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The application of remote sensing and geographic information system techniques for the analysis of land use and land cover changes in Wayanad district of Kerala#

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Abstract

Mapping Land Use and Land cover Changes (LULC) and detecting changes using remote sensing and Geographic Information System (GIS) techniques is a cost-effective way of gaining a good understanding of the land cover alteration processes caused by land use change and their effects. This study assessed the transformation of the Wayanad district landscape over a period of 23 years. LANDSAT satellite images (of 30 m resolution) encompassing the area at three epochs were classified into nine classes (coffee dominated mixed crop, built-up, evergreen forest, deciduous forest, grassland, mixed crop with built-up, paddy, tea plantation, and waterbody) using the maximum likelihood algorithm, resulting in classes for each land use. The results showed that over the past 23 years, coffee-dominated mixed crops have increased by 0.84% in 2014 and 11.84% in 2022 compared to 1999; deciduous forest area decreased 3.6% and increased 0.6% in 2014 and 2022, respectively. Tea plantations increased by 0.9% in 2014 and by 0.49% in 2022, which decreased by 0.41% compared to 2014. Built-up has increased by 6.42% and 6.02% in 2014 and 2022 respectively, and slightly decreased by 0.4% compared to 2014. Evergreen forest areas increased in 2014 by 6.68% and 2.28% in 2022 and decreased by 4.44% compared to the previous time period. Grass land areas have decreased by 6.25% and 5.33%, respectively, and mixed crops with built-up areas has decreased by 0.74% and remained the same in the last two epochs, while paddy and waterbodies have decreased by 3.4%, 15.79%, and 0.07 and 0.19%, respectively, in 2014 and 2022 of the total geographical area.

Keywords: *Remote sensing, GIS techniques, LULC, forest cover*

Change in land use/cover is a crucial driver of global change and have substantial consequences for many international policy concerns (Nunes and Auge, 1999). Due to the broad and quick changes in the distribution and features of tropical forests, land use/land cover (LULC) shifts in particular in tropical regions are of great importance (Meyer, 1993; Houghton, 1994). Land cover is the physical and biological cover over the land's surface, including water, vegetation, barren soil, and/or man-made structures. Land cover is indispensable for global monitoring studies, resource administration, and planning. Land use is defined by the arrangements, initiatives, and inputs people use to produce, alter, or maintain a

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particular land cover type. Detecting changes in land use or cover helps us understand how the landscape changes over a known time period with sustainable management. Land use/cover change is a profound and increasing process that is primarily driven by natural phenomena and human activities, which in turn induce changes that have an effect on natural ecosystems (Ruiz-Luna and Berlanga-Robles, 2003; Turner and Ruscher, 2004). Land use/cover information is necessary in many elements of sustainable land resource management and policy formulation, as a prerequisite for monitoring and simulating land use and environmental transformation, and as the foundation for land use statistics at all levels (Jansen and Di Gregorio, 2004).

The GIS enables planners to examine statistical data to determine the geographical evolution of a certain area, which aids in decision-making. Finding the changes during a particular time period of much importance. Geographic Information System (GIS) is an information technology that has been utilized to frame public policy for environmental and forest planning as well as for decision-making over the last two decades (Bassole *et al.,* 2001). GIS and other related technologies offer foresters a strong tool for keeping records, analyzing data, and making decisions. Remote sensing and geographic information systems (GIS) are indispensable instruments for generating accurate and timely data on the spatial distribution of land use/land cover variations over large areas (Selcuk *et al.,* 2008).

Remote sensing data is widely and effectively used in LULC classification (Brahmabhatt *et al.,* 2000; Alaguraja *et al*., 2010; Sinha *et al.,* 2013) owing to its ability to acquire data repeatedly, its suitability for computer processing, and less cost compared to traditional methods (Karwariya and Goyal, 2011; Sinha *et al.,* 2013). Aerial photographs and repetitive satellite images are useful for both qualitative and quantitative evaluations of land cover changes as well as visual evaluations of changing natural resource characteristics at a specific time and space (Tekle and Hedlund, 2000).

Recent human incursions into wilderness areas such as forests and wetlands have resulted in the degradation or eradication of these habitats. Loss of habitat and habitat fragmentation are significant conservation concerns for species. The use of remote sensing by forest managers has steadily increased, due to improved integration of imagery with GIS technology and databases, as well as implementations of the technology that better meet forest managers' information requirements (Wulder and Franklin, 2003). Remote sensing has made a big step forward by making it easier to get high-spatial- and high-spectral-resolution data from a wide range of sensors and platforms, such as photographic and digital cameras, video capture, and airborne and spaceborne multispectral sensors. Improved differentiation of forest cover and physiological characteristics is promised by hyperspectral photography. Applications for radar are being created that can see through the forest canopy and offer details about the forest floor. Advanced digital analysis methods and selective use of complementary data have yielded greater detail than ever before regarding forest structure, function, and ecosystem processes (Hill and Leckie, 1999; Culvenor, 2003).

Using coarse and high-resolution remote sensing data, a number of studies on deforestation and degradation in tropical forests have been carried out (Kanga *et al*., 2011). Used satellite images from different time periods

Fig. 1. Location of the Study Area

to measure how forests change over time is becoming an important way to figure out the threat an ecosystem is facing (Kanga *et al.,* 2013). GIS, on the other hand, provides an environment for the analysis of digital data beneficial for change detection, database development, modelling of future change, and data dissemination for efficient management planning. In majority of developing nations, remote sensing techniques are deemed suitable for assessing past and prospective deforestation rates (Kanga *et al.,* 2014; Kanga *et al.,* 2015). The goal of this study was to present the current perspective on the different types of forest cover and land cover and changes that have taken place over the last 23 years in Wayanad district, to integrate visual interpretation with supervised classification using GIS, and to investigate the potential

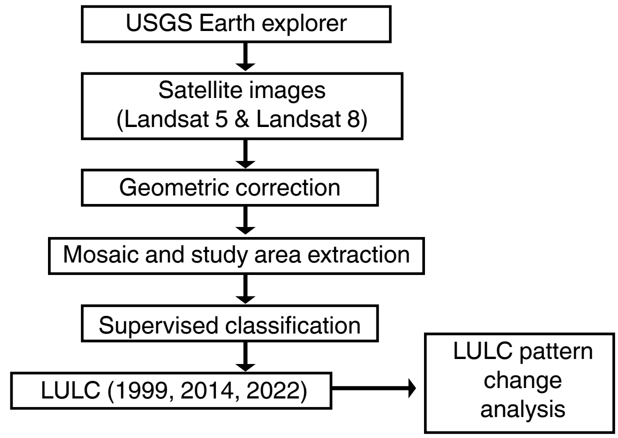

Fig. 2. Flow Chart of the Research Methodology

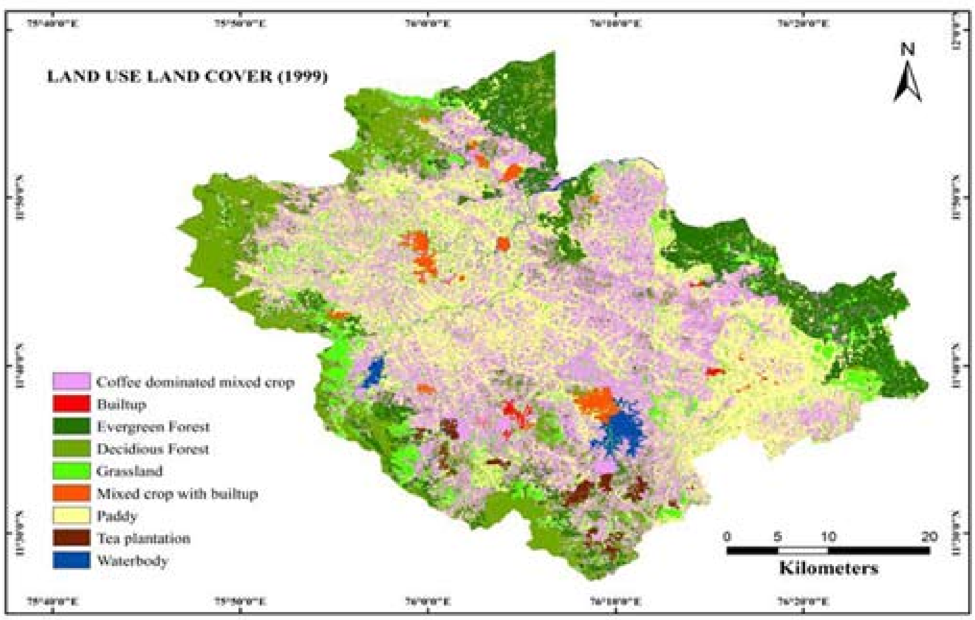

Fig. 3. LULC Classification of Wayanad district (1999)

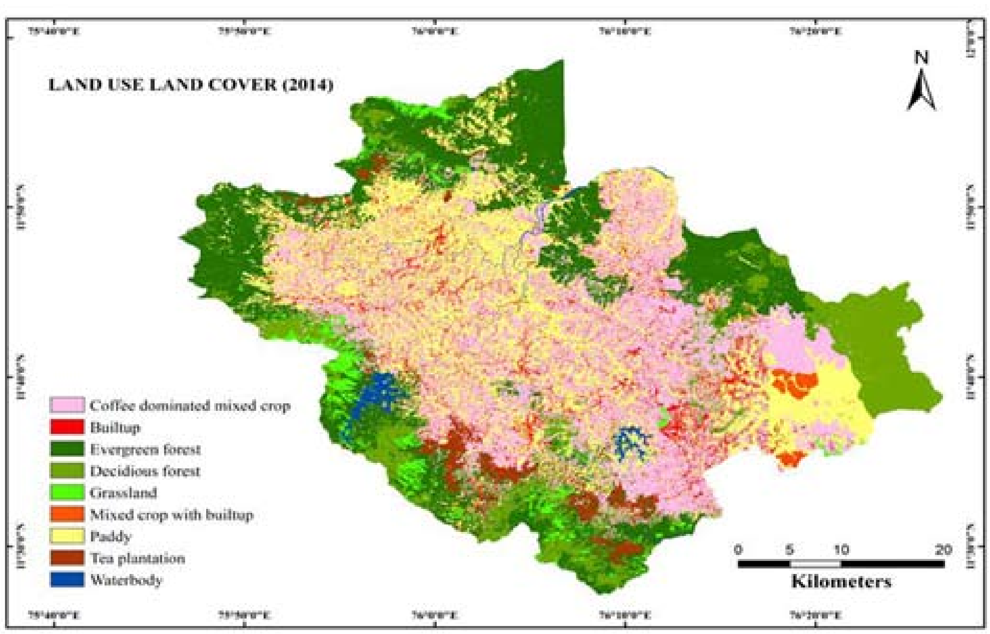

Fig. 4. LULC Classification of Wayanad district (2014)

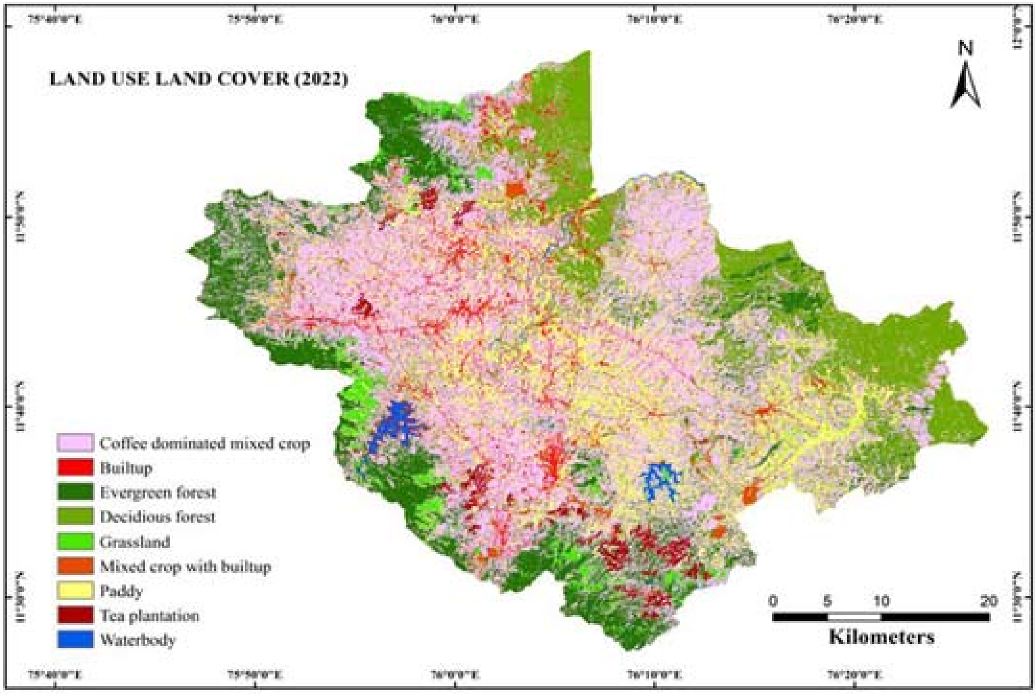

Fig. 5. LULC Classification of Wayanad district (2022)

of integrating remote sensing and GIS in studying the spatial distribution of different land cover and forest cover changes.

Materials and Methods

Study area

Wayanad is located between the latitudes of 11° 27' and 15° 58' in the north and 75° 47' and 70° 27' in the east. Located at the southernmost portion of the Deccan plateau, its crowning glory is the majesty of the western ghats, which comprises of high ridges interspersed with magnificent forests, dense jungles, and deep valleys. In the district's centre, the hills are of a lower elevation, whereas in the district's northern region, the hills are high and have a rugged and mountainous appearance. The eastern region is open and flat. Due to this peculiar terrain, there are rivers that flow east and west. The low slopes are covered with tea, coffee, pepper, and cardamom plantations, while the valleys are dominated by paddy cultivation. More than 80% of the residents of Wayanad depend directly or indirectly on agriculture for their livelihood. Wayanad's most important commodities include coffee, pepper, tea, banana, paddy, cardamom, ginger, and vegetables.

Wayanad district contains three forest divisions: North Wayanad, South Wayanad, and Wayanad Wildlife Division. The North Wayanad Division has a total forest area of 215.48 square kilometers, which comprises of 133.90 square kilometers of reserve forest and 66.52 square kilometers of vested forest. The South Wayanad Forest Division oversees 325.89 square kilometers of forest. It consists of 67.52 square kilometers of reserve forest and 251.91 square kilometers of forested land. Wayanad Wildlife Sanctuary encompasses an area of 344.55 square kilometers. The combined forest area of the three forest divisions is 885.92 square kilometers, which includes the proposed reserve forest area (Fig. 1).

Analysis performed

Landsat images procured from USGS Earth explorer of years 1999, 2014 and 2022 were used for the study (Table 1). All the images were geometrically corrected before the analysis. LULC analysis was carried out using maximum likelihood supervised classification and a total of 9 LULC categories were identified in the study area such as coffee dominated mixed crop, built-up, evergreen forest, deciduous forest, grassland, mixed crop with built-up, paddy, tea plantation and waterbody. A total of 100 training samples were generated throughout the study area for the accuracy assessment. The training samples were created using "Create accuracy assessment points" tool in ArcGIS (Fig. 2).

Table 1. Satellite images used for the study

Specifications	Year		
	1999	**2014**	**2022**
Satellite series	Landsat 5	Landsat 8	Landsat 8
Sensor	TM	OLI	OLI
Bands used	2,3,4	3,4,5	3,4,5
Date of acquisition	30/04/1999	17/11/2014	03/04/2022
Path & Row	144,52 145,52	144,52 145,52	144,52 145,52
Spectral resolution	30	30	30

Table 2. LULC Distribution 1999, 2004, and 2022

LULC Classes	Year					
	1999		2014		2022	
	Area (km²)	% of area	Area (km²)	% of area	Area (km²)	% of area
Coffee dominated mixed crop	635.692	29.86	653.563	30.70	887.599	41.70
Built-up	12.721	0.60	136.711	6.42	128.248	6.02
Evergreen forest	277.794	13.05	419.899	19.73	326.230	15.33
Deciduous forest	318.103	14.94	241.457	11.34	331.011	15.55
Grassland	189.257	8.89	56.246	2.64	75.8124	3.56
Mixed crop with built-up	27.058	1.27	11.201	0.53	11.213	0.53
Paddy	626.062	29.41	549.930	25.83	320.209	15.04
Tea plantation	19.326	0.91	38.625	1.81	29.857	1.40
Waterbody	22.662	1.06	21.034	0.99	18.494	0.87

Results and discussion

A supervised maximum likelihood classification, specifically using the full Gaussian method, was conducted on three photos. The resulting classification products offer a comprehensive representation of the primary land use and land cover characteristics of the forest in Wayanad district for the years 1999, 2014, and 2022.

The LULC maps of Wayanad district for the years 1999, 2014, and 2022 are illustrated in Figures 3, 4, and 5, respectively.

The data furnished in Table 2. illustrate the current land use/cover status and the changes in land use/ cover across several land use categories as well as the quantitative representation of the spatial coverage of land cover, expressed in square kilometer and percentages. In 1999, the area of coffee dominated mixed crop was 635.692 km^2. Subsequently, this area rose to 653.563 km^2 in 2014 which a further increase to 887.599 km^2 in 2022. The built-up areas increased from 12,721 km^2 to 136,711 km^2 and to 128,248 km^2 in 1999,2014 and 2022 respectively. The extent of the evergreen forest area also witnessed an increase from 277.794 km^2 to 419.899 km^2 during1999 to 2014, thereafter it shrunk to 326.230 km^2 in 2022, indicating a decline during the year 2014 to 2022. The area of deciduous forest witnessed a decline from 318.103 km^2 in 1999 to 241.457 km^2 in 2014, followed by a subsequent increase to 331.011 km^2 in 2022. The grassland area drastically declined from 189.257 km^2 to 56.246 km^2 in 2014 and then increased to 75.8124 km^2 in 2022. Therefore, there was an increase in the grassland area in 2022 when compared to the measurements recorded in 2014.

The area of mixed crop with built-up land declined from 27.058 km^2 to 11.201 km^2 and slightly increased 11.213 km^2 in 1999, 2004 and 2022 respectively, indicating no significant change in the last two measurements. The area of paddy declined significantly from 626.062 km^2 to 549.930 km^2 and to 320.209 km^2, exhibiting a substantial reduction between the years 1999 and 2022. The tea plantation area experienced an initial increase from 19.326 km^2 to 38.625 km^2 from1999 to 2014 followed by a subsequent reduction to 29.857 km^2 in 2022. There was a reduction in area compared to the measurements recorded in 2014, but there was an increase in area when compared to the figures recorded in 1999. The area of the waterbody experienced a reduction from 22,662 km^2 to 21.034 km^2 from 1999 to 2014, followed by a subsequent decline to 18.494 km^2 in 2022. The area of water bodies was showing a decline trend throughout the course of three distinct time periods.

The findings indicate that there had been a gradual increase in coffee-dominated mixed crops over a period of 23 years, with a growth rate of 0.84% in 2014 and 11.84% in 2022, as compared to the baseline year of 1999. Conversely, there had been a decline in the extent of deciduous forest area, with a loss of 3.6% in 2014 and a subsequent increase of 0.6% in 2022. The tea plantations experienced a growth rate of 0.9% in 2014, followed by a lower growth rate of 0.49% in 2022. However, this growth rate represented a decline of 0.41% when compared to the growth rate observed in 2014. The built-up area witnessed sequential growth of 6.42% from 1999 to 2014 and in 2022 there was a slight decrease of 0.4% compared to the reported data in 2014. The extent of evergreen forest regions recorded a notable growth of 6.68% in 2014 and a further increase of 2.28% in 2022. However, in comparison the data of 1999, there was a decline of 4.44% in the evergreen forest areas. The grassland areas had experienced a reduction of 6.25% and 5.33% in the respective time periods. Similarly, the combined areas of mixed crops and built-up areas have declined by 0.74% and remained unchanged in the last two time periods. In terms of paddy fields and waterbodies, there had been a decline of 3.58%, 14.37%, 0.07%, and 0.19% in the years 2014 and 2022, respectively, in relation to the total geographical area.

The study found a sharp decrease in grassland

and a notable rise in built-up areas in Wayanad district, suggesting that human activities are altering the grassland for agriculture and urban development. Decreases were observed in the cultivation of paddy and mixed crops with built-ups, suggesting changes in agricultural practices, climate change, and tourism promotion. The decline of the waterbodies was attributed to changes in land use, such as urbanisation, deforestation, and agricultural expansion.

Franklin (2001) stated that combining remote sensing and geographic information systems (GIS) results in synergistic advantages, improving the effectiveness of monitoring, mapping, and managing forest resources. GIS and RS are considered highly reliable methods for analysing changes in land cover patterns over time, according to Lillesand *et al*. (2003) and Quan *et al.* (2013). Selcuk *et al*. (2003) determined that the application of GIS and remote sensing technologies was essential for generating accurate and timely data on the spatial patterns of land use and land cover changes across large areas. De Sy *et al*. (2012) proposed that the most effective methods for monitoring forest degradation via remote sensing could differ greatly based on aspects including the root causes of deterioration, the particular type of forest, the severity of the impact, and the location. Weng (2002) and Singh and Kumar (2012) emphasise the importance of policymakers and scientists being cognizant of the spatial dimensions of land use and land cover to effectively make informed decisions regarding land resources. Geologists, land and water managers, and urban planners are all interested in studying the location, distribution, type, and extent of land use and land cover change.

Sishodia *et al*. (2020) and Weiss *et al.* (2020) suggested that remote sensing has transformed crop monitoring and interventions to enhance agricultural productivity through its many methodologies and applications in agriculture. According to Quane (2010) and Elhag (2016), the use of remote sensing-supported GIS technology has shown usefulness in water resource management. Geeraert *et al*. (2019), Belay and Mengistu (2019), Minta *et al*. (2018), and Feyissa and Gebremariam (2018) reported a rapid decline in forest cover in the study region. Nagessa *et al.* (2020) found in their study that agricultural land, grassland, and settlement areas increased, whereas dense and open forest cover decreased in Ethiopia. In the present study, agriculture land and forest cover areas increased, but grassland areas declined rapidly. Evergreen and deciduous forest areas increased; in 1999, the areas were 13.05% and 14.94%, respectively. Evergreen forests showed an increasing trend in 2014 and declined in 2022 compared to the previous period; the areas were 19.73% and 15.33%, respectively, increasing the area compared to 1999. Deciduous forest areas showed an increase in area compared to 1999; it was 14.94%, but in 2022, the area was 15.55%. In 2014, the percent of area declined to 11.34%. The grassland area decreased from 8.89% to 2.64% in 2014, and further to 3.56% in 2022. There was a steady rise in coffee-dominated mixed crops over 23 years, with growth rates of 0.84% in 2014 and 11.84% in 2022, compared to 1999. In 2014, tea plantations increased at a pace of 0.9% annually, and in 2022, they grew at a lower rate of 0.49% compared to 1999. The percentage of Paddy Field has been declining over the years: 29.41% in 1999, 25.83% in 2014, and 15.04% in 2022.

Ahmad *et al.* (2022) found a decline in water bodies and a rise in built-up areas over a 20-year period from 2000 to 2020 in the Peshwar Basin, Pakistan. According to a study by Hegzay and Kaloop (2015), the built-up areas in the Egyptian governorate of Daqahlia have expanded by 30%. Roy and Kasemi (2021) observed that the built-up area expanded from 4.30% in 1991 to 20.25% in 2019, leading to the depletion of valuable agricultural land, unused land, and vegetation. The present study shows an increase in the percentage of water body area and built-up area. The built-up area increased by 6.42% between 1999 and 2014, then decreased by 0.4% between 2014 and 2022. A decrease of 0.07% and 0.19% was seen in waterbodies in 2014 and 2022, respectively, relative to the total geographical area.

Conclusion

The objective of this study was to provide a contemporary outlook on the various categories of land cover and their transformations within the Wayanad district over a span of 23 years. Additionally, the study aims to combine visual interpretation with supervised classification techniques utilizing Geographic Information Systems (GIS). The findings of the study indicate that there was an increase in the area of deciduous forest, evergreen forest in Wayanad over a period of 23 years. Increase was also noted coffee dominated mixed crops and tea plantation. There was a drastic decline in the grass land and significant increase in built-up area indicating that human activities are transforming grass land of Wayanad district. Declining trends were also noticed for paddy cultivation, water bodies and mixed crop with built-up indicating shift in agricultural patterns, climate change and tourism promotion. This findings of the indicate remotely sensed data, namely imageries, play a significant and very valuable role in the mapping and monitoring of land use and land cover dynamics in Wayanad region. The analysis of Geographic Information Systems (GIS) has demonstrated the efficacy of GIS in addressing spatial challenges and offering valuable information to support decision-making processes.

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Conflict of interest

There is no potential conflict of interest

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