



ORIGINAL PAPER

Open Access



Evaluating urban green and blue spaces with space-based multi-sensor datasets for sustainable development

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Abstract

Urban green and blue spaces refer to the natural and semi-natural areas within a city or urban area. These spaces can include parks, gardens, rivers, lakes, and other bodies of water. They play a vital role in the sustainability of cities by providing a range of ecosystem services such as air purification, carbon sequestration, water management, and biodiversity conservation. They also provide recreational and social benefits, such as promoting physical activity, mental well-being, and community cohesion. Urban green and blue spaces can also act as buffers against the negative impacts of urbanization, such as reducing the heat island effect and mitigating the effects of stormwater runoff. Therefore, it is important to maintain and enhance these spaces to ensure a healthy and sustainable urban environment. Assessing urban green and blue spaces with space-based multi-sensor datasets can be a valuable tool for sustainable development. These datasets can provide information on the location, size, and condition of green and blue spaces in urban areas, which can be used to inform decisions about land use, conservation, and urban planning. Space-based sensors, such as satellites, can provide high-resolution data that can be used to map and monitor changes in these spaces over time. Additionally, multi-sensor datasets can be used to gather information on a variety of environmental factors, such as air and water quality, that can impact the health and well-being of urban residents. This information can be used to develop sustainable solutions for preserving and enhancing urban green and blue spaces. This study examines how urban green and blue infrastructures might improve sustainable development. Space-based multi-sensor datasets are used to estimate urban green and blue zones for sustainable development. This work can inform sustainable development research at additional spatial and temporal scales.

Keywords Urban green spaces, Blue spaces, Sustainable development, Space-based multi-sensor datasets, Data fusion, Spatial resolution, SAR, Sustainable development

1 Introduction

The huge geographical distribution of landscape patches and the overall urban layout evolves constantly with urban expansion under the impact of various elements, the most important of which are blue-green infrastructures, which is known as the urban landscape pattern. Blue-green areas, at the macro level, are the sum of blue and green space, comprising all water and green space, that makes up the city's overall landscape pattern (Eggmann, 2022; Loukanov et al., 2020; Shahmohamadi et al., 2011). Mountains, forest land, farmland, grassland, and ecological corridor, as well as huge green space, belt

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green space, protective green belt, public open space, and green roofs in the city, are all examples of “green space” (Song et al., 2021; Wang et al., 2022). The term “blue space” refers to both linear and planar water bodies, such as rivers and marshes. An indivisible “organic aggregation” of the urban ecological framework, urban blue-green space is a governing factor closely associated with urban sustainable development and residents’ lives (Ile & Ziemelniece, 2019; Rana & Iлина, 2021). To accomplish urban ecological security and system integrity, improve urban functions and charm qualities, and ensure high-quality urban growth, increasing the share of blue and green space is a critical phase (Kai et al., 2022; Plieninger et al., 2022). There is a lot of evidence suggesting if communities could interact with natural processes and systems, they would be better able to adapt. People and wildlife benefit from blue-green infrastructure in a variety of ways (Cooper et al., 2022; Shahid et al., 2021). All of these advantages contribute to better human health and urban ecosystems. As a result of these qualities, humans are more resilient to the effects of climate change, particularly greater temperatures and flooding, which are two of the most serious climate threats (Halder et al., 2021; He & Shi, 2022). Instead, it might be more advantageous to establish a collection of ‘win-win’ Blue-Green Infrastructure (BGI) solutions that, in most cases, offer net advantages and minimal unfavourable trade-offs. Water, transportation, and housing are just a few of the sectors that make up urban infrastructure systems (Hirpa et al., 2022; Singh et al., 2020). These systems interact with one another, as well as other infrastructures and the environment (Yan et al., 2021). From resource extraction to pollution and waste, each of these industries places various strains on the environment and human well-being (Halbac-Cotoara-zamfir et al., 2021). A planned technique to connect the constituents of a structure is provided by systems thinking. This can assist decision-makers in developing a shared understanding of the system and making decisions that support the overall goals (Nowak et al., 2022; Si et al., 2022). This method can also aid stakeholders in comprehending their operations from the standpoint of sustainable development, taking into consideration environmental, social, and economic factors. As a result, they’ll be able to evaluate BGI’s contribution to mitigating their impacts and lowering operational expenses (Liu et al., 2022; Shubin, 2019).

For metropolitan regions dealing with the effects of climate change, blue-green infrastructure offers a practical and worthwhile answer. It sustains grey infrastructure and, in some situations, replaces it. In urban landscape design, BGI links vegetation systems and urban hydrological functions (blue infrastructure and green infrastructure). It offers larger overall socioeconomic benefits than

the combination of its constituent parts. A city that successfully integrates natural systems to manage blue-green infrastructure to provide offer ecological and aesthetic benefits. However, a similar resource often offers a variety of benefits that advance both “green” and “blue” goals. Cities and communities can gain via effective infrastructure, increased collaboration, and heightened advantages by consciously planning for green–blue infrastructure that accomplishes several goals. Changes like green–blue infrastructure solutions, or in the size or target areas for their implementation, may be necessitated by examining the fundamental forces that motivate the development of such systems. Amenity-driven and local economic value-creating activities may prioritize the maintenance and development of gateway areas, pedestrian pathways, and rejuvenation areas by, for instance, planting more trees, gardening, and installing water features (Yang Song et al., 2020, 2022). Focus may switch to large-scale programs in parks and canal corridors, where rainwater may be locally collected and harvested for irrigation purposes. Green policies and environmental initiatives may support BGI technologies. Whether BGI is expressly addressed in a sustainability program or not, the BGI strategy aligns with often-claimed program goals including reducing the urban heat island effect, improving air quality, and flood mitigation. Transport and other grey infrastructure projects have increased competition for urban public areas. As ecosystems lose vegetation, industrialized regions provide fewer ecological services. Fragmented city natural systems don’t operate well. Their advantages are less than their potential. Changes in land use and development of urbanized regions affect biodiversity, air quality, groundwater supplies, urban water infiltration, flood hazards, and city centre overheating. Blue and Green Infrastructure is a major Nature-Based Solution (NBS) for sustainable stormwater management in cities, and it extends Ecosystem Services (ES). BGI is vital for improving living conditions and counteracting climate change when planning and constructing heavily urbanized places. The grading approach was used to evaluate BGI’s ideas for developing sustainable urban public spaces. Using BGI technologies to enhance urban functioning and appeal demands a holistic strategy. Conscious planning and design should employ the offered information to make BGI solutions as successful as feasible in creating urban public areas (Fernandez et al., 2022).

Green cover in form of forest cover occupies 30 per cent of the Earth’s surface and it serves as a vital habitat for millions of species (Jones et al., 2019; Shubin, 2019). These are responsible for clean air and water, as well these are also crucial for combating climate change (Halder et al., 2021). The path forward for mitigating climate change issues is guided by sustainable development.

Climate change mitigation is guided by sustainable development. Some comprehensive places aim to bring people, activities, buildings, and public spaces together (Antoszewski et al., 2022; Aryan et al., 2019; Ghorbanian et al., 2020). Some decisive actions are required to reduce the loss of natural habitats and biodiversity to support global food and water security, climate change mitigation and The various types of features available on Earth can be easily visualised and assessed using high-resolution satellite images (Du et al., 2022; Kuenzer et al., 2019). It can also be analysed at various spatiotemporal scales. These are capable of delivering precise data at desired spatial scales. These approaches are also very useful and reliable in any of those scenarios (Gou et al., 2022; Shafique & Luo, 2019). It can analyse the effects of green and blue spaces on human health and well-being (Gallet, 2012; Hamel & Tan, 2022; Tagne Nossi et al., 2021). Previously, some researchers proposed that blue spaces are more effective for mental human health and well-being. These are also capable of improving physical and mental health (Cao et al., 2022; Loukanov et al., 2020). The green and blue spaces in high spatial resolution satellite images demonstrate the relationship between various vegetation indicators and their impacts in built-up areas. Various methods of quantifying the effect of temperature on vegetation have aided policy and planning (Angelidou et al., 2016; Verga & Khan, 2022).

These studies look into a variety of environmental characteristics to find solutions to environmental problems (Almeida et al., 2022; Barmelgy et al., 2022; Berdejo-Espinola et al., 2022). Researchers analysed indicators from the perspectives of environmental, social, and economic development to produce a comprehensive plan for making our lives safer and more secure (Ahmad et al., 2020; Fan et al., 2022; Stange et al., 2022). The research is needed to identify ecological zones and their connections to suburban areas, with a particular focus on green infrastructure design. These are beneficial to the future development of smart cities and initiatives to maintain green infrastructure (Chen et al., 2022; Wilbers et al., 2022). Several bits of research suggest that heat-induced death studies are being conducted to determine the true impact of heat waves on humanity (Clauzel & Bonneville, 2019). Understanding the amount of green cover required to avoid these situations is beneficial. According to several studies, increasing the amount of green space can lower the death rate (Drosou et al., 2019; Liang et al., 2019).

The blue space has various health and well-being benefits for people. Researchers have also conducted studies to better grasp the insights into climate adaptation plans that can be implemented. To determine the influence of these policies as inputs on sustainability, it is necessary to understand management policies for green

areas (Bokaie et al., 2016). For urban cooling in hot desert climate change, good planning with sustainable urban green and blue spaces around residential complexes is required (Ayad et al., 2020). These approaches are critical for examining the role of blue-green development in the long run. With a reduction in urban heat island effects, sustainable development minimises greenhouse gas emissions (Shabahang et al., 2019). The current study focuses on assessing urban green and blue spaces using multi-sensor datasets and suitable feature validation to determine the magnitude of green and blue cover over the study region. With space-based inputs, it will aid in understanding the reasons behind the loss of urban areas in the region (Bassuk et al., 2015; Wei et al., 2021). Green and blue spaces have also been linked to psychological grieving, and the research community is paying more attention to the benefits of increased blue spaces for mental health and grief reduction.

The current research demonstrates the use of synthetic aperture radar (SAR) remote sensing to visualise the distribution of green and blue spaces. The scheme investigates the spatial distribution of green and blue areas to comprehend their orientation and pattern to conduct a complete spatial study of the features. Multi-sensor datasets will be easier to understand for green and blue space improvement and management thanks to the approach of analysing green and blue spaces with space-based multi-sensor datasets for sustainable landscape development. The study's recommendations assist decision-makers and planners in delivering diverse green infrastructure benefits to communities. The basic element of urban natural ecological space is "blue-green" space (Bolte et al., 2019; Sikorska et al., 2019). Rapid urbanisation has a substantial impact on urban blue-green space patterns and poses a serious threat to the urban ecological environment (Alves et al., 2019). The change in the characteristics of blue and green space during urban expansion is critical for urban ecological conservation and sustainable development (Ariza et al., 2019). The spatio-temporal evolution characteristics and coordinated development level of the blue-green space and built-up area are analysed in this work using a complete approach of remote sensing picture, landscape pattern analysis, sector analysis, and coupling analysis. The findings revealed that land use and landscape patterns in the centre city witnessed significant changes, with the most notable shift being the occupation of blue-green space by urban built-up regions, resulting in increased landscape fragmentation and decreased variability. Green space in cities is gradually becoming marginalised and confined in small regions.

The blue space has a clear blocking effect on the built-up area's expansion, and its spatial structure tends to stabilise over time. Furthermore, the degree of connection

between urban blue-green space and the urban constructed area is inverted U-shaped, and the level of coordinated development among the three has reached a moderate imbalance. Strengthening the protection of blue-green space, limiting city sprawl, and improving the quality of urban development are all urgently needed.

2 Literature review of major research in the domain

2.1 Summary of significant research contributions (as per Scopus database)

Table 1 summarises the comprehensive list of selected well-acknowledged literature having top citations with that particular keyword. This list of literature

presented in the table summarises the top 10 citations with keywords like *'feature extraction'*, *'object detection'*, *'green feature extraction'*, *'optical and SAR data fusion and 'multi-sensor data fusion*. An extensive review of the Scopus database has been performed for the year from 1992 to 2022 with the selected search keywords (*i.e. feature extraction, object detection, green feature extraction, optical and SAR data fusion and multi-sensor data fusion*). The first column of the table contains the details of the authors along with the year of publication of the article and the second column in the table reports the corresponding research title (as shown in the Scopus database). It can be observed that the majority of researchers have pursued research related

Table 1 Significant research with the highest number of citations

Authors	Title
(Labib & Harris, 2018)	"The potentials of Sentinel-2 and Landsat-8 data in green infrastructure extraction, using object-based image analysis (OBIA) method"
(Chen et al., 2018)	"Social functional mapping of urban green space using remote sensing and social sensing data"
(Cheng & Han, 2016)	"A survey on object detection in optical remote sensing images"
(Shen, Huang, Zhang, Wu, & Zeng, 2016)	"Long-term and fine-scale satellite monitoring of the urban heat island effect by the fusion of multi-temporal and multi-sensor remote sensed data: A 26-year case study of the city of Wuhan in China"
(Petropoulos, Kalivas, Georgopoulou, & Srivastava, 2015)	"Urban vegetation cover extraction from hyperspectral imagery and geographic information system spatial analysis techniques: Case of Athens, Greece"
(Cho, Seo, Kumar, & Rajkumar, 2014)	"A multi-sensor fusion system for moving object detection and tracking in urban driving environments"
(Zhang, Zhang, & Lin, 2014)	"Improving the impervious surface estimation with a combined use of optical and SAR remote sensing images"
(Berger et al., 2013)	"Multi-modal and multi-temporal data fusion: Outcome of the 2012 GRSS data fusion contest"
(Prakash, Singh, & Pathak, 2012)	"A fusion approach to retrieve soil moisture with SAR and optical data"
(Kabir, He, Sanusi, & Wan Hussina, 2010)	"Texture analysis of IKONOS satellite imagery for urban land use and land cover classification"
(Ban, Hu, & Rangel, 2010)	"Fusion of Quick bird MS and RADARSAT SAR data for urban land-cover mapping: Object-based and knowledge-based approach"
(Amarsaikhana et al., 2010)	"Fusing high-resolution SAR and optical imagery for improved urban land cover study and classification"
(Camps-Valls & Bruzzone, 2009)	"Kernel Methods for Remote Sensing Data Analysis"
(Sirmacek & Unsalan, 2009)	"Urban-area and building detection using SIFT key points and graph theory"
(Koetz, Morsdorf, van der Linden, Curt, & Allgöwer, 2008)	"Multi-source land cover classification for forest fire management based on imaging spectrometry and LiDAR data"
(Stramondo, Bignami, Chini, Pierdicca, & Tertulliani, 2006)	"Satellite radar and optical remote sensing for earthquake damage detection: Results from different case studies"
(Stramondo et al., 2006)	"Satellite radar and optical remote sensing for earthquake damage detection: Results from different case studies"
(Pu, Gong, Michishita, & Sasagawa, 2006)	"Assessment of multi-resolution and multi-sensor data for urban surface temperature retrieval"
(Flanders, Hall-Beyer, & Pereverzoff, 2003)	"Preliminary evaluation of eCognition object-based software for cut block delineation and feature extraction"
(Dousset & Gourmelon, 2003)	"Satellite multi-sensor data analysis of urban surface temperatures and land cover"
(Gong, Marceau, & Howarth, 1992)	"A comparison of spatial feature extraction algorithms for land-use classification with SPOT HRV data"

to land use land cover and feature extraction methods with the help of multiple different satellite images and software tools. Several researchers have pursued research on data fusion with the help of multi-sensor images. Some of these papers are based on data fusion along with feature extraction from different datasets. The data about research findings from these datasets are properly analysed and evaluated.

Figure 1 indicates the highest number of citations among the selected top 10 citations over the year 1992–2022 as per the indicated keyword list. Total gross citations over the year 1992–2022 are 1599. Among all these years, the highest number of citations occurred in the year 2009 with 1154 and the lowest number of citations was 236 in the year 2018.

The highest citation is showing that this year most research studies have been done compared to other years, as indicated by the number of citations by the significant research. The lowest number of citations refers to the decreasing inclination of the research interest in the research domain over that particular year. Figure 1 illustrates the influence of the keyword over the year 1992 to 2018. It can be observed that most cited keywords include “Extraction”, “Sensing”, “Urban”, “Detection”, “Building”, “Classification”, “Image”, “Analysis”, and “Object”.

These mentioned keywords visualise the attention of the research interest. Figure 1 shows that these mentioned keywords are more impactful keywords with record numbers of citations. Usually, problems of qualitative (and more subjective) data analysis help us to identify the focus area of the research. These will provide scientifically credible and robust approaches for processing data with an appropriate tool.

3 Material and method

3.1 Study area

Green and blue space management are required for the sustainable development of any region. Some of the earlier researchers have attempted a suggestive plan for the management and development of green and blue spaces. The current work is executed in the Udaipur district for understanding the orientation of green and blue spaces (as shown in Fig. 2). The district of Udaipur lies in the southern part of Rajasthan state and it is also known as ‘Mewar’. The location of the district lies amongst latitudes 23.49’ and 25.28’ N and longitudes 73.01’ and 75.49’ E with an average altitude of 579.4 m above sea level. The district covers approximately an area of 12,596 sq. km, and it accounts to be about 3.67% of the State of Rajasthan. The district is surrounded by Rajsamand district in the north part, Banswara District in the southeast region, Chittorgarh & Pratapgarh district in the east part, and Dungarpur in the south and Gujarat in the southeast direction, Sirohi in the West & Pali in North-west. The district of Udaipur has nine administrative subdivisions (i.e., Community Development Block (taluk)s) comprising Gogunda, Kherwara, Kotra, Lasadia, Phalsiya, Salumbar, Sarada, Udaipur, and Vallabhnagar. The district experiences a hot semi-arid climate with three prominent seasons comprising summer, monsoon, and winter seasons. The region typically has hot weather due to the desert lands in the region.

The annual mean rainfall is reported around 637.0 mm and has saline groundwater due to the presence of highly rich calcium salts in the region. The district has an abundant agricultural pattern with the sowing of maize and jawar crops in the Kharif season and wheat, and mustard in the Rabi seasons but these are fully dependent on the accessibility of water sources. As per the 2011 census, the Udaipur district has a total urban population of around 608,426 persons with a population density of 262 persons

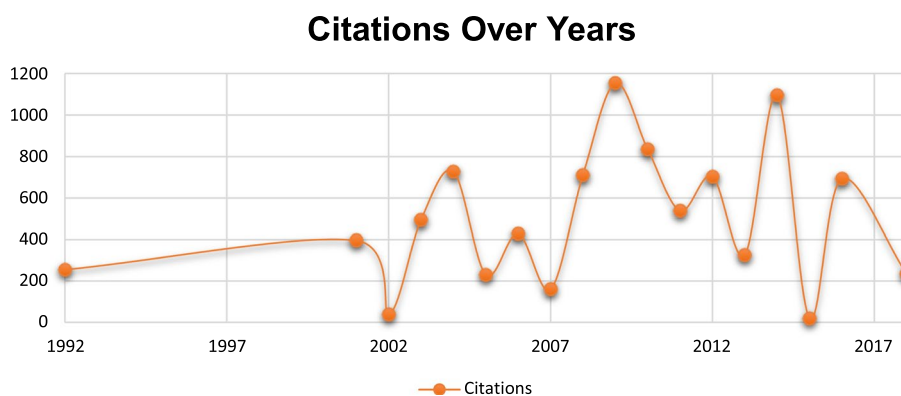


Fig. 1 Citations of top 10 research documents according to search keywords

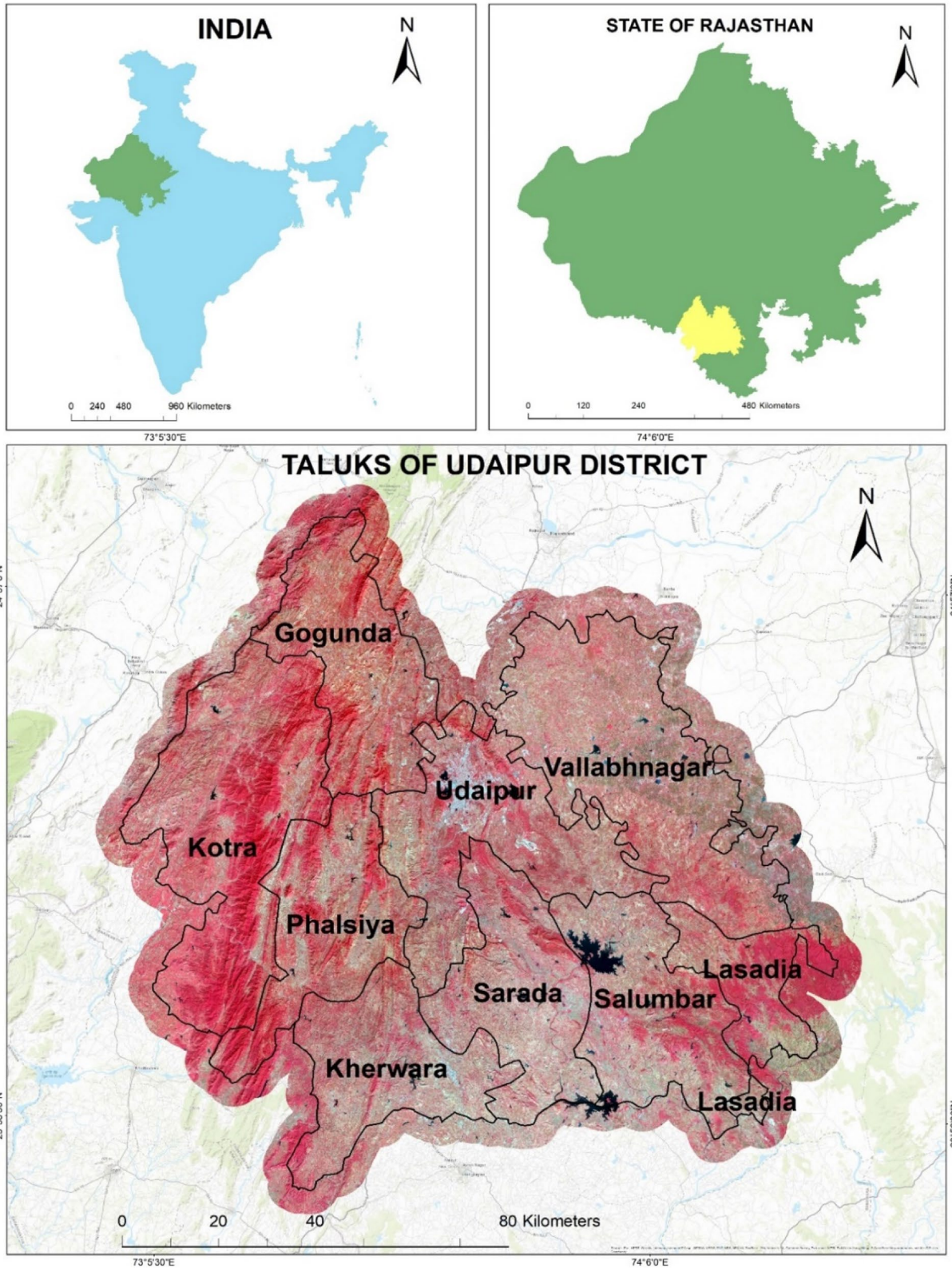


Fig. 2 Location Map for Udaipur District (Rajasthan, India)

per sq. km. The rapid development due to urbanization has resulted in the evolution of urban areas and these changes are necessary to be deliberated for complex problem-solving. Several authors have explored green and blue spaces with the help of geospatial approaches. The rapid development of geospatial technology across the various disciplines to achieve sustainable development. The whole system of geospatial technology works remotely sensed datasets, and these can be further used for analysis and visualisation on any spatio-temporal scale. Thus, this research focuses on the assessment of green and blue spaces around the Udaipur district of Rajasthan.

3.2 Datasets used

3.2.1 Sentinel 1A/B dataset

The required synthetic aperture radar (SAR) data of microwave imaging satellite is accessed from Sentinel-1A/B data archive. Sentinel-1 provides datasets with a spatial resolution of 20 m in all weather conditions with a day and night imaging capability and these are very much useful for marine monitoring, land monitoring, and emergency services. The cited data is accessible from ESA Copernicus open-access hub, which is available at <https://scihub.copernicus.eu/>. The metadata specifications of these datasets are defined in Table 2.

3.2.2 Landsat 8 dataset

The Landsat 8 datasets are assimilated from an American earth observation satellite data archive and it was launched to orbit on 11 February 2013. It was launched as part of the Landsat Data Continuity Mission, and it is

the eighth satellite in a series of the Landsat program to reach orbit successfully.

Table 3 summarises the synoptic details of the Landsat 8 mission and datasets used for the current work. The spatial resolution of the images obtained with the TIRS sensor in Landsat 8 is 100 m and the reason behind this resolution is to obtain surface temperature characteristics which will help to understand the process of heat and moisture transfer in the agricultural sector, water management, etc.

3.3 Software used

The current work uses proprietary software like ERDAS version 15, and ArcGIS version 10. x and open-source software like SNAP. These are used for pre-processing as well as analysis of satellite datasets with effective usage of algorithms to provide the required output. The software also offers post-processing data handling functions to perform the pre-requisite functionalities.

3.4 Methodology

Figure 3 visualises the exhaustive framework to execute the planned approach for the current work from the downloaded datasets.

3.4.1 Data download from the data archive

The required satellite datasets are assimilated from the data archive at <https://scihub.copernicus.eu/>). Likewise, the other pair of Landsat 8 datasets are accessed from Landsat 8 satellite archive available at <https://lpdaac.usgs.gov/tools/usgs-earthexplorer/> or <https://earthexplorer.usgs.gov/>. The data is available from an American Earth observation satellite as one of the eighth satellites in the Landsat program to reach orbit successfully. It was launched to serve as the Landsat Data Continuity Mission, it is the outcome of the collaboration between NASA and the United States Geological Survey. Both of these mentioned datasets are free for academic and research purposes. The detailed approach for pre-processing and using these datasets is shown in Fig. 3.

3.4.2 Pre-processing of downloaded datasets

The downloaded satellite datasets are pre-processed on Arc Desktop and Erdas software. General pre-processing steps include atmospheric corrections, radiometric corrections, geometric corrections, layer stacking of images, mosaicking of individual image tiles, image enhancement, contrast enhancement, extraction of the study area, and classifications of features with standard operating procedures. Later on, these pre-processed datasets are used for further classification to extract the desired classes of our interest. Similarly, SNAP software provides functionality for SAR data pre-processing

Table 2 Metadata of Sentinel 1A/B dataset

Parameters	Description
Processing System Identifier	ESA Sentinel-1 IPF 003.10
Data Name	S1A_IW_GRDH_1SDV_20191229T010121_20191229T010146_030556_037FEA_07BE
Data Type	GRD
ACQUISITION_MODE	IW
PROC_TIME	29-DEC-2019 03:29:51.150163
Satellite	SENTINEL-1A
Map projection	WGS84(DD)
DEM	SRTM 3Sec
Range bandwidth	56.5
Azimuth bandwidth	327.0
Range looks	40.0
Azimuth spacing	80.0
mds1 polar	VH
mds2 polar	VV

Table 3 Metafile details of Landsat 8 dataset

Data		Details			
DIGITAL_OBJECT_IDENTIFIER		https://doi.org/10.5066/P975CC9B			
LANDSAT_PRODUCT_ID		LC08_L1TP_148043_20211109_20211117_02_T1			
SPACECRAFT_ID		LANDSAT_8			
SENSOR_ID		OLI_TIRS			
PROCESSING_LEVEL		L1TP			
TARGET_WRS_PATH/ROW		148/43			
DATE_ACQUIRED		2021-11-09			
OUTPUT_FORMAT		GEOTIFF			
SCENE_CENTER_TIME		05:32:47.8429240Z			
Sensor	Band Number	Band Name	Wavelength (µm)	Resolution (m)	Band Applications
OLI	1	Coastal	0.43–0.45	30	Coastal and aerosol studies
	2	Blue	0.45–0.51	30	Bathymetric mapping, distinguishing soil from vegetation, and deciduous from coniferous vegetation
	3	Green	0.53–0.59	30	Emphasizes peak vegetation, which is useful for assessing plant vigour
	4	Red	0.63–0.67	30	Discriminates vegetation slopes
	5	NIR	0.85–0.88	30	Emphasizes biomass content and shorelines
	6	SWIR 1	1.57–1.65	30	Discriminates moisture content of soil and vegetation; penetrates thin clouds
	7	SWIR 2	2.11–2.29	30	Improved ability to track moisture content of soil and vegetation and thin cloud penetration
	8	Pan	0.50–0.68	15	15-m resolution, sharper image definition
	9	Cirrus	1.36–1.38	30	Improved detection of cirrus cloud contamination
TIRS	10	TIRS 1	10.60–11.19	30 (100)	100-m resolution, thermal mapping, and estimated soil moisture
	11	TIRS 2	11.50–12.51	30 (100)	100-m resolution, thermal mapping, and estimated soil moisture
SUN_AZIMUTH		154.06651176			
SUN_ELEVATION		44.57271416			
Scene size		170 km × 185 km (106 mi × 115 mi)			
Design life		5 years (Minimum)			

enclosing calibration, multi-look operation, speckle filter operation, and terrain correction operation. SNAP software is also used to overlay the boundary of the study area on the pre-processed datasets to understand the orientation and spatial distribution of green and blue cover. These processed datasets serve as input to understand and identify the various green and blue features, based on backscatter intensity values.

3.4.3 Database design

The processed set of datasets from optical and SAR satellite systems are further amalgamated for database generation, which can be further used to perform the preferred analysis.

The required raster datasets are obtained from the Landsat archive, which is furthermore used to make the classified maps. It can be observed that the district

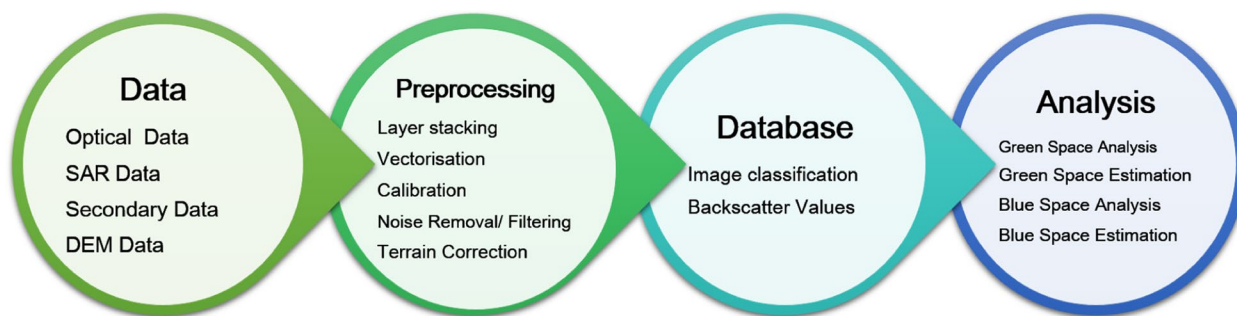


Fig. 3 A comprehensive approach to the assessment of green and blue spaces

Table 4 Area of the individual taluk

Sl. No	Taluks of Udaipur District	Area in Sq. km	Percentage Coverage
1	Gogunda	1219.83	10.17
2	Kherwara	1083.78	9.03
3	Kotra	2053.81	17.12
4	Lasadia	605.48	5.05
5	Phalsiya	1124.79	9.38
6	Salumbar	1201.96	10.02
7	Sarada	1182.70	9.86
8	Udaipur	1470.68	12.26
9	Vallabhnagar	2052.95	17.11
Total Area		11,995.98	100.00

is divided into nine Community Development Blocks (taluk)s namely Gogunda, Kherwara, Kotra, Lasadia, Phalsiya, Salumbar, Sarada, Udaipur, and Vallabhna- gar. The corresponding area of the respective Commu- nity Development Block (taluk)s is estimated and it is reported in Table 4. It can be observed that Kotra is the largest Community Development Block (taluk) followed by Vallabhna- gar and Udaipur with the largest area. The gross area of the Udaipur districts is estimated to be 11,995.98 sq. km. Out of all Community Development Blocks (taluk), Lasadia Community Development Block (taluk) is the smallest in terms of area coverage with 605.48 sq. km.

Cluster analysis (or clustering) is the division of a data collection into subsets (clusters or classes), with the data in each subset (ideally) sharing some common attrib- ute, such as proximity according to some defined dis- tance metric. Data clustering is a statistical data analysis approach that is utilised in a variety of domains, includ- ing machine learning, data mining, pattern recognition, image analysis, and bioinformatics. K-clustering is the term for the computational task of categorising data collection into k clusters. A prior probability, a cluster centre, and a cluster covariance matrix define clusters.

The Mahalanobis distance between a cluster centre and a pixel is determined by cluster centres and covariance matrices.

A normalised Gaussian function of the Mahalanobis distance between the cluster centre and pixels is defined as a pixel likelihood function for each cluster. Iteratively, posterior cluster probabilities, cluster centres, and covar- iance matrices are recalculated. The cluster prior and posterior probability are adjusted in the E-step for each cluster. The M-step recalculates all cluster centres and covariance matrices from the updated posteriors, max- imising the resulting data likelihood function.

In green infrastructure (GI) planning, local commu- nities, landowners, and organizations identify, develop, and protect their local land network to sustain good eco- logical functioning. It’s framework helps us see natural resources as vital to our survival because they offer fun- damental services for healthy living and infrastructure provide essential services for a healthy lifestyle as a part of the natural environment. Green infrastructure design focuses on the most significant natural and cultural resources for our present and future requirements. A green infrastructure plan identifies, evaluates, and prior- itizes areas vital to a healthy community in the future. We must prioritize them and take steps to assure their long- term conservation.

4 Results and discussions

Green infrastructure (GI) planning is a long-term land- scape approach to space conservation. Local commu- nities, landowners, and organizations work together to identify, develop, and protect their local land network to sustain good ecological functioning. Urban green and blue spaces and related ecosystem services (ES) may help solve urban sustainability difficulties (e.g., climate change, and public health issues). Green areas offer eco- system services for human health amidst urban land-use expansion and environmental consequences. The eco- system services concept links human-environmental

interactions via biodiversity and abiotic aspects. Green infrastructure (GI) in urban settings emphasizes green spaces and natural areas' quality and quantity.

4.1 Land use and land cover

The Landsat 8 datasets are processed to generate the land use and land cover maps for the region. Thereafter, a buffer of 5 km is used to clip the land use and land cover over the selected study region. The desired classification is performed with an unsupervised classification scheme to separate the satellite image into the five major classes comprising waterbodies (i.e. for understanding the orientation of blue spaces/ blue cover/water bodies including lakes, ponds, reservoirs, and open water in the region), forest as green cover (i.e. to understand the condition of green cover without agriculture but it includes different other vegetation cover, shrubs, and plantations), urban, agriculture, and barren land. This step provides the feature extraction from the optical datasets for further detailed analysis. The resultant land use and the land cover map are shown in Fig. 4.

The obtained results of various land use and land cover classes are further quantified to understand the amount of area occupied by each land use. The estimations and classifications of every class are executed with ArcGIS software. The spatial distribution of various land use and land cover classes can be observed in Fig. 4, which shows that agricultural land is more dominant in the region followed by forest and barren land. The indicative quantified values for each land cover type are reported

Table 5 Area under various classes

Sl. No	Class Name	Area (sq. km)	Percentage
1	Water Bodies	130.08	1.08
2	Urban Area	398.36	3.32
3	Barren Land	2431.67	20.27
4	Forest	3465.83	28.89
5	Agriculture Land	5570.04	46.43
Total Area		11,995.98	100.00

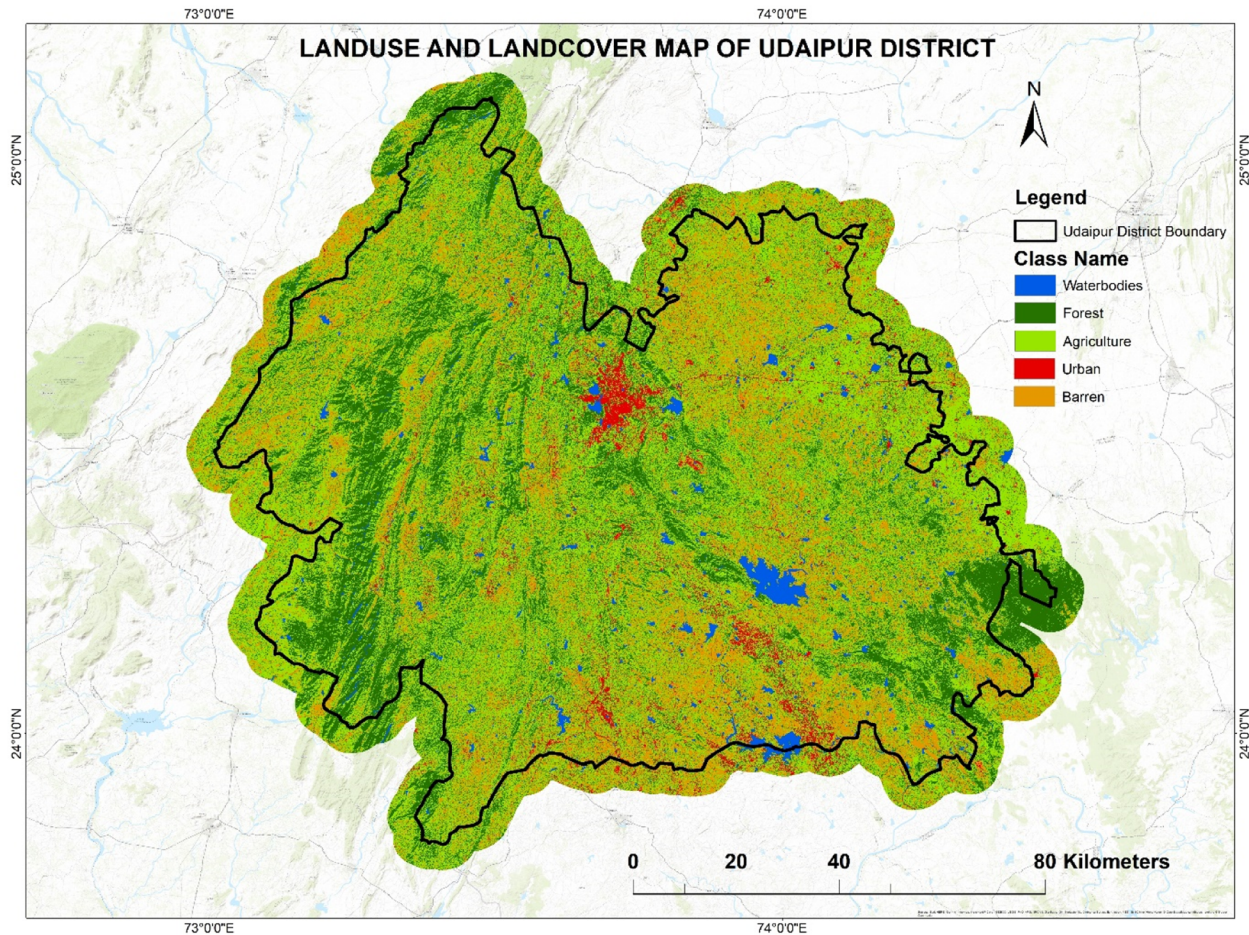


Fig. 4 Land use-land cover classes over the region

Table 6 Summary of the taluk-wise area distribution over the land use land cover classes

Name	Gogunda Area (km ²)	Kherwara Area (km ²)	Kotra Area (km ²)	Lasadia Area (km ²)	Phalsiya Area (km ²)	Salumbar Area (km ²)	Sarada Area (km ²)	Udaipur Area (km ²)	Valabhagar Area (km ²)	Total Area (km ²)	Percentage Coverage
Barren Land	199.3911	246.9981	327.371	121.5645	167.3166	316.4627	302.4512	221.7805	528.3303	2431.666	20
Urban Area	20.8213	43.0746	10.7074	3.6447	24.6832	51.2413	70.7981	118.9524	54.4345	398.3575	3
Agriculture Land	584.5374	524.6683	896.6688	220.1992	520.7034	491.1545	529.3826	707.5728	1095.1552	5570.0422	47
Waterbody	4.2148	7.1309	6.619	2.6633	4.9107	59.7544	17.9979	14.7102	12.0825	130.0837	1
Forest	410.8624	261.9069	812.4442	257.4072	407.1776	283.3513	262.0669	407.6672	362.9429	3465.8266	29
Total	1219.827	1083.7788	2053.8104	605.4789	1124.7915	1201.9642	1182.6967	1470.6831	2052.9454	11,995.976	100

in corresponding Tables 5 and 6 to understand the condition of each land-use type, which can be used further to design approaches for sustainable development of the region.

It can be observed in Table 6 that reports agricultural land occupies most of the areas at 46.43% of the total area, followed by forest land at 28.89%, and barren land at 20.27%. Whereas water bodies occupy only 1.08% along with 3.32% of the urban area.

4.2 Distribution across different community development blocks (taluk)

The distribution analysis of different land use and land cover categories is executed to realise the distribution of various land cover. It also estimates the areas of each class for every Community Development Block (taluk). The complete district is analysed Community Development Block (taluk) wise for estimation of green and blue spaces to understand the distribution across the region. The distribution of these features guides toward sustainable development.

Figure 5 displays the spread of land use and land cover within the mentioned region. The map shows the detailed classifications with five selected classes namely *water bodies, forest area, urban land, agricultural land, and barren land* respectively.

Table 6 delivers the area enclosed by the specified land-use and land cover classes in each Community Development Block (taluk). Barren land has a noticeable amount in most of the region. If we see the condition of the Gogunda Community Development Block (taluk), it has a very less amount of water bodies with an area of 4.2148 sq. km in comparison to barren land, urban area, agricultural land, and forest cover. Lasadia Community Development Block (taluk) has the least water body coverage among all the Community Development Blocks (taluk) s of the district with 2.6633 sq. km having 220.1992 sq. km as agricultural land, 3.6447 as an urban area, and 257.4072 as forest cover and it has an area of 32.5152 sq. km as barren land. Likewise, it can be seen for other Community Development Blocks (taluk)s also that there are imbalances of resources across the district and it is required to be balanced before going sustainable planning of the available resources in the region. Human-induced activities are responsible for gradient shifts in land use and land cover of the resources across the region, which is indirectly causing the decline of green and blue spaces over the region. Table 6 reports the Community Development Block (taluk) wise summary of the land use and land cover classes in square kilometres and the total area of each class. It is quite evident from the mentioned table that agricultural land is dominant in the Udaipur district has an area of 5570.0422 sq. km trailed by a forest area of

3465.8266 sq. km., and barren land of 2431.666 sq. km. There is ~1% per cent as water body (blue spaces, which is almost marginal in comparison to the green cover and agricultural land), green cover (excluding agricultural area) of ~29%, and urban area of ~3% of the total area.

4.3 SAR image processing and analysis

A systematic analysis is executed with SAR images for the complete study area. These SAR data perform well with water bodies and vegetation cover; therefore these are used to visualise the extent of features comprising water, vegetation, and urban features for the study region. The SAR images are pre-processed for visual interpretation of derived classes and overlay of the Community Development Block (taluk) boundary over it. Figure 6 exhibits the Sentinel-1A-GRD amplitude data (VH Polarisation) of the Udaipur district.

Figure 7 visualises the raw SAR (GRD) amplitude data of Udaipur city in VH polarisation. This figure shows the details of land use and land cover. Likewise, Fig. 5 shows the Sentinel-1A-GRD calibrated data (VH Polarisation) of the Udaipur district to visualise the arrangement of the land use and land cover. Typical values of vegetation features can be observed as the grey colour has a value of around 0.026, water bodies in dark black colour with a value of 0 and urban areas in whitdiscue colour with a higher backscatter value. This white pixel specifies the high backscatter values and black pixels deduce the low backscatter values and grey pixels also show nearly low backscatter values. This process of calibration converts the raw SAR image to a backscatter intensity image as a sigma0 image.

Figure 8 shows the Sentinel-1A-GRD Multi-Looked data of the Udaipur district in VH polarisation. This process creates a useful product with less noise and also generates an approximate square pixel spacing size. During the multi-looking operation of the earlier data with range looks of 4, 20 azimuth looks of 20 with 31.2 m range spacing, and 80.0 m azimuth spacing is provided to the system. The multi-look operation generates the results with 1 look in range direction and 3 looks in azimuth direction with a ground range square pixel size of 13.95 m.

Figure 9 exhibits the terrain corrected Sentinel-1A-GRD image of the Udaipur district in VH polarisation to envision the topographic coverage of the region. This figure shows the overlay of various Community Development Blocks (taluk) (shown in different colours) with precise details. This image is obtained after range-Doppler terrain correction to speckle filtered Sentinel-1A-GRD image. The terrain correction tool uses the SRTM 3Sec DEM (90 m pixel spacing) and the mentioned DEM data sets are automatically downloaded by the software from the cloud server. The terrain correction process also

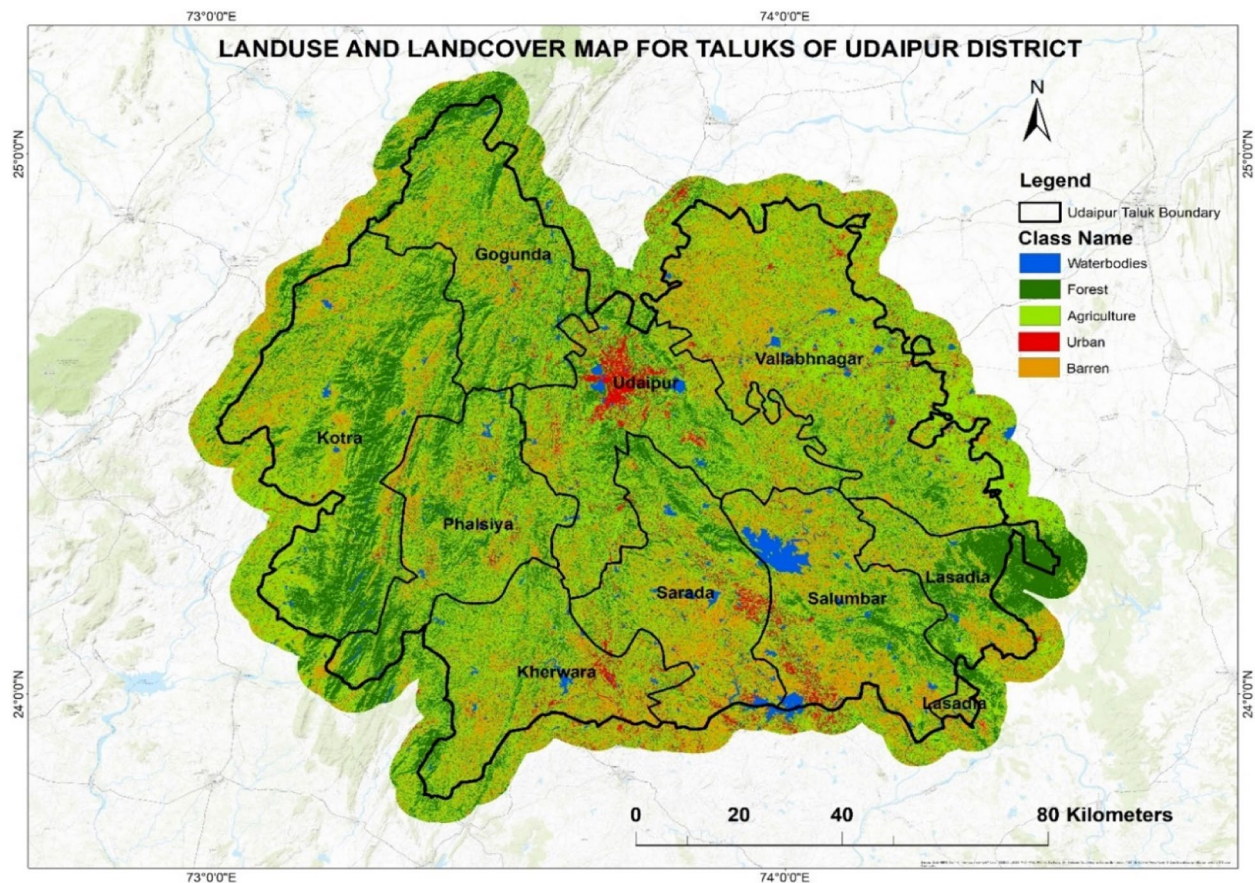


Fig. 5 Spatial distribution of different land use-land cover classes over the region

projects the image in the proper orientation and aligns the true north position to the corrected image (facing north on the top). Figure 9 shows the Sentinel-1A-GRD terrain corrected image of the Udaipur district.

Figure 9 demonstrates terrain corrected image of the Udaipur district in VH polarisation to visualise the different features of the region. A thorough visual interpretation and analysis of green and blue spaces are performed with the SAR datasets. The designated spaces are spatially analysed for a detailed interpretation of the results.

4.4 Green and blue space analysis of selected area for detailed map generation

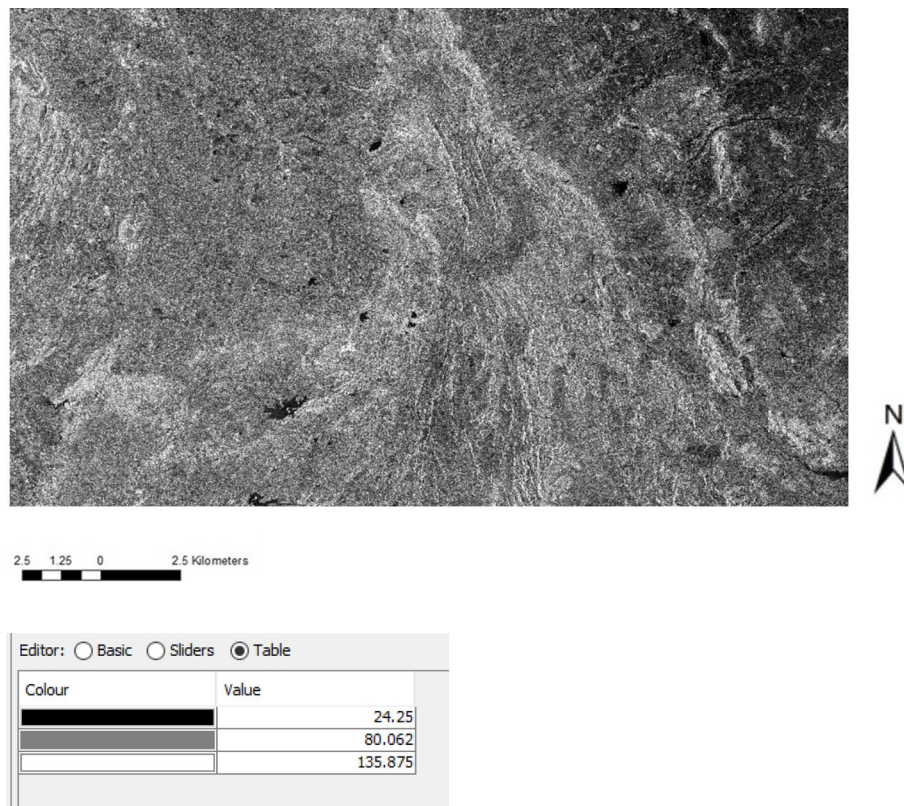
4.4.1 Distribution of green and blue covers

The classified images of the study region are further analysed to separate the green and blue cover in the region. The obtained results are aggregated as per the requirement and the two major classes are made namely green cover and blue cover for the entire region.

Figure 10 displays the distribution of green and blue spaces in the study area across various Community Development Block (taluk)s. It shows only two

prominent classes' namely *green and blue spaces*. Thereafter the corresponding area is deliberated for both the class. A separate estimation for each Community Development Block (taluk) is performed and a selected map of one of the Community Development Blocks (taluk) is made to understand the distribution of green and blue spaces. Each Community Development Block (taluk) is analysed for the accessibility of green and blue space to understand the distribution across the district. The whole area is classified into either *green spaces or blue spaces*. Figure 10 shows the binary classification in two classes namely green space and blue spaces. It can be observed that the urban blue spaces are negligible in comparison to the urban green space.

Also, Table 6 specifics the summary of *green space and blue space* in each Community Development Block (taluk). It can be observed that Kotra has more area coverage of all having area of 819.0632 sq. km (*including green space and blue space areas*), followed by Udaipur Community Development Block (taluk) having 422.3774 sq. km of area and mostly consisting of green spaces comprising ponds, lakes, canals. Figure 11 shows



Value color-
 24.25- Water (Dark Black)
 80.062- Green part (Grey)
 135.875- (White)

Fig. 6 Sentinel-1A-GRD amplitude data (VH Polarisation) of the Udaipur district

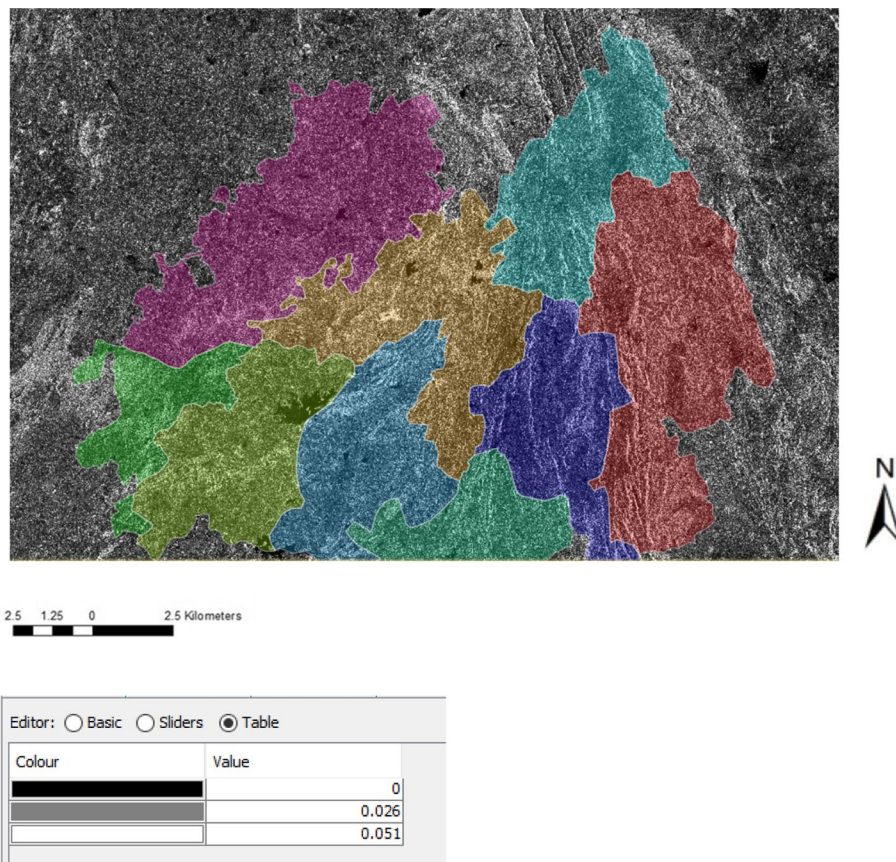
the green cover including agricultural land in green colour and the blue colour corresponds to the water body the black colour shows the outer boundary and zonal configuration of the region.

It was observed that there is greener space in the entire area compared to the blue spaces. Kotra Community Development Block (taluk) has a more green space area of 812.442 sq. km and Udaipur Community Development Block (taluk) with 407.6672 sq. km. Similarly, Salumbar Community Development Block (taluk) has an area of 59.7544 sq. km as blue space, followed by Sarada with 17.9979 sq. km. It can be inferred that there is a need to develop more blue space areas in Gogunda, and Lasadia Community Development Block (taluk) to balance the blue space and green cover areas that need to be developed in Kherwara, Sarada, and Lasadia Community Development Block (taluk).

4.4.2 Spatial distribution of green spaces

Figure 10 exhibits the green cover over the four arbitrary zones to showcase the availability of green spaces across different zones. This green cover contains areas covered with agricultural land, vegetation, shrubs, plantations, and forest land. The study provides valuable information to reveal the cross-sector interactions and feedback to demonstrate the importance of BGI in improving the general quality of life in cities. Funders and stakeholders may use tools like these to identify the benefits of shared projects and funding streams, assess whom they need to collaborate with, and figure out how to focus green finance to maximise the natural capital benefits of any development.

Table 7 displays Region 1 having the highest coverage of green spaces at 12.3685 sq. km, trailed by Region 2 & Region 4 having an area of 8.8907 sq. km & 8.8184 sq. km. respectively. Whereas Region 3 exhibits the least



Value color-

0- Water (Dark Black)

0.026- (Grey)

0.051- (White)

Fig. 7 Sentinel-1A-GRD calibrated data (VH Polarisation) of the Udaipur district

area of only 2.7366 sq. km. as green cover. In Fig. 11, it is visible that the area has the highest green area patches compared to other zones. There are many parks and gardens also. The entire green cover has a gross area of 32.8142 sq. km. Table 8 provides a summary of green and blue spaces across the district.

4.4.3 Spatial distribution of blue spaces

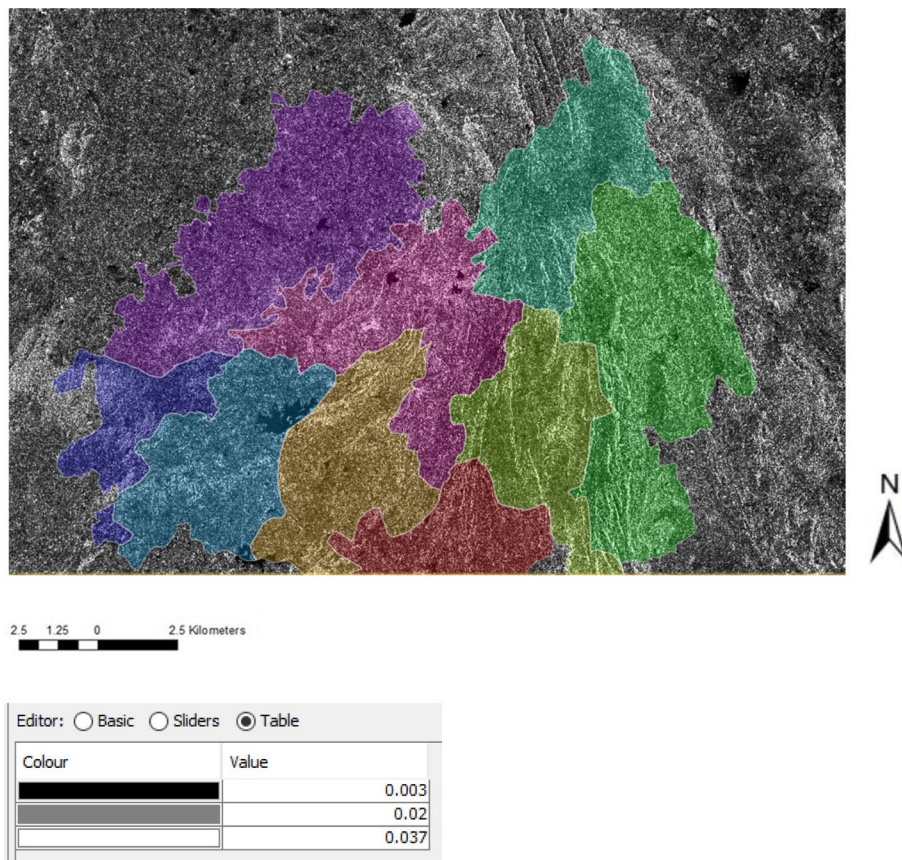
Figure 12 exhibits the distribution of blue spaces across the four zones of Udaipur city. The figure shows the availability of blue spaces comprising lakes, ponds, reservoirs, and open water.

Table 9 exhibits Region 3 as the highest coverage of blue spaces with 4.51 sq. km of area coverage, trailed by Region 1 and Region 2 having an area of 3.2836 sq. km & 1.1214 sq. km. respectively. Whereas Region 4 exhibits the least area with only 1.0765 sq. km. as urban blue

cover. In Fig. 13, it is evident that the area has the lowest urban blue spaces with the majority of patches in Region 1 and Region 3 compared to other zones. The total coverage of the urban blue spaces is 9.9915 sq. km over the region. Region 1 and Region 3 is having the most prominent class in water bodies, which leads to good green cover over the region, similarly, Zone 2 and Zone 4 have low blue cover, which results in relatively low green cover.

4.5 Validation of results

Figure 13 specifics the condition of the selected feature in three forms comprising SAR image, Optical image, and classified image. It visualises the contrast of actual orientation to quantified values. The estimations and analysis of the results are further validated for the selected sample locations for the green and blue spaces. Figure 13 shows selected sites with green space with their corresponding



Value color-
 0.003- Water (Dark Black)
 0.02- (Grey)
 0.037- (White)

Fig. 8 Sentinel-1A-GRD Multi-Looked data (VH Polarisation) of the Udaipur district

satellite image in SAR & optical systems along with the classified image. These images exhibit a relatively good match with the corresponding. While the paybacks described in this article are far from exhaustive, a basic mapping approach may be used to evaluate the benefits across a variety of industries and stakeholders. During the pre-planning phase of new developments, the proposed technique can be useful for engagement and open dialogues. This method, in particular, could aid in a better understanding of the impact of new housing projects on water service provision. This strategy might be used by individual sectors, such as transportation, to maximise the benefits of their system. The approach can also be used to evaluate the influence of new housing developments on overall urban sustainability, serving as a foundation for environmental net gain analyses that have the potential to profoundly alter how we build in the future.

4.6 Limitations of the study

While space-based multi-sensor datasets offer a valuable tool for evaluating urban green and blue spaces, there are several limitations to their use for sustainable development. Some of these limitations include:

- a) *Spatial resolution*: The spatial resolution of space-based multi-sensor datasets may not be high enough to accurately capture the details of urban green and blue spaces. This can result in inaccurate assessments of the quality and quantity of these spaces.
- b) *Spectral resolution*: Different types of vegetation and water bodies may have similar spectral characteristics, making it difficult to distinguish between them using space-based multi-sensor datasets.
- c) *Atmospheric interference*: The presence of clouds, haze, or other atmospheric conditions can interfere

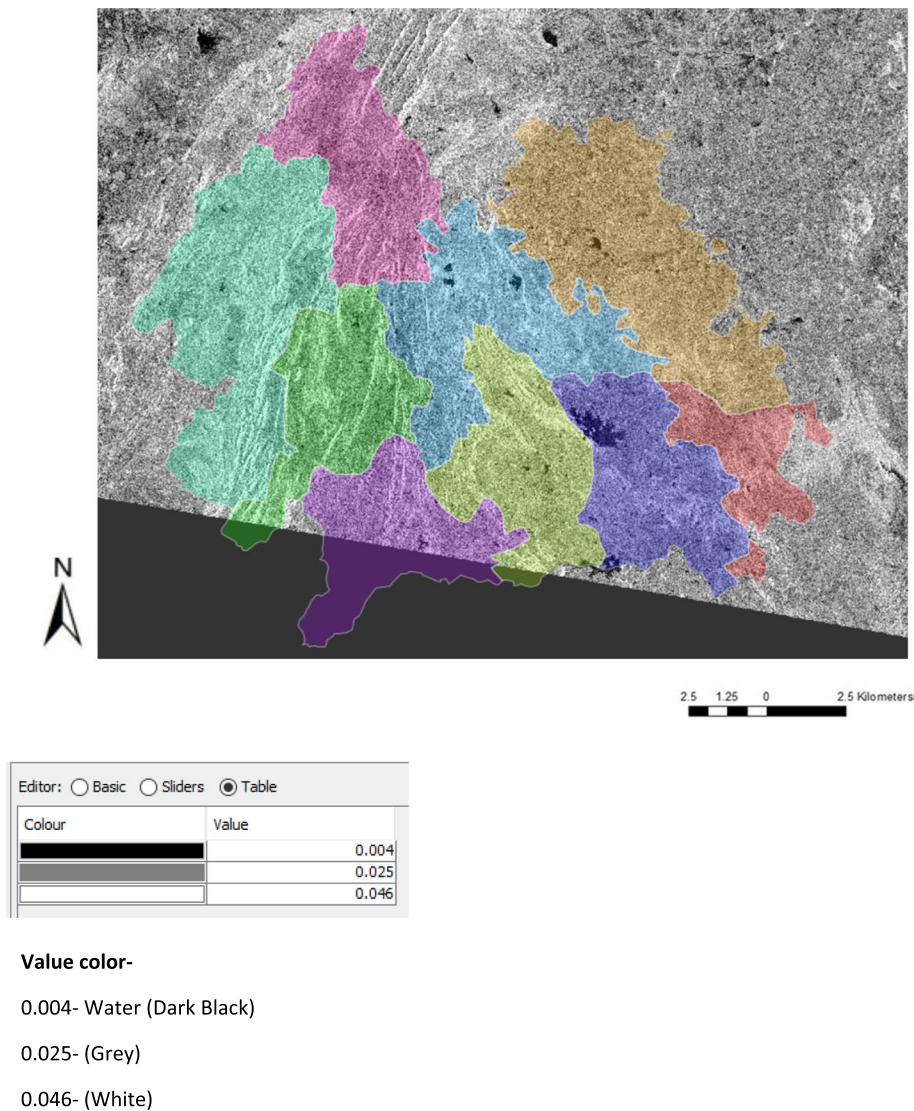


Fig. 9 Sentinel-1A-GRD terrain corrected image of the Udaipur district

with the accuracy of remote sensing data, making it difficult to accurately assess urban green and blue spaces.

- d) *Temporal resolution*: Space-based multi-sensor datasets may not provide frequent enough data to capture changes in urban green and blue spaces over time.
- e) *Data availability and cost*: Access to space-based multi-sensor datasets may be limited, especially for researchers in developing countries or with limited resources. Additionally, the cost of acquiring and processing these datasets can be prohibitive.
- f) *Lack of ground truth data*: Space-based multi-sensor datasets may lack ground truth data to validate and calibrate the remote sensing data, which can lead to

inaccuracies in assessments of urban green and blue spaces.

- g) *Limited ability to capture social dimensions*: Space-based multi-sensor datasets may not capture important social dimensions of urban green and blue spaces, such as access, use, and perception by different groups of people.

Generally, while space-based multi-sensor datasets are a valuable tool for evaluating urban green and blue spaces, they should be used in conjunction with other methods and data sources to ensure a comprehensive and accurate assessment of sustainable development.

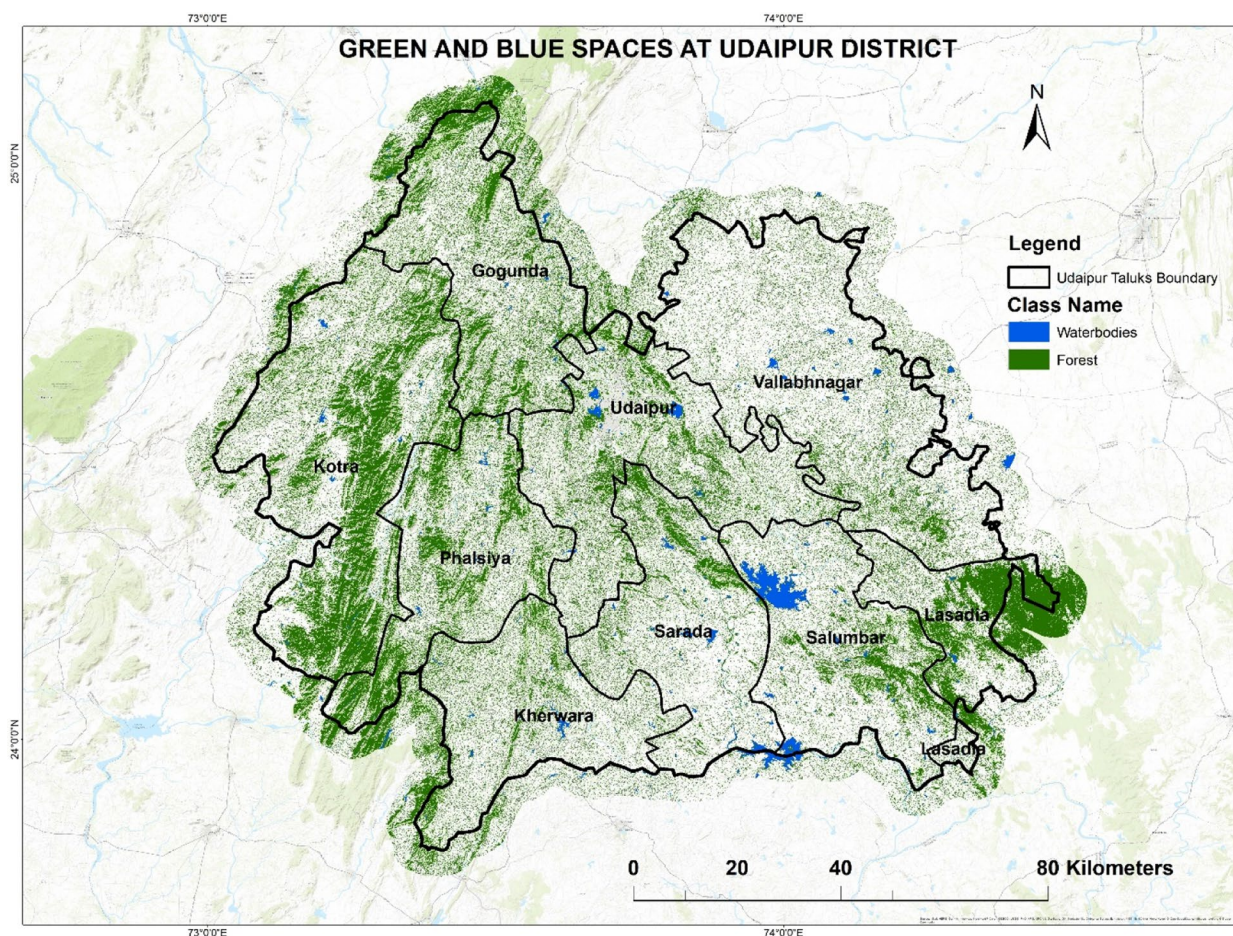


Fig. 10 Distribution of Blue-Green Spaces over different zones

5 Conclusion

The public’s understanding of sustainable growth has lagged substantially behind the progress made in reducing greenhouse gas emissions. Integrated management plans bring together people, activities, and public spaces for sustainable development over the long term. Examining the work’s strengths, weaknesses, and best practices is the main focus. The right modelling approach can be selected with the help of these suggestions. Green space and the presence of water share a physical connection. Using a comprehensive strategy, we must maximize synergies between the green cover and water while minimizing the costs of doing so. The nexus is capable of managing the interdependency of sustainability’s key individual resources. The strong drive for growth, however, gives rise to a plethora of ideal ideals, such as the concept of the “smart city”, which supports regional sustainable development plans. Methods like this aim to strike a balance between available resources and those that are required. It seeks to make use of sustainable development resources and solutions, such as urban

green and blue spaces, that are crucial to the success of the Sustainable Development Goals. With today’s state-of-the-art computers, we can now take advantage of spatial inputs, which, when applied to urban issues, often yield the most effective strategies. On this front, recent studies have estimated the amount of usable urban green and blue space using multi-sensor datasets based on space to provide multi-dimensionally optimal solutions. It can be put to use in resource tracking, analysis, and analysis, as well as in interpretation and mapping. A similar effort can be put into researching sustainable development on a spatial and temporal scale.

5.1 Recommendations and future research for policy or practice

Evaluation of urban green and blue spaces using space-based multi-sensor datasets can provide valuable information for sustainable development policies and practices. Here are some recommendations and future research areas for evaluating urban green and blue spaces:

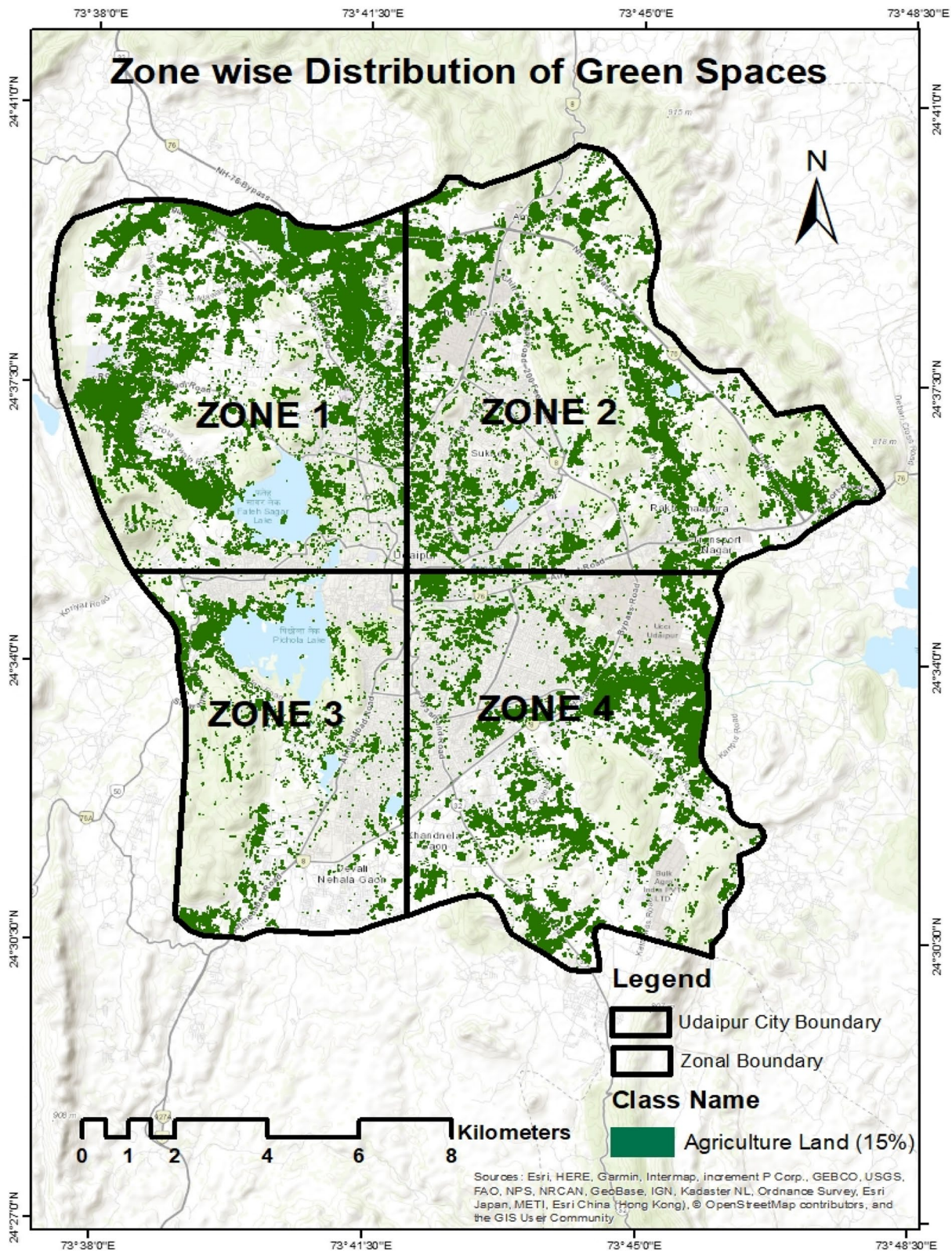


Fig. 11 Distribution of urban green spaces over different zones

Table 7 Distribution of blue spaces across a selected area

S. No	Region	Feature Name	Area (sq. km)	Percentage
1	Region 1	Blue Cover/Waterbody (Lakes + Ponds + Reservoirs + Open Water)	3.2836	32.8639343
2	Region 2		1.1214	11.22354
3	Region 3		4.51	45.1383676
4	Region 4		1.0765	10.774158
Total Area			9.9915	100.00

Table 8 Summary of green and blue spaces across the district

S. No.	Taluks Name	Feature	Area (sq. km)	Total Area (sq. km)
1	Gogunda	Blue Spaces	4.2148	415.0772
		Green Spaces	410.8624	
2	Kherwara	Blue Spaces	7.1309	269.0378
		Green Spaces	261.9069	
3	Kotra	Blue Spaces	6.6190	819.0632
		Green Spaces	812.4442	
4	Lasadia	Blue Spaces	2.6633	260.0705
		Green Spaces	257.4072	
5	Phalsiya	Blue Spaces	4.9107	412.0883
		Green Spaces	407.1776	
6	Salumbar	Blue Spaces	59.7544	343.1057
		Green Spaces	283.3513	
7	Sarada	Blue Spaces	17.9979	280.0648
		Green Spaces	262.0669	
8	Udaipur	Blue Spaces	14.7102	422.3774
		Green Spaces	407.6672	
9	Vallabhnagar	Blue Spaces	12.0825	375.0254
		Green Spaces	362.9429	

- a) *Develop standardized methodologies for evaluating urban green and blue spaces:* There is a need to develop standardized methodologies for evaluating urban green and blue spaces using space-based multi-sensor datasets. These methodologies should be able to capture the spatial and temporal variability of green and blue spaces, as well as their functional and aesthetic values.
- b) *Incorporate socio-economic indicators:* It is important to incorporate socio-economic indicators, such as income, education, and race, in the evaluation of urban green and blue spaces. This will help identify disparities in access to green and blue spaces and provide insights into how to address these disparities.
- c) *Assess the impact of urban green and blue spaces on health and well-being:* There is a growing body of evidence linking urban green and blue spaces to improved health and well-being outcomes. Future research should focus on assessing the impact of urban green and blue spaces on specific health outcomes, such as mental health, physical activity, and obesity.
- d) *Develop tools for decision-making:* Decision-makers need tools that can help them make informed decisions about the development and management of urban green and blue spaces. These tools should be user-friendly, incorporate multi-sensor datasets, and be able to generate actionable insights.
- e) *Address data gaps:* There are still data gaps that need to be addressed, particularly in developing countries where data collection may be limited. Future research should focus on developing innovative data collection methods, such as crowdsourcing and citizen science, to fill these gaps.
- f) *Incorporate climate change considerations:* Climate change is expected to have significant impacts on urban green and blue spaces. Future research should incorporate climate change considerations, such

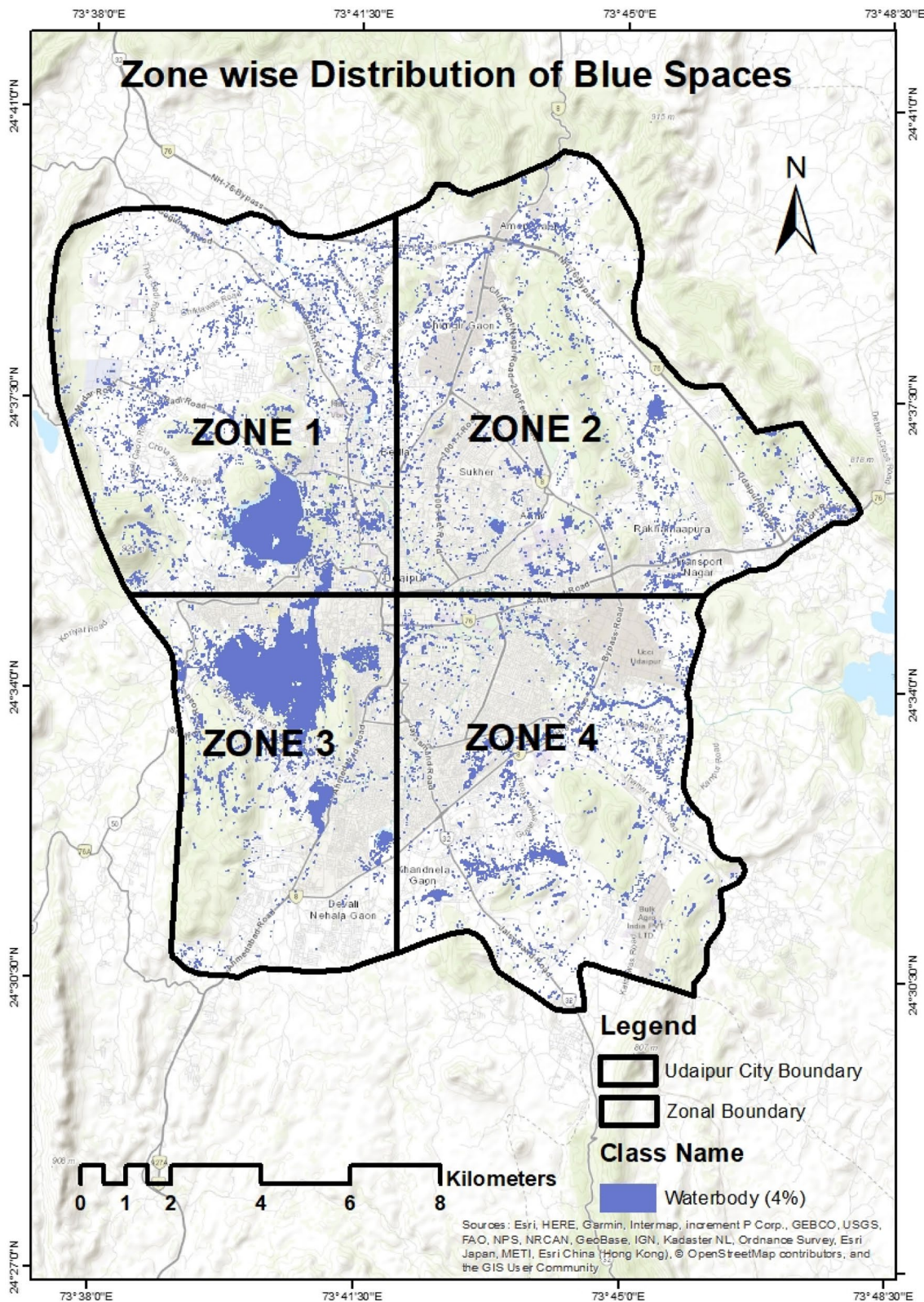
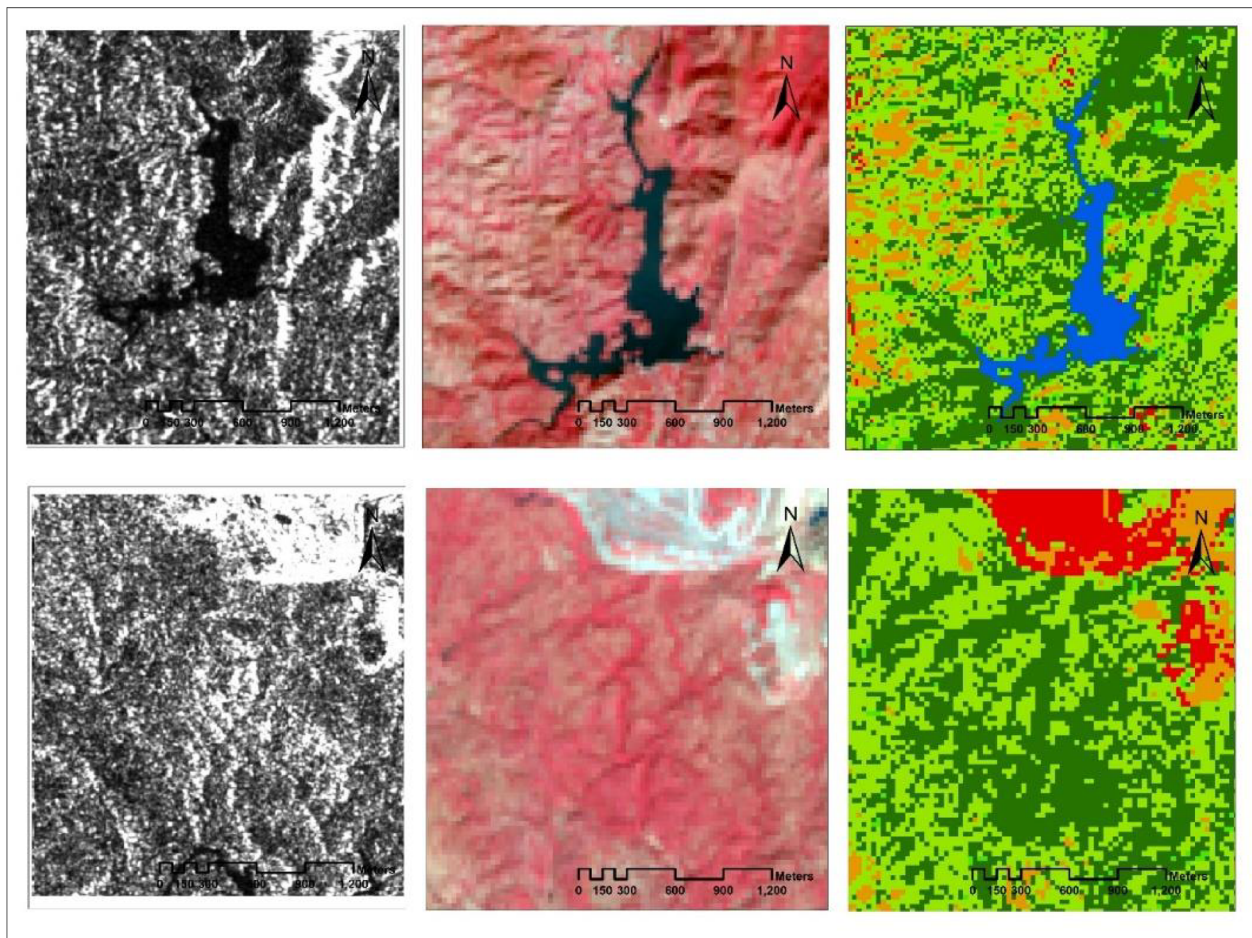


Fig. 12 Distribution of urban blue spaces over different zones

Table 9 Distribution of green spaces across a selected area

S. No	Region	Feature Name	Area (sq. km)	Percentage
1	Region 1	Green Cover (Agriculture + Vegetation + Shrubs + Plantations)	12.3685	37.69252336
2	Region 2		8.8907	27.09406294
3	Region 3		2.7366	8.339682211
4	Region 4		8.8184	26.87373149
Total Area			32.8142	100.00



a) SAR Image

b) Optical Image

c) Classified Image

Fig. 13 Selected Green and Blue Spaces

as sea-level rise and extreme weather events, in the evaluation of urban green and blue spaces.

- g) *Foster collaboration between researchers and practitioners*: Collaboration between researchers and practitioners is essential for translating research findings into actionable policies and practices. Future research should focus on fostering collaboration and knowledge exchange between these two groups

Acknowledgements

We are thankful to Copernicus Sentinel data policy for the free, full, and open data policy adopted to provide open access data available at <https://scihub.copernicus.eu/> to all users via a simple self-registration. This work was undertaken as part of a full-time PhD program and it was supported for completing the full-time PhD by the SAC-ISRO project funds [Grant Number Urb-01] from Space Applications Centre (ISRO), Department of Space, Govt. of India. The authors are also thankful to the ERASMUS+ Staff Mobility grant for the visit as a Visiting Researcher to the Department of Geoinformatics – Z_GIS, Paris Lodron University of Salzburg, Schillerstrasse 30, 5020 Salzburg, Austria to undertake the research discussion at a finer level.

Conflicts of interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

Authors' contributions

Dr Deepak Kumar (DK) conceived and designed the study, and Dr Sunita (SS) performed the research. Deepak Kumar (DK) and Dr Shah Nawaz (SH) analyzed and supervised the work. Dr Sulochana Shekhar (DS) contributed to the critical structuring of the manuscript and editorial inputs. Conceptualization, methodology and formal analysis: DK, SS, SH; investigation: DK, SH, DS; visualization: DK, SS, DS; writing—original draft: DK, SS; writing—review and editing: DK, SH, DS; All authors read and approved the final manuscript.

Funding

Not Applicable.

Availability of data and materials

The datasets used and/or analyzed during the current study are available from the corresponding author upon reasonable request.

Declarations

Ethics approval and consent to participate

Not applicable.

Consent for publication

All authors read and approved the final manuscript.

Competing interests

The authors declare no competing interests.

Received: 2 February 2023 Revised: 5 March 2023 Accepted: 12 March 2023

Published online: 17 March 2023

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