and the universal value. 2) Both at a local and global level, more studies that use landscape metrics and land use scenarios are needed, in order to track the historical changes of the landscape and to compare cultural heritage policies under different political regimes; this is one of our future directions to be investigated.
Duan et al. 2019	Land Use and Land Cover Change in the Kailash Sacred Landscape of China.	Kailash Sacred Landscape in China (KSL-China)	To investigate the patterns and dynamics of LUCC and the driving forces using remote sensing data and meteorological data.	1) increasing human disturbance has accelerated intensive land use, particularly conversion from cropland to built-up land for infrastructure construction due to tourism development. 2) the rangeland suffered from obvious fluctuations owing to climatic warming and drought.	1) Balanced agriculture and service-based ecotourism development is suggested for a substitute for livestock-focused animal husbandry.
Maurya et al. 2021	Impacts of Land Use Change on Water Quality Index in the Upper Ganges River near Haridwar, Uttarakhand: A GIS-Based Analysis.	Shivpuri Rishikesh Haridwar	To detect local land use changes and their spatial correlation with surface water quality.	Site-based water quality analysis in our study indicates that agricultural land use and human gatherings for religious purposes affect water quality.	1) more public concern, awareness and active participation should be required at the local level to save the water and enrich the quality of life. 2) Water restoration in critical areas should be employed to improve the quality.

**Table 3** (continued)

Author/Date	Theoretical Framework	Study Area	Objectives	Results	Implications for future research
Singh & Bedi, 2021	Sustainable Waste Management for Religious Tourism - Case of Pilgrim City Mathura.	Mathura	To assess the solid waste generation, management, and practices in urban religious places.	The waste management sector has a limited ability to handle waste, meaning that the natural environment is not capable of absorbing more waste than it currently does. Therefore, mitigation measures should be implemented that increase the environment's capacity to absorb waste in a sustainable manner. Additionally, restrictions should be placed on religious practices that cause environmental degradation.	There is a need for sustainable tourism and initiatives like religious waste management and "Green Temples." These recycle and reuse the solid waste produced through mass religious tourism.

urban revitalization and the intangible cultural heritage of India, focusing on the Kumbh of Prayagraj.

The existing literature provides insightful perspectives on sustainability, tourism impacts, and urban challenges in pilgrimage cities, but there are discernible research gaps in comprehensively understanding the direct correlations between cultural events like 'Kumbh Mela' and urban morphology, particularly in the context of land use transformations. Previous studies, such as those by Shinde KA (2017) and Kumar Dutta (2022), focus on urbanization and sustainability challenges but lack specific exploration of event-induced urban transformations. While V.S. & Firoz (2022) and Chadha & Onkar (2016) highlight the importance of sustainability and land management challenges, there's a dearth of detailed analyses concerning the temporal impact of large-scale cultural gatherings on land use dynamics. Moreover, studies like A Forouhar, M Hasankhani (2018) and C Duan et al. (2019) discuss conservation and heritage policies but do not directly address the immediate urban changes induced by cultural events like 'Kumbh Mela'. Therefore, there's a pronounced research gap in examining the direct implications of 'Kumbh Mela' on urban morphology, land use transformations, and their subsequent influence on the city's infrastructure in pilgrimage cities like Prayagraj.

### 3 Study area

Prayagraj is located at the intersection of three rivers (Fig. 1). Its latitudinal extent is  $25^{\circ} 26' 08.88''$  N and its longitudinal extent is  $81^{\circ} 50' 46.72''$  E. Its rich alluvial soil was created by the eroding components of the great Himalaya and the Vindhyan uplands (Yadav et al. 2020). It experiences a humid subtropical climate, with summertime highs of up to  $48^{\circ}\text{C}$  and wintertime lows of up to  $9^{\circ}\text{C}$ . According to the Indian Census of 2011, the city has a population of 59,54,390 people. The temporary communities are built along the banks of the rivers Ganga and Yamuna, which are inhabited by numerous "kalpavasis," ascetics, and saints. Up to thirty million people can be found in these temporary settlements. It was during the 2019 Ardh Kumbh that infrastructure improvement on a larger scale—including road widening at important public locations, historic sites, and the Sangam area—took place. Prayagraj Development Authority (PDA) has built over 150km of road as part of the effort to widen roads and has improved the majority of the squares. Additionally, it built five overpasses to help with traffic. As per Press Information Bureau (PIB) (<https://pib.gov.in/PressReleaseDetail.aspx?PRID=1598364>), about 3000 encroachments were removed from about 65 locations in different parts of the town.

At the confluence of the three rivers Ganga, Yamuna, and fabled Saraswati, the city of Prayagraj is renowned for hosting the Hindu religious festival known as the "Kumbh Mela." Millions of people come to take a "Snan" (bath) at this point in order to see numerous "sadhus" (ascetics) who attend this festival. By taking a holy bath and attending a "Satsang" (a spiritual discourse) hosted by the godmen, pilgrims who have travelled a great distance believe that all their sins will be forgiven. The city hosts the "Maha Kumbh," which occurs every 144 years (in 2001), the "Purna Kumbh," which happens every 12 years (in 2013), and the "Ardh Kumbh," which happens every 6 years (in 2019). For about 55 days, this festival was in full swing.

## 4 Material and methods

### 4.1 Data acquisition

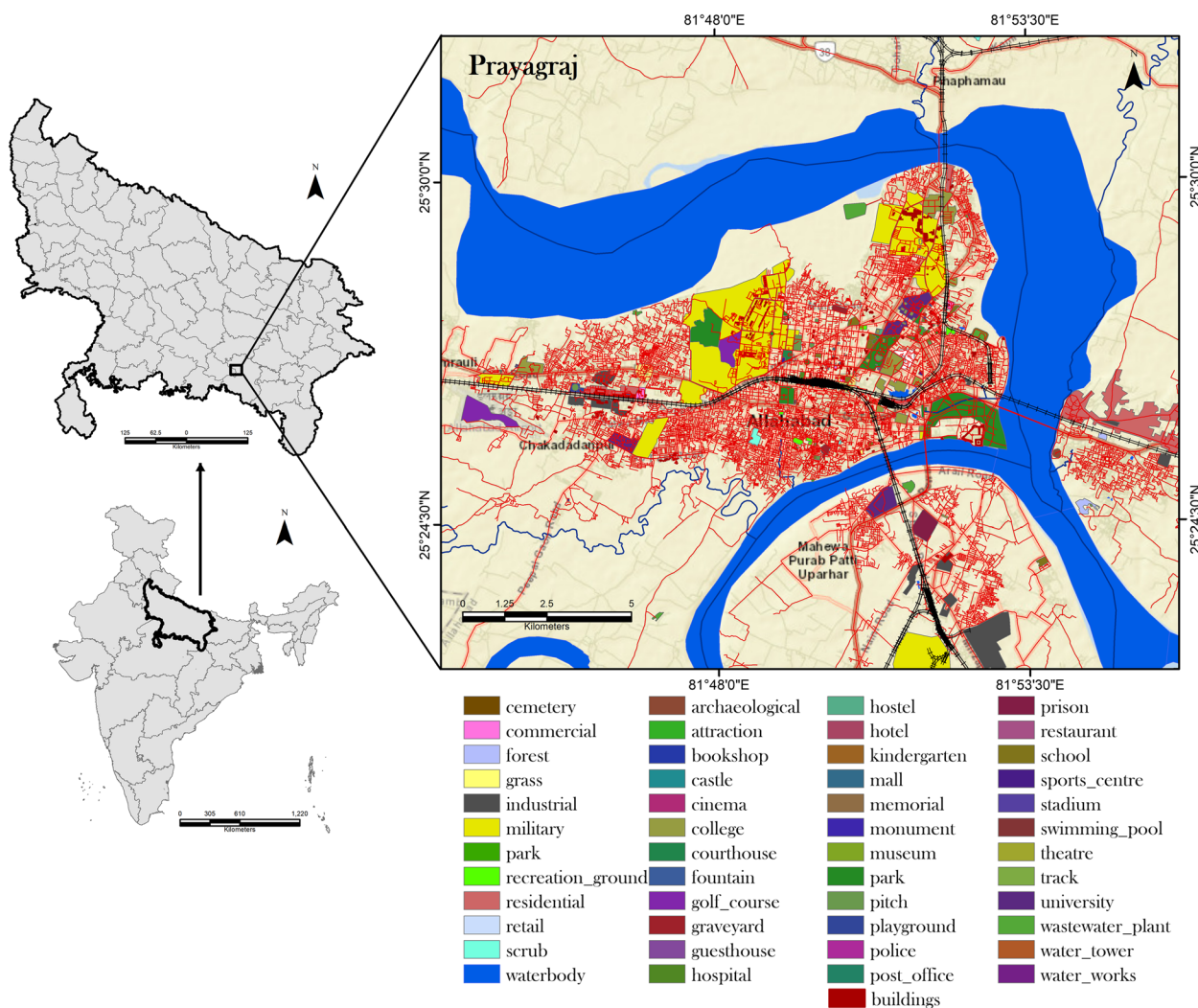
For the entire study period, which was divided into three parts, namely pre-Kumbh (2016), Kumbh (2019), and Post-Kumbh (2022), urban dynamics of the city as well as of temporary settlements of Kumbh were calculated using satellite data acquired from Sentinel-2 which was downloaded from the United States Geological Survey (USGS) Earth Explorer website (<https://earthexplorer.usgs.gov/>). The features of the database are listed in Table 4.

### 4.2 LULC classification

Image classification is the process of extracting classes of information from a multispectral raster image (Yedage et al. 2015a, b). The Sentinel 2 satellite has a total of thirteen bands in its multi-spectral raster image. To accurately classify the satellite image used in this study, 2, 3, and 4 bands were combined. Unsupervised and supervised image classification are the two most common image classification methods used in remote sensing image analysis. For supervised image analysis, a full LULC classification outline was prepared based on the field knowledge and characteristics (Fig. 2). The post-classification change approach is currently the most widely used change detection technique (Sarif and Gupta, 2022). Post-classification changes are the changes in land cover that occur after a thorough classification of land uses. Other change detection techniques include image rationing, image differencing, image regression, and post-classification comparison. All of the methods are pixel-based, so they are constrained by pixel count and precision (Lu et al. 2004).

### 4.3 Accuracy assessment

The receiver operating characteristics (ROC) was used to calculate the area under the curve (AUC) of the ROC curves for accuracy assessment of the LULC maps and



**Fig. 1** Location of the study area

**Table 4** Sentinel 2 image characteristics for the study

	Acquisition date	Spatial Resolution	Band use	Source
Pre-'Kumbh'	09 February 2016	10m	2,3,4	USGS
'Kumbh'	13 February 2019	10m	2,3,4	USGS
Post-'Kumbh'	07 February 2022	10m	2,3,4	USGS

Band 2 - Green, Band 3 - Red, Band 4 - Near-Infrared

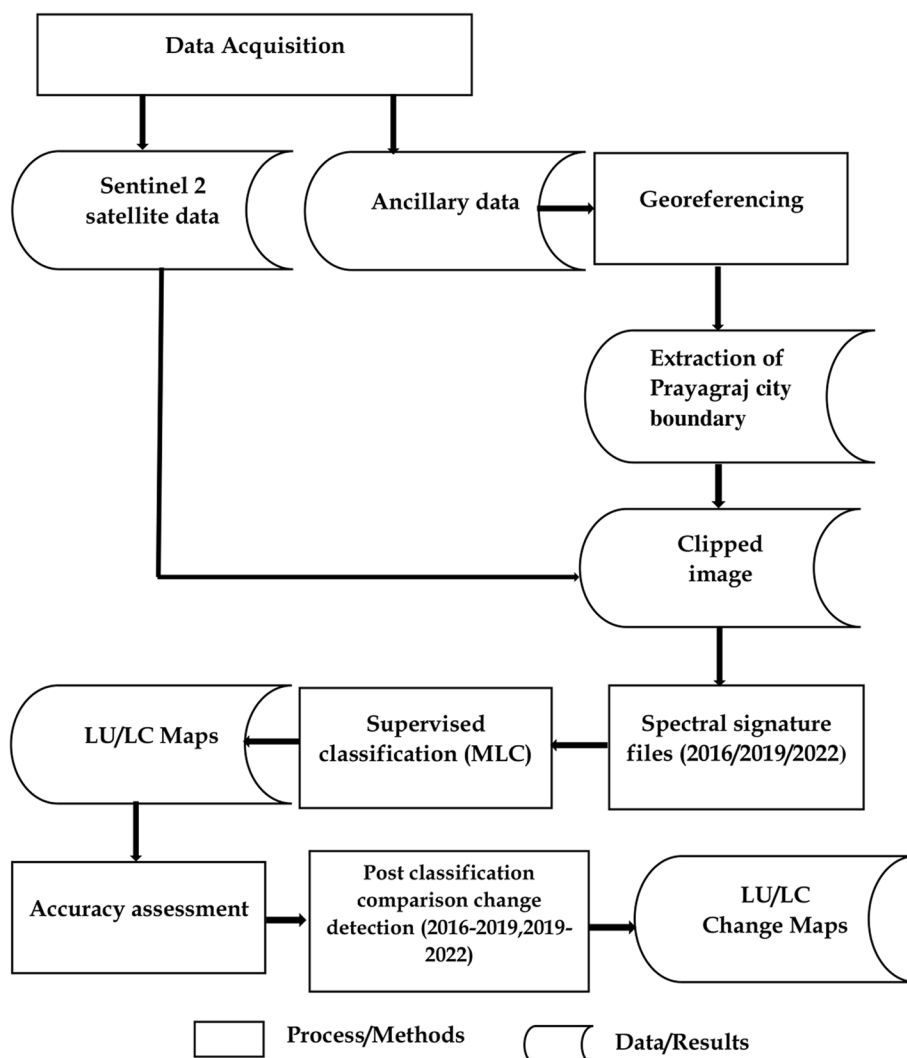
comparability in terms of specificity to portraying the situation on the ground (Pontius & Schneider, 2001). The exchange between false-positive levels (1-specificity) and genuine positive levels (sensitivity) is represented graphically by the ROC curve and is shown on the X and Y axes, respectively (Pourghasemi et al. 2013; Mahato et al. 2021). The study took into account 80 locations

that showed the particular land use. The ROC curve was finally created using the SPSS software platform (v-22). In this study, the precision of the anticipated number is shown by the area under the curve (AUC).

**4.4 Change detection**

There are several methods for detecting changes, including post-classification comparison, image rationing, image differencing, image regression, etc. All of the methods have accuracy and pixel count restrictions because they are pixel-based. For evaluating LU change, a lot of people use the maximum likelihood classification (MLC) method. In this study, supervised MLC, a maximum likelihood algorithm was used for the classification of multispectral images. Water body, river sediment, fallow land, vegetation, built-up, and agricultural land are the six LULC classes (Table 5)





**Fig. 2** Methodological framework for LULC change

**Table 5** Land cover classification scheme used in this study

Land cover outline	Description
Waterbody	Area covered by perennial rivers, streams, ponds, dams
River sediment	River sands
Fallow land	Uncultivated agricultural land, open and bare land, degraded forested area, exposed soils
Vegetation	Shrubs, dense evergreen trees, wetland forest, open forest
Built-up	Settlements and roads
Agricultural land	Irrigated, harvested and cultivated crop field

that were categorized and mapped in the study. The earlier change and the current change were compared using image differencing, post-classification comparison techniques, and transition matrices. The LULC transformation separates multi-temporal images into thematic maps and then implements a pixel-by-pixel comparison of the classified images. This is known as the post classification comparison technique. On multitemporal images, it lessens the effects of atmospheric, sensor, and environmental differences and provides a thorough change matrix (Lu et al. 2004; Mahato and Pal, 2018). The magnitude change for each land-use class was calculated by deducting the area coverage from the second and first years (Eq. 1).

$$\text{Magnitude change} = \text{Magnitude of the new year} - \text{Magnitude of the previous year} \tag{1}$$

Percentage change (trend) for each land use type was then calculated by dividing magnitude change by the base year (the initial year) and multiplied by 100 as shown in the Equation (Eq. 2) below (Hossain and Moniruzzaman, 2021; Yedage et al. 2015a, b).

$$A (\%) = [(A 2 - A1)/A 1] \times 100 \tag{2}$$

Where, A (%)=a relative change of LULC class between earlier period A1, and later period A2 in (ha). To obtain the annual rate of change for each land-use type, the different rates and magnitude of change for two periods that is 2016 to 2019 (3 years), and 2019 to 2022 (3 years), respectively were calculated.

### 5 Results

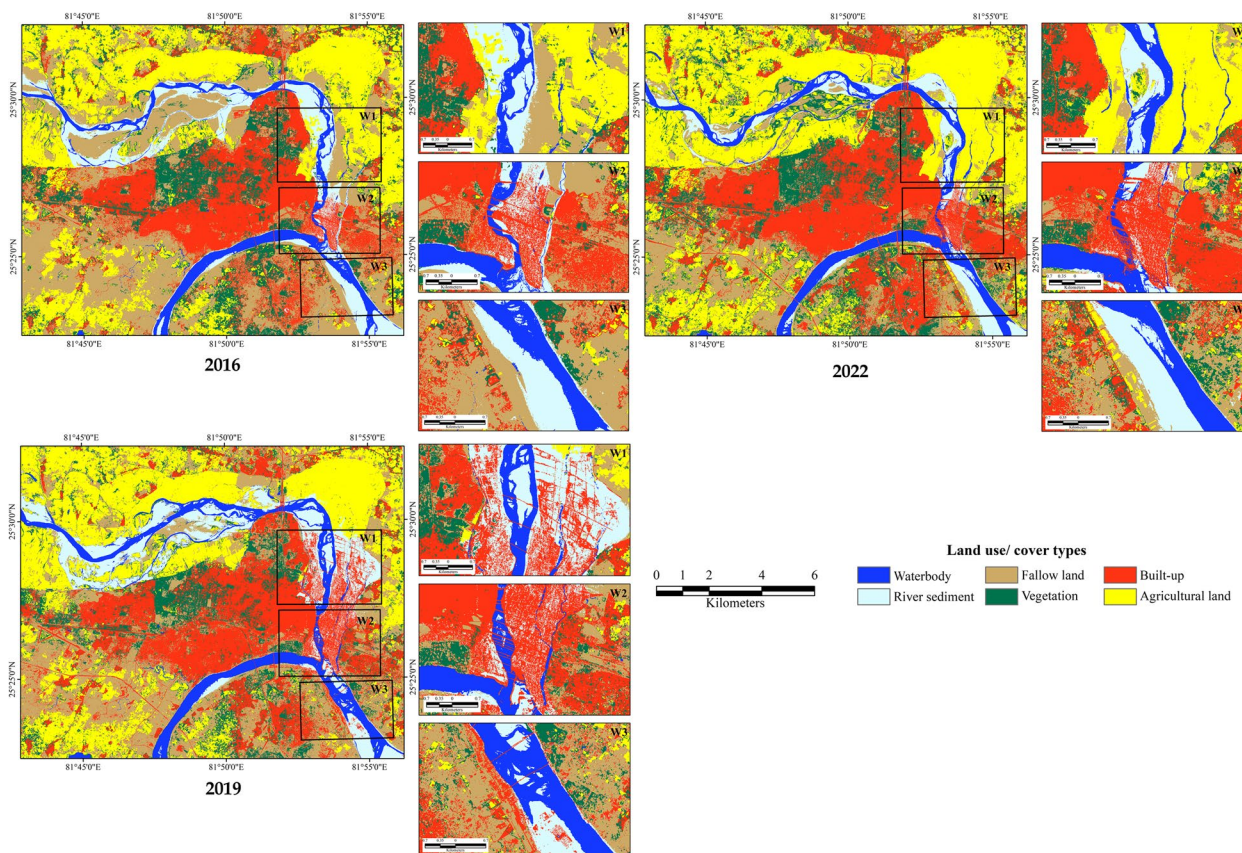
#### 5.1 LULC analysis (2016-2022)

For this study LULC for 2016 (Pre-Kumbh), 2019 (Kumbh), 2022 (Post-Kumbh) were classified (Fig. 3). During pre ‘Kumbh’ period, fallow land covered the major area by 131.24km<sup>2</sup> (30.12%) which is subsequently followed by the agricultural land cover of 116.65km<sup>2</sup> (26.77%), built-up cover of 84.47km<sup>2</sup> (19.39%), vegetation cover of 54.39km<sup>2</sup> (12.48%), river sediment cover

of 30.01km<sup>2</sup> (6.89%) and waterbody cover of 18.92km<sup>2</sup> (4.34%). As shown in Table 6 for the ‘Kumbh’ period, Agricultural land covered the major area of LULC categories by 125.68km<sup>2</sup> (28.85%) which is subsequently followed by fallow land cover area of about 98.22km<sup>2</sup> (22.54%), built-up area cover of about 98.04km<sup>2</sup> (22.50%), vegetation cover area of about 47.92km<sup>2</sup> (11%), river sediment cover area of about 37.91km<sup>2</sup> (8.70%) and waterbody cover area of about 27.91km<sup>2</sup> (6.41%). In Post-Kumbh period, agricultural land covered 147.72km<sup>2</sup> (33.91%) which is subsequently followed by the built-up cover area of about 109.43km<sup>2</sup> (25.12%), fallow land area cover of about 72.02km<sup>2</sup> (16.53%), vegetation cover area of about 63.61km<sup>2</sup> (14.60%), waterbody cover area of about 22.65km<sup>2</sup> (5.20%) and the river sediment cover area of about 4.64km<sup>2</sup> (4.65%).

#### 5.2 Validation of LULC analysis

To determine the accuracy of the three LULC maps used in this study, the ROC and frequency ratio plot, were used. ROC curve analysis is a common method to assess the accuracy of a diagnostic test (Berbaum et al. 2002). The ROC curve is a graphical representation of the



**Fig. 3** Land use land cover during 2016, 2019 and 2022

**Table 6** Aerial distribution of LULC cover over Prayagraj

Year	Area	Waterbody	River sediment	Fallow land	Vegetation	Built-up	Agricultural land
2016	km <sup>2</sup>	18.92	30.01	131.24	54.39	84.47	116.65
	%	4.34	6.89	30.12	12.48	19.39	26.77
2019	km <sup>2</sup>	27.91	37.91	98.22	47.92	98.04	125.68
	%	6.41	8.70	22.54	11.00	22.50	28.85
2022	km <sup>2</sup>	22.65	20.26	72.02	63.61	109.43	147.72
	%	5.20	4.65	16.53	14.60	25.12	33.91

trade-off between the false-negative and false-positive rates for every possible cutoff value. By tradition, the plot shows the false-positive rate (FPR) on the X-axis and the true-positive rate (TPR) on the Y-axis. The area under the ROC curve (AUC) characterizes the quality of a forecast system by describing its ability to anticipate the correct occurrence or non-occurrence of pre-defined 'events'. The best method has a curve with the largest AUC; the AUC varies from 0.5 to 1.0 (Fig. 4). If the model does not predict the occurrence of the landslide any better than chance, the AUC would equal 0.5. A ROC curve of 1 represents the perfect prediction. The quantitative-qualitative relationship between AUC and prediction accuracy can be classified as follows: 0.9–1, excellent; 0.8–0.9, very good; 0.7–0.8, good; 0.6–0.7, average; and 0.5–0.6, poor (Berbaum et al. 2002). The AUC value for the built-up, vegetation and agricultural land falls in the range of 0.848–0.948 (Table 7) which means these classes showed excellent accuracy for all the three periods of the study area. Hence, it is concluded that the binary logistic regression model employed in this study showed good accuracy for the three LULC maps of the study area.

### 5.3 LULC changes

The study period is divided into three stages i.e. pre – Kumbh (2016), Kumbh (2019) and post-'Kumbh'(2022) to examine the effect of development that happened due to the 'Kumbh Mela'. This was studied through LULC maps of a particular year and change detection of two periods i.e., 2016–2019 and 2019–2022 (Fig. 5). Additionally, to comprehend the pattern of land changes brought on by the city's infrastructure development in response to the 'Kumbh' festival. The area of built-up land increased by 5.81% between 2016 and 2019 and was derived from fallow land, then vegetation (1.61%). According to this, vegetation and fallow land were converted in extensive urbanization. 4.3% of the fallow land area and 1.83% of the vegetation area were turned into agricultural land (Table 8).

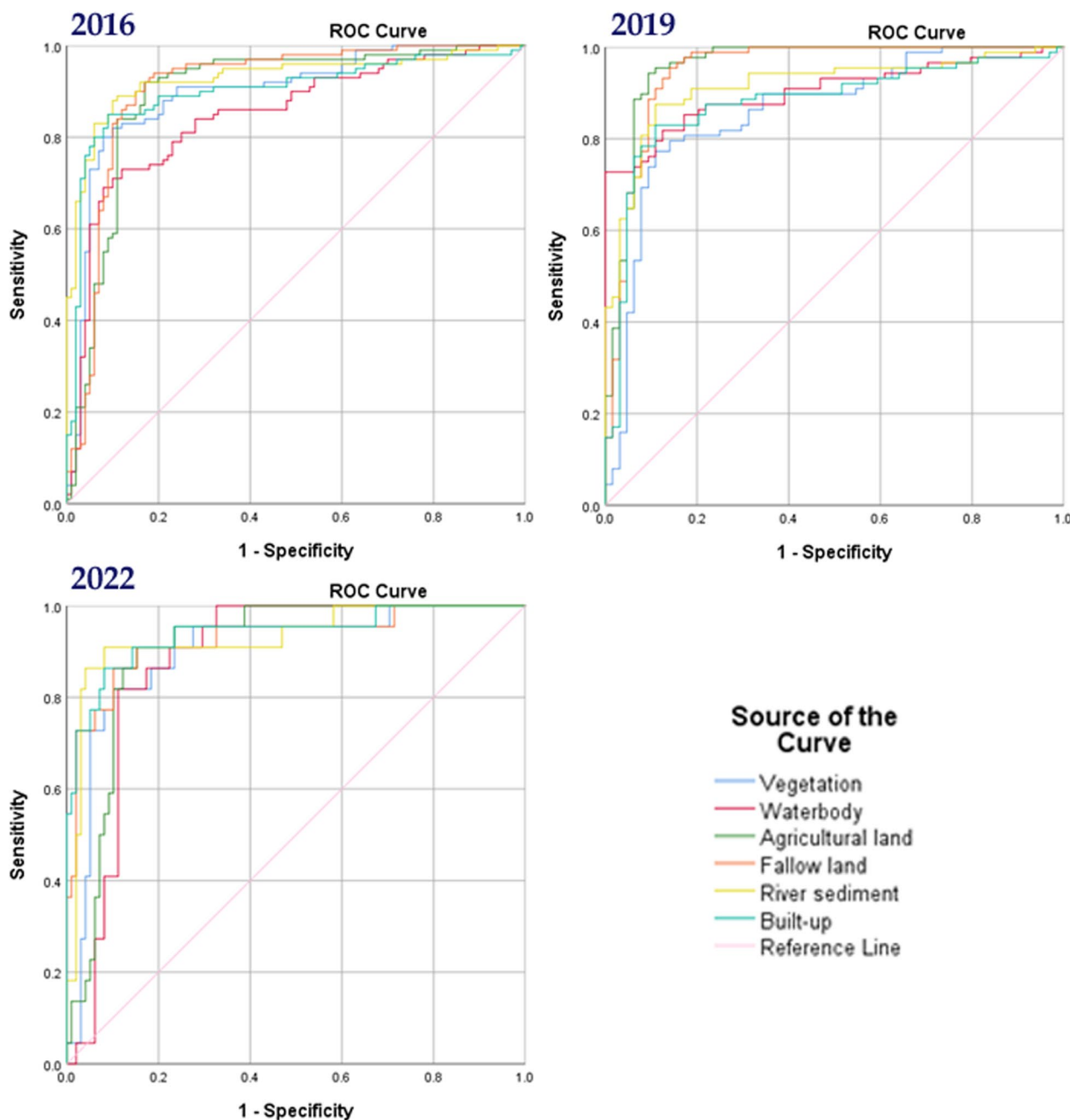
A large portion of the land, both developed and undeveloped, was acquired from agricultural land. A different trend of vegetation gain by built-up was seen as a result of

the city's plantation drive's beautification of squares and walking lanes. and Temporary housing was constructed in the "Kumbh" area at the expense of 1.93% of river sediment and 1.03% of fallow land, respectively (Table 8). The overall shift from 2016 to 2019 explains how urbanization took place at the expense of vegetation and fallow land. Since it couldn't be kept fertile, the majority of the agricultural land was converted to fallow land. These lands were used to build highways on the outskirts of the city, which explains the increase in economic benefit. This was done to enable the proper operation of the 'Kumbh' by providing transportation services, which explains the increase in economic gain.

From 2019 to 2022, the built-up area showed the same trend, with an increase in fallow land (4.55%) and vegetation (2.12%), indicating that LULC classes of fallow land and vegetation were suffering as a result of urbanization. This transition was unusual from the previous one in that vegetation grew on fallow land and agricultural land, respectively, by 3.80% and 1.97% of their respective areas. Agroforestry and afforestation policies may have been implemented as a result of this transition. Given that much of the development and construction has been delayed for a longer period of time, Covid-19 may also be one of the causes of the growth in vegetation.

The three-time windows demonstrate the temporary settlement brought on by the 2019 Kumbh festival had accumulated built-up class from the other classes. This suggests that the majority of agricultural land (1.03%), followed by fallow land (0.65%), and river sediment (0.31%), has been used to develop the built-up class. This is the fertile and practical terrain that can support the density and dynamism of the temporary city as well as the long stretches of largely stable agricultural landscapes in between.

In the year pre- 'Kumbh' period, the majority of land was occupied by the fallow land followed by agricultural land, built-up and vegetation. This means some of the agricultural land was left uncultivated because of less availability of resources which could hamper the food supplies. While change of trend was seen in the 'Kumbh' time the agricultural land was the major LULC class



**Fig. 4** Validation of LULC classes

because many of the uncultivated fallow lands were used to cultivate crops and some of the fallow land was used for new built-up areas (Fig. 6). There was a small decrease in the vegetation class due to the urbanization induced by the 'Kumbh' festival. In the post-'Kumbh' period the same trend was noticed regarding the increase in agricultural land (Fig. 6). While there is a significant increase in the vegetation due to the shift towards agroforestry, afforestation and plantation drive happened because

of the 'Kumbh' festival to beautify squares and dividers. COVID-19 could also be one of the factors for the increase in vegetation as much of the construction and development has been laid back for a longer duration of time. There was a significant increase in the built-up LULC class since 2016 because of the development of a new civil airport, 6 new over bridges, new railway stations and road widening. Land-use change can have significant implications for food security, in addition to



**Table 7** Values of the AUC for each LULC class

Test Result Variable(s)	Area Under the Curve		
	2016	2019	2022
Built-up	0.898	0.86	0.899
Vegetation	0.848	0.903	0.882
Waterbody	0.896	0.958	0.905
Agricultural land	0.909	0.948	0.927
Fallow land	0.929	0.915	0.93
River sediment	0.901	0.878	0.94

its environmental repercussions (Xiao et al. 2006). Conversion of farmed land to non-farm purposes including housing, manufacturing, and infrastructure, along with an increasing population, is seen as a severe danger to future food supplies in several countries (Paarberg, 1997). The LULC change in Prayagraj may have been brought on by human activities such as clearing encroachments, enlarging roads, building overbridges, and constructing railway lines. This infrastructure improvement was carried out to facilitate the Kumbh Mela, a massive pilgrimage gathering that takes place in the study area.

#### 5.4 City infrastructural changes

About five over bridges have been constructed during the Kumbh at different places and it has smoothened road traffic at railway crossings and places like Allahabad High Court. To facilitate the upcoming pilgrims and tourists a new civil airport named Bamrauli airport has been constructed which connects to several important cities including Kolkata, Nagpur, Indore, Lucknow, New Delhi, Bengaluru, Ahmadabad, Dehradun and Patna with Air services.

The roads in Sangam, as well as those leading to public areas like Civil Lines, Katra, and Chowk, as well as those leading to historical structures like the Allahabad High Court, Akbar Fort, and Khushroo Bagh, have all been widened. As part of the effort to widen roads, about 150Km of new road have been built in the city. Due to removal of encroachments, vehicular transportation has improved and congestion on the roads has decreased. Sixty-five roads in various locations throughout the town of Prayagraj have had about 3000 encroachments cleared. The Jhalwa region, which is on the outskirts of the city, is where residential plotting is done because the land prices are lower than in other areas (Fig. 7). The pace of medical school and bypass road construction has increased. This location is closer to the recently constructed civil airport. This area may be a developing peri-urban area that is displacing agricultural land that has been left fallow. Infrastructure growth brought about by pilgrimage contributed to urbanisation. For better connectivity to

the domestic and international airports, the civil airport in Bamrauli was constructed (Fig. 7). Traveling pilgrims and tourists from around the world will find this to be more convenient.

Municipal solid waste management like collection, storage, transportation, recycling, and disposal consume a sizeable portion of municipal budgets. As such, a solid-liquid and biowaste plant has been set up as part of a Smart City plan (Fig. 8). The city's revitalization for the 2019 'Kumbh' was made possible by this pioneering manufacturing facility, which creates tiles and bricks from construction waste. By recovering energy from waste, municipalities can lessen this burden. Municipalities can either use energy they salvage for their everyday operations or sell it to the power grid. East of Sasur Khaderi Nadi and south of Kakaria Ghat work is currently being done on a brand-new railroad bridge known as the GMR (Gandhi Mallikarjuna Rao) Yamuna Railway bridge (Fig. 8). It is designed to accommodate the majority of goods trains so they can clear the way for passenger trains. The 'Alopi Bagh' flyover and the Allahabad High Court flyover have both been built. Because there are so many lawyers working here and there are no parking facilities, they park their cars on the road, which increases traffic. The 'Alopi Bagh' flyover, which connects to the main civil lines area, the old city, and leads to Naini, was built to alleviate the worst traffic congestion because this is the common junction for buses arriving from Varanasi via Jhusi (New industrial area).

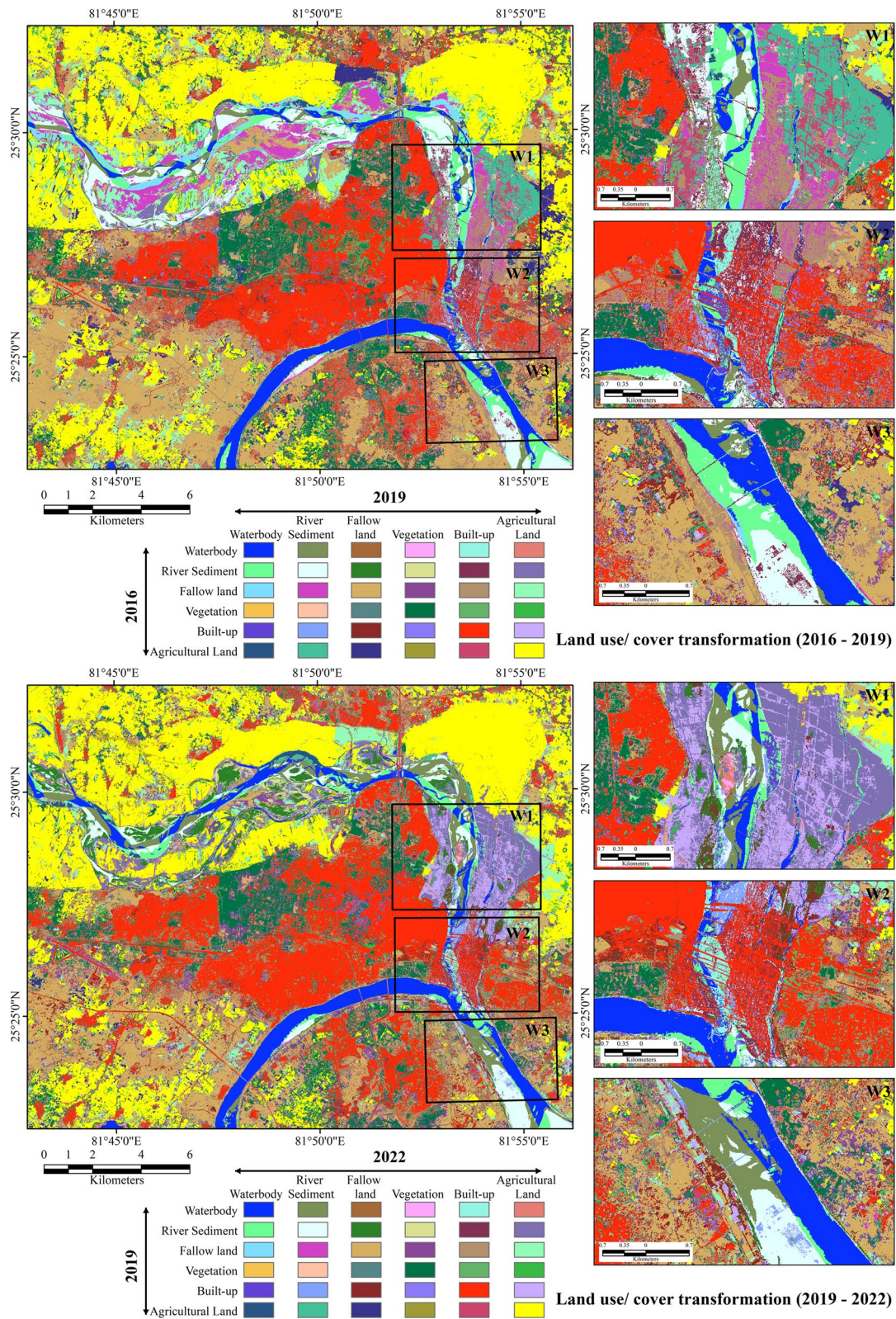
The Yamuna River divides Naini from the city center. It is an industrial area that has grown to include residential areas over the past few years. Currently, the Naini railway station has grown to become a junction (Fig. 9). The majority of the railway stations in Prayagraj City, including Allahabad Junction, Allahabad City, Jhusi, Prayag, Prayag ghat, Naini, Daraganj, and Subedarganj, have not only undergone significant cosmetic improvements but have also received impressive civic amenities. It involves building new platforms, installing lifts, constructing stepped platforms, connecting all platforms with footbridges, and more. Due to 'Kumbh Mela', Allahabad Junction was unable to handle rush-hour traffic, so other railway lines, including Naini, Daraganj, Jhusi, and Prayag, were renovated and developed in order to prevent the influx of passengers, including pilgrims and tourists, which, if not managed, could cause stampedes.

## 6 Discussion

### 6.1 Kumbh-cultural and ecosystem importance

Kumbh mela brings millions of people together and plays a central role in building cultural importance (Saha and Khare, 2020). It involves various social and cultural activities and it has been labelled as intangible cultural





**Fig. 5** Land use/cover transition (2016-2019 and 2019-2022)

**Table 8** Change detection/transformation matrix (2016-2019 and 2019-2022)

		2019					
2016	Waterbody	Waterbody	River sediment	Fallow land	Vegetation	Built-up	Agricultural land
	Waterbody	2.86	1.14	0.04	0.05	0.2	0.05
	River sediment	1.93	3.63	0.17	0.11	0.65	0.4
	Fallow land	1.03	2.49	15.22	1.26	5.81	4.3
	Vegetation	0.16	0.15	1.85	6.89	1.61	1.83
	Built-up	0.16	0.2	3.21	1.72	13.43	0.66
	Agricultural land	0.27	1.1	2.05	0.96	0.8	21.6
		2022					
2019	Waterbody	Waterbody	River sediment	Fallow land	Vegetation	Built-up	Agricultural land
	Waterbody	3.5	1.86	0.18	0.21	0.25	0.41
	River sediment	1.14	2.1	1.78	0.57	0.31	2.79
	Fallow land	0.05	0.08	10.58	3.8	4.55	3.47
	Vegetation	0.06	0.02	0.64	6.86	2.12	1.3
	Built-up	0.22	0.41	2.37	1.18	16.91	1.4
	Agricultural land	0.23	0.18	0.97	1.97	0.96	24.52

heritage of humanity by the United Nations Educational, Scientific and Cultural Organization (UNESCO) in 2017 (Saha and Khare, 2020). This cultural and religious amalgamation not only sustains tourism but also provide livelihood to millions of people (Silva, 2020). It is essential to conserve cultural heritage to promote tolerance and strengthen solidarity and inclusiveness in the society. It also promotes cultural Ecosystem Services (CES) of aesthetics, spiritual and recreational experiences on a mass scale, and requires spatial planning and sustainable development of the event. CES are considered essential for general awareness and conservation programs. Therefore, it is important to incorporate CES into decision making and planning (Daniel et al. 2012). Remote sensing and GIS have been widely used to plan developmental activities; however, their applications are limited when it comes to conserve cultural heritage events like Kumbh. It is important to understand the cultural importance of religious gatherings like Kumbh and motivate people to promote sustainable practices and ecosystem protection.

## 6.2 Implications and policy takeaways

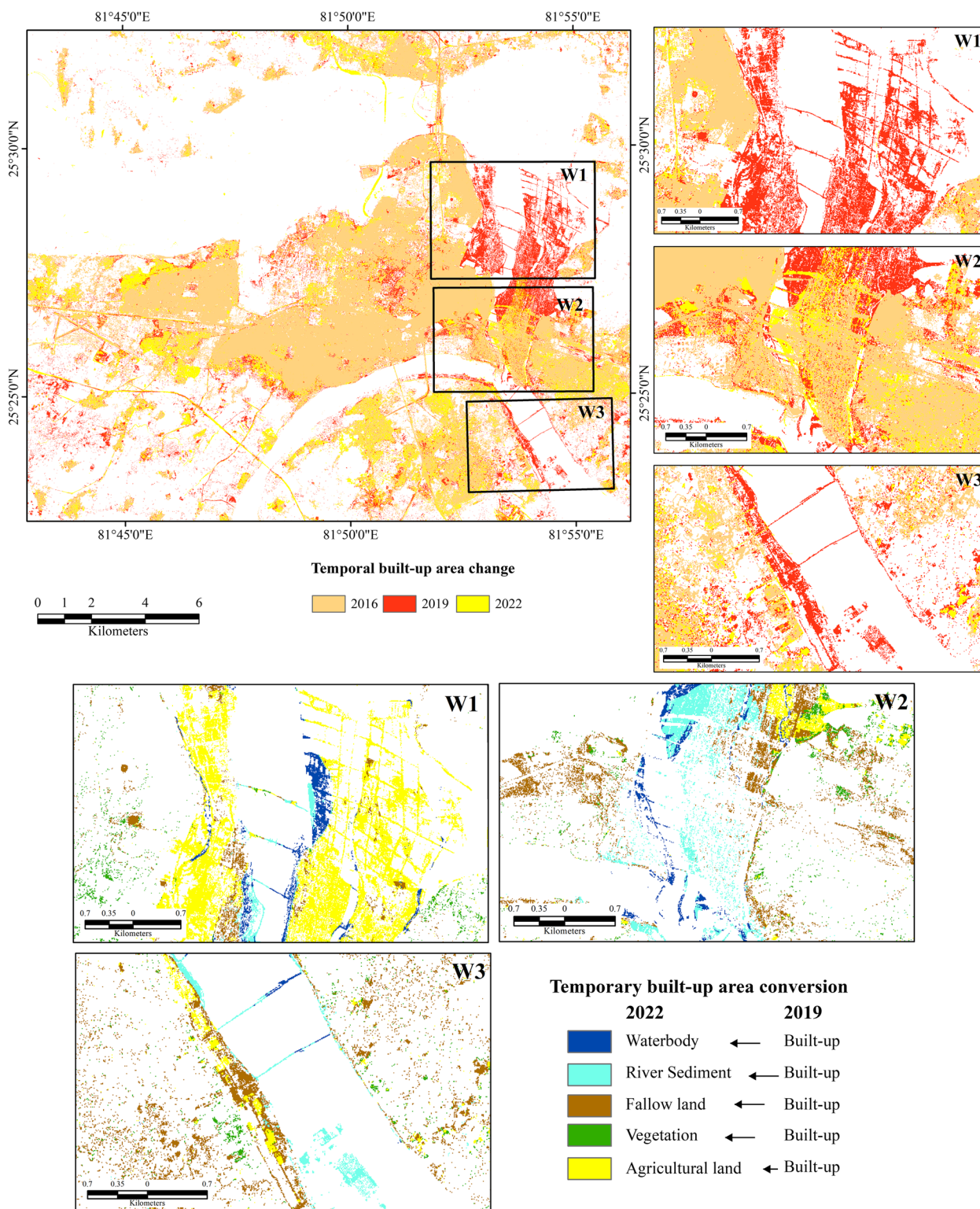
The implications and policy takeaways derived from the study emphasize the critical need for comprehensive and sustainable approaches to address the multi-faceted challenges arising from land transformation in pilgrimage centers, particularly as influenced by events like the 'Kumbh'. Efforts aimed at balancing the preservation of cultural heritage, environmental conservation, and community well-being are paramount for these centers to continue attracting visitors while

safeguarding their unique identity. Sustainable infrastructure development emerges as a pivotal strategy, necessitating careful planning to accommodate pilgrim influx without compromising local resources or ecosystems. Integrated waste management systems, encompassing waste segregation and recycling, stand imperative to curbing the environmental impact of pilgrim activities. Prioritizing cultural heritage management through visitor management plans and sustainable tourism practices becomes crucial for preserving these sites amid developmental changes. Additionally, conducting thorough environmental impact assessments before new developments is vital to identify and mitigate potential ecological ramifications. Engaging local communities in decision-making processes further ensures their perspectives and needs are considered, fostering more inclusive and community-centered development.

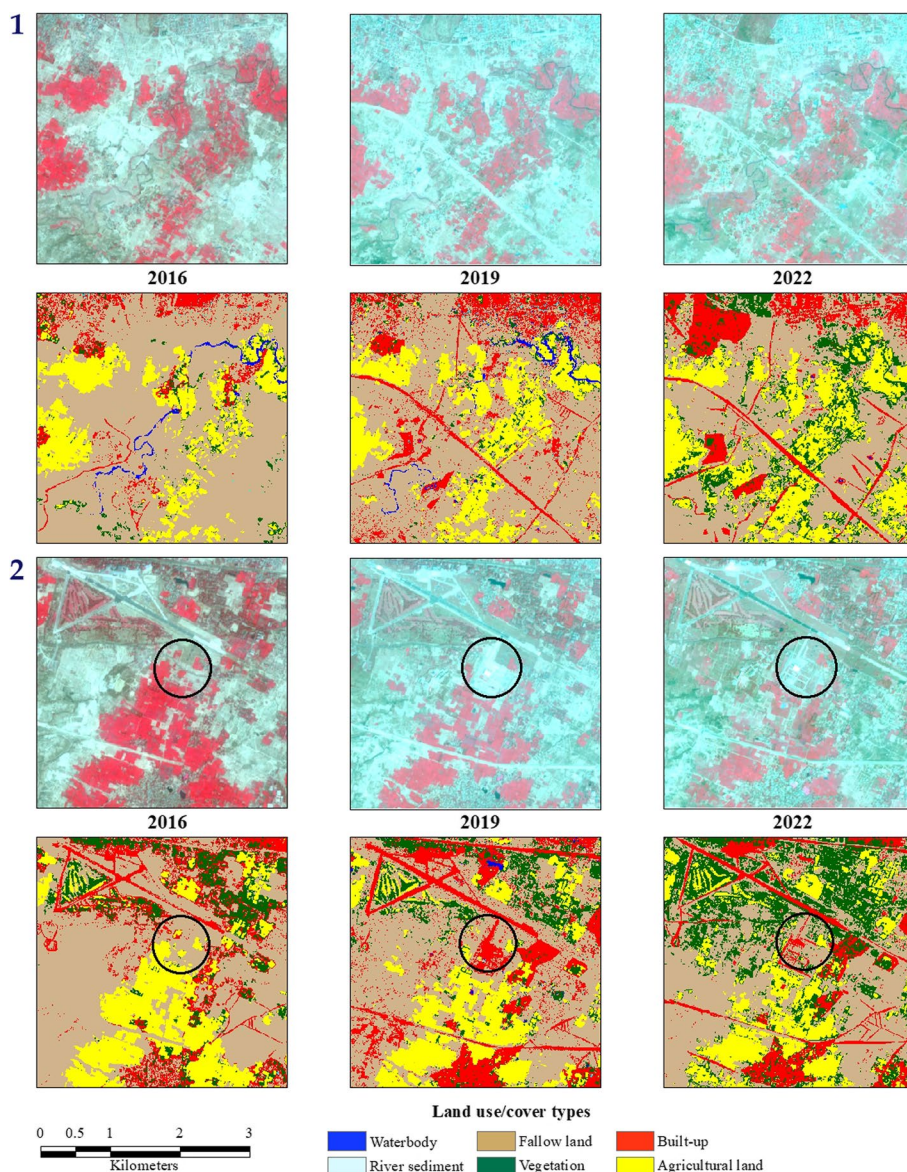
## 7 Conclusion

The LULC of the city may change as a result of a pilgrimage festival like 'Kumbh'. Through infrastructure development, such as road enlargement, road, railway, and airport construction, as well as the erection of industries and hotels, the 'Kumbh' has the potential to alter the physical, social, economic, and ecological environments. This study was chosen to examine the effects of the LULC change as influenced by urban development. By providing pilgrims and tourists with the bare necessities and facilities they need, as well as the citizens of the city with a sustainable urban infrastructure,





**Fig. 6** Temporary built-up area changes and conversion in the 'Kumbh' area (2019-2022)

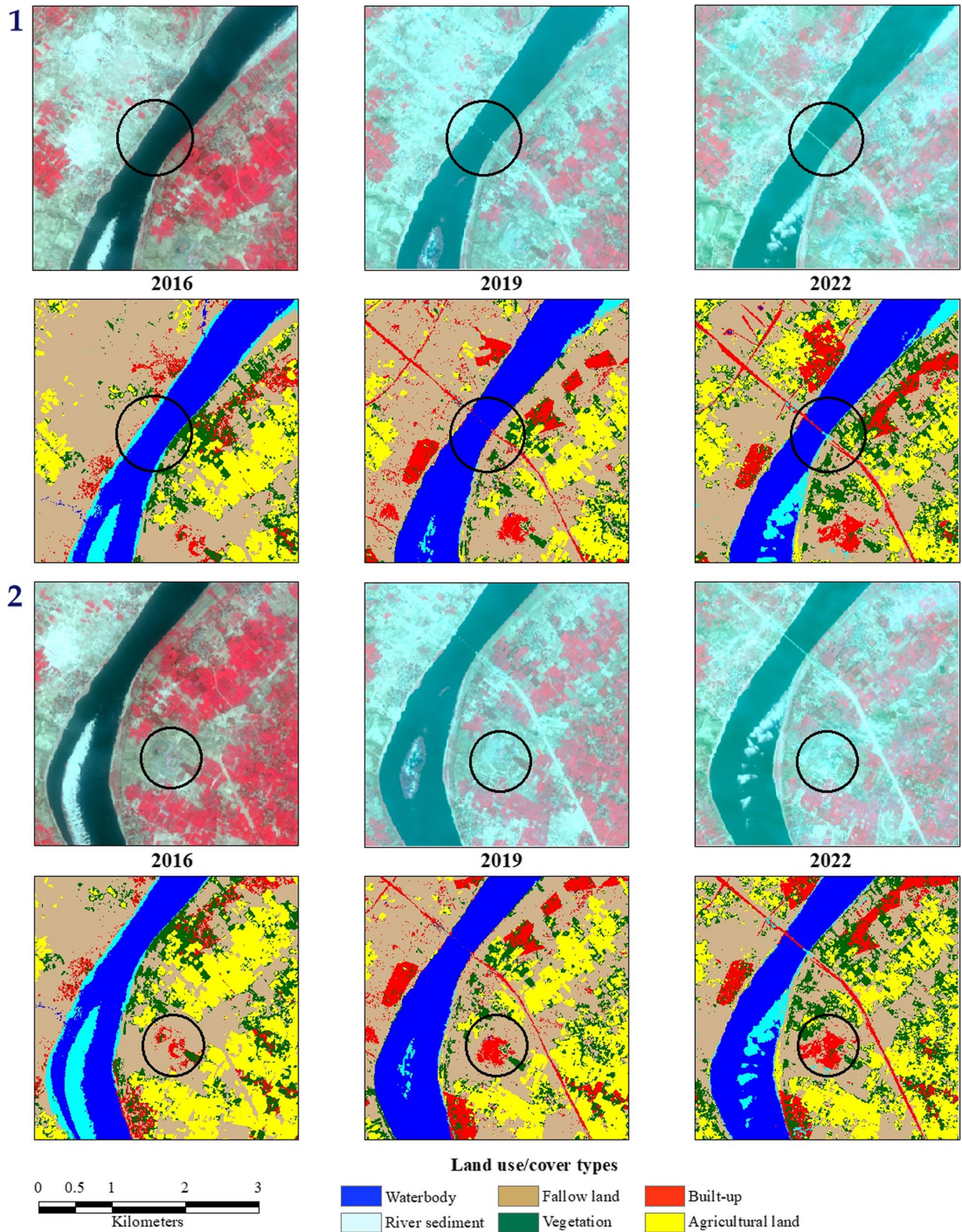


**Fig. 7** City infrastructural change 1. Urban development in Jhalwa region; 2. A new civil airport at Bamrauli

these developments were made to ensure that the ‘Kumbh’ could operate successfully. In order to learn about the LULC for 6 years, which has been divided into Pre-Kumbh (2016), ‘Kumbh’ (2019), and Post-‘Kumbh’ phases, the study has used the MLC supervised classification (2022). Up until 2022, there was an increase in the built-up area trend, which went from 19.39 to 25% of the total area (Table 2). Urbanization is happening at the expense of vegetation, fallow land, and agricultural land, and it is increasing significantly. The success of the agroforestry policy and the plantation drive is also demonstrated by an eye-catching increase in vegetation. For the ecological setting of such urban centers, the COVID-19 is a blessing in disguise.

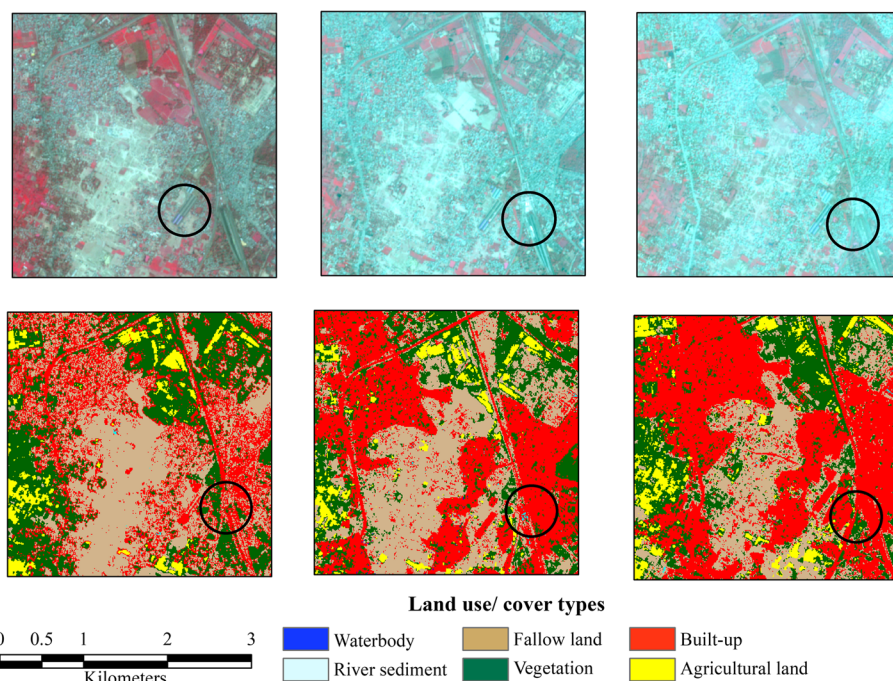
The ROC curve and AUC method were used to assess accuracy and provide the accuracy level for each class across the various periods. The main LULC classes, such as built-up, vegetation, and agricultural land, have AUC values close to 0.9, indicating excellent data accuracy. The change matrix of the study area was investigated using the post-classification change detection technique. When 10 million people live there on auspicious days, it functions as a mini-city and is built on agricultural land and river sediment. The successful movement of the crowds inside this miniature city was made possible by the pontoon bridges that were constructed across the river. They were also a crucial component in the rapid relocation of the river system. The Solid-liquid Biogas Plant is the first





**Fig. 8** City infrastructural change 1. GMR Yamuna Railway bridge; 2. Solid-Liquid biogas plant





**Fig. 9** Urbanization in Naini and expansion of Naini junction

facility to turn construction waste into bricks and tiles. This method of managing solid waste in the city is efficient. Environmental deterioration might be partially controlled if the developments are planned carefully. It can be assumed that both positive and negative effects resulted from it. Examining the LULC changes brought on by pilgrimage could help with resilient and sustainable urban planning. This study discovered that the ‘Kumbh’ not only brought together a sizable number of people, but it also increased the capacity of this holy city for accommodating people by developing its infrastructure. It also helped us understand how the Kumbh affected the ecosystem services provided by the cultural sector. It encourages geospatial technologies to comprehend how this level of pilgrim gathering affects developmental activities and planning.

**Acknowledgements**

Authors would like to acknowledge URGENT project for providing equipment and lab facilities to conduct this study.

**Authors’ contributions**

Yadav D. collected data, prepared maps, and wrote part of manuscript; Mahato S. supervised, framework of the study, wrote part and finalized the manuscript; Choudhary A. visualized the work and finalized the work; Joshi PK. Supervised, correction, editing and finalized the manuscript.

**Funding**

The authors declare that no funds, grants, or other support were received during the preparation of this manuscript.

**Availability of data and materials**

All the data and materials related to the manuscript are published with the paper, and available from the corresponding author upon request.

**Declarations**

**Competing interests**

The authors declare that they have no conflict of interest.

Received: 14 July 2023 Revised: 12 December 2023 Accepted: 5 January 2024

Published online: 21 March 2024

**References**

Aggrawal, V., Dikid, T., Jain, S. K., Pandey, A., Khasnobis, P., Choudhary, S., Chandra, R., Patil, A., Maramraj, K. K., Talyan, A., Singh, A., Babu, B. S., Kumar, A., Kumar, D., Raveesh, P. M., Singh, J., Kumar, R., Qadri, S. S., Madan, P., et al. (2020). Disease surveillance during a large religious mass gathering in India: The Prayagraj Kumbh 2019 experience. *International Journal of Infectious Diseases*, *101*, 167–173. <https://doi.org/10.1016/j.ijid.2020.09.1424>

Berbaum, K. S., Dorfman, D. D., Franken, E. A., & Caldwell, R. T. (2002). An empirical comparison of discrete ratings and subjective probability ratings. *Academic Radiology*, *9*(7), 756–763. [https://doi.org/10.1016/S1076-6332\(03\)80344-6](https://doi.org/10.1016/S1076-6332(03)80344-6)

Bhadula, S., Sanskriti Vishwavidyalaya, D., Sharma, V., & Joshi, B. D. (2012). Impact of mass bathing on water quality of Ganga River during Maha Kumbh-2010. *Nature and Science of Sleep*. <http://www.sciencepub.net/nature>

Bhardwaj, S. M. (1973). *Hindu places of pilgrimage in India; A study in cultural geography*. University of California Press.

- Bhutiani, R., Khanna, D. R., Kulkarni, D. B., & Ruhela, M. (2016). Assessment of ganga river ecosystem at Haridwar, Uttarakhand, India with reference to water quality indices. *Applied Water Science*, 6(2), 107–113. <https://doi.org/10.1007/s13201-014-0206-6>
- Bisht, A., Kamboj, N., & Kamboj, V. (2022). Groundwater quality and potential health risk assessment in the vicinity of solid waste dumping sites of quaternary shallow water aquifers of Ganga Basin. *Water, Air, & Soil Pollution*, 233(12), 485. <https://doi.org/10.1007/s11270-022-05954-6>
- Brace, C., Bailey, A. R., & Harvey, D. C. (2006). Religion, place and space: a framework for investigating historical geographies of religious identities and communities. *Progress in Human Geography*, 30(1), 28–43. <https://doi.org/10.1191/0309132506ph5890a>
- Buzinde, C. N., Kalavar, J. M., Kohli, N., & Manuel-Navarrete, D. (2014). Emic understandings of Kumbh Mela pilgrimage experiences. *Annals of Tourism Research*, 49, 1–18.
- Chadha, H., & Onkar, P. (2016). Changing cities in the perspective of religious tourism – A case of Allahabad. *Procedia Technology*, 24, 1706–1713. <https://doi.org/10.1016/j.protcy.2016.05.200>
- Chandan, S., & Kumar, A. (2019). Challenges for urban conservation of core area in pilgrim cities of India. *Journal of Urban Management*, 8(3), 472–484. <https://doi.org/10.1016/j.jum.2019.05.001>
- Daniel, T. C., Muhar, A., Arnberger, A., Aznar, O., Boyd, J. W., Chan, K. M. A., Costanza, R., Elmquist, T., Flint, C. G., Gobster, P. H., Grêt-Regamey, A., Lave, R., Muhar, S., Penker, M., Ribe, R. G., Schauppenlehner, T., Sikor, T., Soloviy, I., Spierenburg, M., ... & von der Dunk, A. (2012). Contributions of cultural services to the ecosystem services agenda. *Proceedings of the National Academy of Sciences*, 109(23), 8812–8819. <https://doi.org/10.1073/pnas.1114773109>
- David, S., & Roy, N. (2016). Public health perspectives from the biggest human mass gathering on earth: Kumbh Mela, India. *International Journal of Infectious Diseases*, 47, 42–45.
- Duan, C., Shi, P., Song, M., Zhang, X., Zong, N., & Zhou, C. (2019). Land use and land cover change in the Kailash sacred landscape of China. *Sustainability*, 11(6). <https://doi.org/10.3390/su11061788>
- Forouhar, A., & Hasankhani, M. (2018). Urban renewal mega projects and residents' quality of life: Evidence from historical religious Center of Mashhad Metropolis. *Journal of Urban Health*, 95. <https://doi.org/10.1007/s11524-017-0224-4>
- Goel, P., Dhuria, M., Yadav, R., Khasnabis, P., Meena, S., & Venkatesh, S. (2020). Public health surveillance during Simhastha Kumbh, a religious mass gathering in Ujjain district, Madhya Pradesh, India, 2016. *Indian Journal of Public Health*, 64, 198. <https://link.gale.com/apps/doc/A627561118/AONE?u=anon~1b1d3952&sid=googleScholar&id=c77f0476>
- Greenough, P. G. (2013). The Kumbh Mela stampede: Disaster preparedness must bridge jurisdictions. *BMJ*, 346.
- Holman, S. R., & Shayegan, L. (2014). Toilets and sanitation at the Kumbh Mela. [http://www.who.int/healthinfo/global\\_burden\\_disease/metrics\\_daly/en/](http://www.who.int/healthinfo/global_burden_disease/metrics_daly/en/).
- Hossain, F., & Moniruzzaman, D. M. (2021). Environmental change detection through remote sensing technique: A study of Rohingya refugee camp area (Ukhia and Teknaf sub-district). In *Cox's bazar, Bangladesh. In environmental challenges (Vol. 2)*. <https://doi.org/10.1016/j.envc.2021.100024>
- Houghton, R. A. (1994). The worldwide extent of land-use change. *BioScience*, 44(5), 305–313.
- Kala, D., & Chaubey, D. S. (2023). Residents' perception and support before and after a mega-religious event during COVID-19 in India. *International Journal of Religious Tourism and Pilgrimage*, 11(1), 1–12. <https://doi.org/10.21427/W5AK-H759>
- Kanaujia, A. K., & Tiwari, V. (2022). Crowd management and strategies for security and surveillance during the large mass gathering events: The Prayagraj Kumbh Mela 2019 experience. *National Academy Science Letters*, 45(3), 263–273. <https://doi.org/10.1007/s40009-022-01114-w>
- Kanaujia, A. K., & Tiwari, V. (2023). *Water quality analysis of River Ganga and Yamuna using water quality index (WQI) during Kumbh Mela 2019*. Prayagraj: Environment, Development and Sustainability. <https://doi.org/10.1007/s10668-023-02907-9>
- Kumar Dutta, R. (2022). Sustainable development of tourism in Haridwar, Uttarakhand. *INDIAN JOURNAL OF LANDSCAPE SYSTEMS AND ECOLOGICAL STUDIES*. <https://www.researchgate.net/publication/370204028>
- Lambin, E. F. (1999). Monitoring forest degradation in tropical regions by remote sensing: Some methodological issues. *Global Ecology and Biogeography*, 8(3–4), 191–198.
- Lambin, E. F., Geist, H. J., & Lepers, E. (2003). Dynamics of Land-Use and Land-Cover Change in Tropical Regions. *Annual Review of Environment and Resources*, 28(1), 205–241. <https://doi.org/10.1146/annurev.energy.28.050302.105459>
- Lambin, E. F., Turner, B. L., Geist, H. J., Angbalo, S. B., Angelsen, A., Bruce, J. W., Coomes, O. T., Dirzo, R., Fischer, G., Folke, C., & George, P. (2001). The causes of land-use and land-cover change: Moving beyond the myths. *Global Environmental Change*, 11(4), 261–269.
- Lu, D., Mausel, P., Brondizio, E., & Moran, E. (2004). Change detection techniques. *International Journal of Remote Sensing*, 25(12), 2365–2401.
- Mahato, S., & Pal, S. (2018). Changing land surface temperature of a rural Rarh tract river basin of India. *Remote Sensing Applications: Society and Environment*, 10, 209–223.
- Mahato, S., Pal, S., Talukdar, S., Saha, T. K., & Mandal, P. (2021). Field based index of flood vulnerability (IFV): A new validation technique for flood susceptible models. *Geoscience Frontiers*, 12(5), 101175.
- Matlhodi, B., Kenabatho, P. K., Parida, B. P., & Maphanyane, J. G. (2019). Evaluating land use and land cover change in the Gaborone dam catchment, Botswana, from 1984–2015 using GIS and remote sensing. *Sustainability*, 11(19), 5174.
- Matta, G., Srivastava, S., Pandey, R. R., & Saini, K. K. (2017). Assessment of physicochemical characteristics of Ganga Canal water quality in Uttarakhand. *Environment, Development and Sustainability*, 19(2), 419–431. <https://doi.org/10.1007/s10668-015-9735-x>
- Maurya, P. K., Ali, S. A., Alharbi, R. S., Yadav, K. K., Alfaisal, F. M., Ahmad, A., Dittthakrit, P., Prasad, S., Jung, Y.-K., & Jeon, B.-H. (2021). Impacts of land use change on water quality index in the upper Ganges River near Haridwar, Uttarakhand: A GIS-based analysis. *Water*, 13(24). <https://doi.org/10.3390/w13243572>
- Memish, Z. A., Steffen, R., White, P., Dar, O., Azhar, E. I., Sharma, A., & Zumla, A. (2019). Mass gatherings medicine: Public health issues arising from mass gathering religious and sporting events. *The Lancet*, 393(10185), 2073–2084.
- Mishra, B., Baghel, A. S., Paliwal, D., & Chauhan, D. S. (2020). Study of spiritual health determinants in Indian saints (sadhus) at Ujjain Kumbh Mela (Simhastha) 2016. *Journal of Religion and Health*, 59(3), 1233–1257. <https://doi.org/10.1007/s10943-019-00764-3>
- Mishra, P. K., Rai, A., & Rai, S. C. (2020). Land use and land cover change detection using geospatial techniques in the Sikkim Himalaya, India. *Egyptian Journal of Remote Sensing and Space Science*, 23(2), 133–143.
- Nicu, I. C., & Stoleriu, C. C. (2019). Land use changes and dynamics over the last century around churches of Moldavia, Bukovina, northern Romania – Challenges and future perspectives. *Habitat International*, 88, 101979. <https://doi.org/10.1016/j.habitatint.2019.04.006>
- Nikita, B., Bahade, I., & Jawale, M. (2024). Best practices of solid waste management and its application to Nashik City. In N. D. K. A., S. A. Yadav, D. Kunwar, & Jariwala (Eds.), *Recent advances in sustainable waste management practices* (pp. 1–20). Springer Nature Singapore.
- Paarlberg, R. L. (1997). Feeding China: A confident view. *Food Policy*, 22(3), 269–279.
- Patil, V. B., Pinto, S. M., Govindaraju, T., Hebbalu, V. S., Bhat, V., & Kannanur, L. N. (2020). Multivariate statistics and water quality index (WQI) approach for geochemical assessment of groundwater quality—a case study of Kanavi Halla Sub-Basin, Belagavi. *India. Environmental Geochemistry and Health*, 42(9), 2667–2684. <https://doi.org/10.1007/s10653-019-00500-6>
- Petit, C., Scudder, T., & Lambin, E. (2001). Quantifying processes of land-cover change by remote sensing: Resettlement and rapid land-cover changes in South-Eastern Zambia. *International Journal of Remote Sensing*, 22(17), 3435–3456.
- Pontius, R. G., Jr., & Schneider, L. C. (2001). Land-cover change model validation by an ROC method for the Ipswich watershed, Massachusetts, USA. *Agriculture, Ecosystems & Environment*, 85(1–3), 239–248.
- Pourghasemi, H. R., Moradi, H. R., & Fatemi Aghda, S. M. (2013). Landslide susceptibility mapping by binary logistic regression, analytical hierarchy process, and statistical index models and assessment of their performances. *Natural Hazards*, 69(1), 749–779.

- Project, TB, Finlay, V., Hilliard, A., Patel, G., & Elkin, C. (2012). Published by the Alliance of religions and conservation (ARC) with the support of ICLEI, Local Governments for Sustainability. <http://www.arcworld.org/downloads/GPN-India-Handbook.pdf>
- Quadri, S. A., & Padala, P. R. (2021). An aspect of Kumbh Mela massive gathering and COVID-19. *Current Tropical Medicine Reports*, 8(3), 225–230.
- Raghav, S., Singh, S. K., & Bhatia, T. (2020). Environmental Management in the World's largest mass gathering Kumbh Mela. *IJIRST-International Journal for Innovative Research in Science & Technology*, 4(7), 25–34. <https://doi.org/10.26562/IRJCS.2020.APS10080>
- Ruback, R. B., Pandey, J., & Kohli, N. (2008). Evaluations of a sacred place: Role and religious belief at the Magh Mela. *Journal of Environmental Psychology*, 28(2), 174–184.
- Saha, K., & Khare, R. (2020). A Geospatial Approach to Conserving Cultural Heritage Tourism at Kumbh Mela Events in India. In N. Wise & T. Jimura (Eds.), *Tourism, Cultural Heritage and Urban Regeneration: Changing Spaces in Historical Places* (pp. 125–140). Springer International Publishing. [https://doi.org/10.1007/978-3-030-41905-9\\_9](https://doi.org/10.1007/978-3-030-41905-9_9)
- Sarif, M., & Gupta, R. D. (2022). Spatiotemporal mapping of land use/land cover dynamics using remote sensing and GIS approach: A case study of Prayagraj City, India (1988–2018). *Environment, Development and Sustainability*, 24(1), 888–920.
- Sewnet, A. (2015). Land use/cover change at infraz watershed, Northwestern Ethiopia. *Journal of Landscape Ecology*, 8(1), 69–83.
- Sharma, A., Gupta, B., Petersen, E., Lee, S. S., & Zumla, A. (2023). Enhancing preparedness for reducing transmission and globalisation of antimicrobial resistance at the Ardh Kumbh Mela 2025, the world's largest recurring religious mass gathering. In *International Journal of Infectious Diseases* (Vol. 137, pp. 79–81). Elsevier B.V. <https://doi.org/10.1016/j.ijid.2023.10.014>.
- Shinde, K. A. (2012). Place-making and environmental change in a Hindu pilgrimage site in India. *Geoforum*, 43(1), 116–127.
- Shinde, K. A. (2017). Planning for urbanization in religious tourism destinations: Insights from Shirdi, India. *Planning Practice and Research*, 32(2), 132–151. <https://doi.org/10.1080/02697459.2016.1198197>
- Shinde, K. A. (2021). The environmental impacts of religious and spiritual tourism. In *The Routledge handbook of religious and spiritual tourism* (pp. 315–331). Taylor and Francis Inc.. <https://doi.org/10.4324/9780429201011-27>
- Shinde, K. A., & Olsen, D. H. (2023). Reframing the intersections of pilgrimage, religious tourism, and sustainability. *Sustainability*, 15(1). <https://doi.org/10.3390/su15010461>.
- Silva, K. (Ed.). (2020). *The Routledge Handbook on Historic Urban Landscapes in the Asia-Pacific (1st ed.)*. Routledge. <https://doi.org/10.4324/9780429486470>
- Singh, R. P. B., Rana, P. S., & Olsen, D. H. (2021). Environment as a sacred space. In *The Routledge handbook of religious and spiritual tourism* (pp. 135–151). Routledge. <https://doi.org/10.4324/9780429201011-12>
- Varma, K., Tripathi, P., Upadhyaya, S., Srivastava, A., Ravi, N. K., Singhal, A., & Jha, P. K. (2022). Assessment of mass bathing event (Kumbh- 2019) impact on the river water quality by using multivariate analysis and water quality index (WQI) techniques at Sangam (Prayagraj). *India. Groundwater for Sustainable Development*, 17, 100750. <https://doi.org/10.1016/j.gsd.2022.100750>
- Veldkamp, A., & Lambin, E. F. (2001). Predicting land-use change. *Agriculture, Ecosystems & Environment*, 85(1–3), 1–6.
- Verburg, P. H., De Koning, G. H. J., Kok, K., Veldkamp, A., & Bouma, J. (1999). A spatial explicit allocation procedure for modelling the pattern of land use change based upon actual land use. *Ecological Modelling*, 116(1), 45–61.
- VS, K., & Firoz, M. (2022). Benchmarking sustainability of pilgrimage cities: A case of three cities in Tamil Nadu, India. *Benchmarking: An International Journal*, 30. <https://doi.org/10.1108/BIJ-09-2021-0547>
- Xiao, J., Shen, Y., Ge, J., Tateishi, R., Tang, C., Liang, Y., & Huang, Z. (2006). Evaluating urban expansion and land use change in Shijiazhuang, China, by using GIS and remote sensing. *Landscape and Urban Planning*, 75(1–2), 69–80. <https://doi.org/10.1016/j.landurbplan.2004.12.005>
- Yadav K Bhatia, S. R. (2020). Assessment of mass bathing on river ganga water quality during kumbh Mela 2019 in Prayagraj, Uttar Pradesh, India. *International Research Journal of Engineering and Technology*. [www.irjet.net](http://www.irjet.net)
- Yadav, S. K., Dubey, A., Singh, S. K., & Yadav, D. (2020). Spatial regionalisation of morphometric characteristics of mini watershed of Northern Foreland of Peninsular India. *Arabian Journal of Geosciences*, 13, 1–16.
- Yamin, M. (2019). Managing crowds with technology: Cases of hajj and Kumbh Mela. *International Journal of Information Technology*, 11(2), 229–237.
- Yedage, A., Sawant, N., & Malave, V. (2015a). Change detection analysis using geo-spatial technique: A case study of South Goa. *Studies*, 10, 11.
- Yedage, A., Sawant, N., & Malave, V. (2015b). Change-detection-analysis-using-geo-spatial-technique-A-case-study-of-South-Goa.Doc. *International Journal of Scientific & Engineering Research*, 6(6). <http://www.ijser.org>

## Publisher's Note

Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.