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ANALYSIS OF FOREST COVER CHANGE IN BEN EN NATIONAL PARK, VIETNAM

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АНАЛИЗ ИЗМЕНЕНИЯ ЛЕСНОГО ПОКРОВА В НАЦИОНАЛЬНОМ ПАРКЕ БЕН ЭН, ВЬЕТНАМ

Abstract. The analysis of land use and land cover (LULC) based on remote sensing and geographic information systems in Ben En National Park, Vietnam, from 2003 to 2023 has revealed significant landscape changes. Assessing the accuracy of the classification results on our Landsat satellite images has shown high reliability, with kappa coefficients above 0.9 for both 2003 and 2023, indicating strong agreement between the classified images and actual reference data. Over the two-decade period, the dominant LULC class remained natural forest, albeit experiencing a substantial reduction in coverage. In contrast, waterbodies and agricultural land expanded significantly. These LULC changes can be attributed to both natural processes and human activities, such as dam construction and water management projects. The most concerning trend is the significant decline in natural forest coverage, primarily driven by deforestation, logging, and land conversion. These activities pose a severe threat to plant biodiversity and the habitats of wildlife within Ben En National Park. Climate change, characterized by erratic weather patterns, exacerbates these challenges, disrupting forest development. Prolonged droughts and heavy rainfall disrupt the growth of planted species, aggravating the situation. Urgent measures are required to address illegal logging and deforestation, coupled with sustainable land management practices to safeguard the park's unique biodiversity. This study underscores the importance of remote sensing and geographic information systems in monitoring and addressing environmental changes, providing essential data for informed decision-making in land use planning and conservation efforts within the national park.

Keywords: Forest cover; Landsat; Deforestation; Remote Sensing; Ben En National Park.

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Аннотация. Анализ использования земель и покрытия земли (LULC) на основе дистанционного зондирования и географических информационных систем в национальном парке Бен Эн, Вьетнам, с 2003 по 2023 год, показал значительные изменения в ландшафте. Оценка точности результатов классификации на наших спутниковых изображениях Landsat показала высокую надежность, с коэффициентами каппа выше 0,9 как в 2003, так и в 2023 году, что указывает на сильное согласие между классифицированными изображениями и фактическими данными. За двадцатилетний период доминирующим классом LULC оставался природный лес, хотя и с существенным сокращением площади. В то время как водоемы и сельскохозяйственные угодья значительно расширились. Эти изменения LULC могут быть объяснены как естественными процессами, так и деятельностью человека, такой как строительство плотин и проекты по управлению водными ресурсами. Самой тревожной тенденцией является значительное сокращение площади природного леса, в первую очередь из-за вырубки деревьев, лесозаготовки и преобразования земель. Эти действия представляют серьезную угрозу растительному биоразнообразию и местообитаниям дикой природы в национальном парке Бен Эн. Изменение климата, характеризующееся нестабильными погодными условиями, усугубляет эти проблемы, разрушая развитие леса. Продолжительные засухи и сильные дожди нарушают рост посаженных видов, ухудшая ситуацию. Неотложные меры необходимы для борьбы с незаконной вырубкой и вырубкой леса, совместно с устойчивыми методами землеустройства, чтобы обеспечить уникальное биоразнообразие парка. Это исследование подчеркивает важность дистанционного зондирования и географических информационных систем в мониторинге и решении экологических изменений, предоставляя необходимые данные для обоснованного принятия решений в планировании земельного использования и усилиях по сохранению в национальном парке.

Ключевые слова: Лесопокрытие; Landsat; Вырубка леса; Дистанционное зондирование; Национальный парк Бен Эн.

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Introduction

Biological diversity forms the foundation of living resources, playing a crucial role in meeting the fundamental needs of human beings [1; 10]. It accelerates the process of decomposition, influences the chemical composition of the atmosphere, and impacts on the global climate, all of which rely on the sustainability of robust and intricate ecosystems. Forest ecosystems fulfil these essential functions, offering significant value from both economic and ecological perspectives by providing various goods and services such as water and soil protection, carbon sequestration, tourism and recreation opportunities, and non-wood forest products [2; 7; 29]. To ensure the long-term sustainability of these forest values, forest ecosystems are commonly conserved through in-situ programs such as National Parks, Nature Conservation Areas, Nature Parks, or Wildlife Development Areas [10]. While National Parks are specifically designated to contribute to global conservation efforts, they often fall short of fulfilling all their intended functions. The land use and spatial patterns of forests in National Parks constantly face the imminent threat of displacement due to rapid population growth, urbanization, excessive exploitation, and illegal logging [9; 32].

Vietnam is blessed with a significant forest cover, encompassing approximately 41% of its land area, equivalent to around 14 million hectares [23]. These forests are home to a wide range of plant and animal species, making them vital ecosystems for biodiversity conservation. Their lush green landscapes, towering trees, and rich biodiversity [6] characterize the forests in Vietnam. However, Vietnam's forests face various challenges and threats. Deforestation remains a significant issue, with an estimated loss of approximately 26,000 ha of forest annually. Factors contributing to deforestation include illegal logging, encroachment for agriculture and settlements, unsustainable land-use practices, and the demand for fuelwood [14; 19]. These activities put immense pressure on the country's forest resources and cousing the degradation and fragmentation of forests. The consequences of deforestation and forest degradation are far-reaching. They include the loss of habitat for numerous plant and animal species, disruption of ecosystems, soil erosion, reduced water quality and availability, and increased greenhouse gas emissions. Addressing these challenges is crucial for the long-term sustainability of Vietnam's forests and the well-being of its people.

In contemporary times, satellite data plays a vital role in monitoring the dynamic changes occurring within forests [4; 13]. The high temporal resolution of remote sensing data makes it highly valuable for detecting alterations in forest cover. The synergistic use of remote sensing and geographic information systems (GIS) technology has proven to be the most effective tool for studying land use and land cover (LULC) on the Earth's surface [15; 19]. Mapping LULC has now become a standard method for monitoring forest cover changes. Consequently, a current study was conducted to assess the changes in forest cover in Ben En National Park, Vietnam by integrating remote sensing with GIS technology.

Materials and methods

Study area

Ben En National Park is located in the southern part of Thanh Hoa province, Vietnam, spanning from 19°31′N to 19°43′N latitude and 105°25′E to 105°38′E longitude, with a total area of 14,735 ha (Fig. 1) [17]. On January 27, 1992, Ben En National Park was established under Decision No. 33/CT by the Chairman of the Council of Ministers of Vietnam, with the objectives of conserving natural ecosystems, restoring wildlife species, conducting scientific research, developing tourism, and improving the livelihoods of the local communities [17]. The park encompasses diverse landscapes including plains, hills, and river valleys. The majority of the park's area consists of plains, while hills and rivers occupy the remaining portion, providing a rich habitat for various animal and plant species. The study area is subdivided into two distinct regions: the mountainous area and the river area, each exhibiting distinctive biological characteristics. Within the mountainous regions, the biodiversity peaks, encompassing tropical forests, temperate woodlands, and primary forests. Evergreen and deciduous tree species coexist, giving rise to a unique ecological equilibrium. The river area of Ben En National Park underscores the intricate interplay between terrestrial life and aquatic ecosystems. The rivers and lakes serve as vital water sources that underpin the survival of a myriad of fish species and aquatic organisms, fostering a delicate ecological harmony. Ben En National Park is situated in a region with a subtropical climate characterized by four distinct seasons: spring, summer, autumn, and winter. The average annual temperature ranges from 23°C to 25°C. Summers are hot and humid, while winters are relatively cold. These favorable climatic conditions have created a conducive environment for the development of diverse species within the national park.

The research area not only holds unique natural values but also plays a crucial role in the economic development of the region. In addition to preserving and maintaining valuable natural resources, the national park attracts visitors from all over to explore and enjoy its remarkable natural beauty. Tourism has become one of the main sources of revenue for the national park, contributing to the development of the local community. With the combination of diverse natural landscapes and economic growth, Ben En National Park proudly stands as an attractive and worthwhile destination in Vietnam.

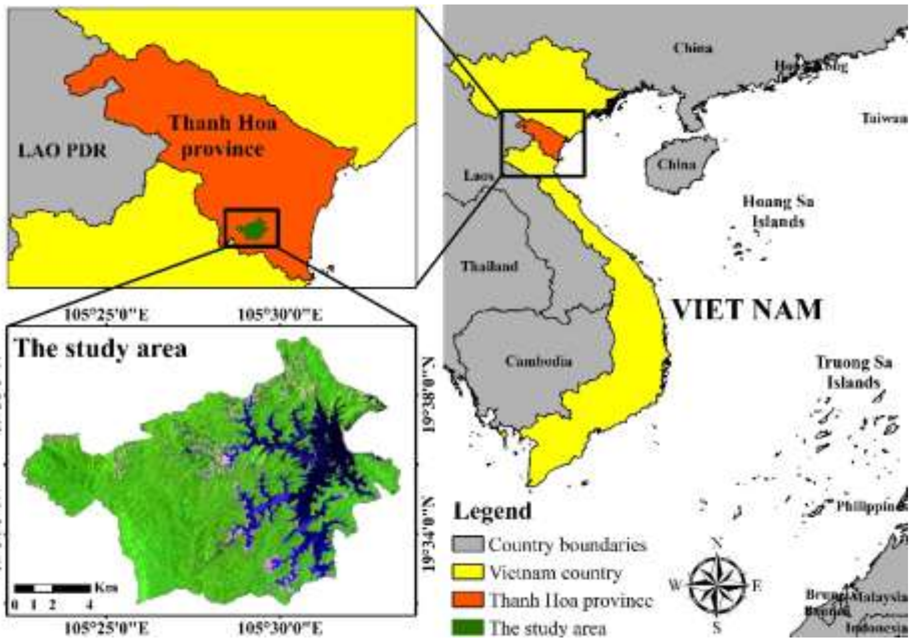

Fig. 1. Study area map of Ben En National Park, Vietnam

Data collection

Two datasets, Landsat 5-TM (2003) and Landsat 8-OLI/TIRS (2023) were obtained from the United States Geological Survey (USGS) GloVis website (https://glovis.usgs.gov) for analyzing LULC changes and mapping. Satellite images with a spatial resolution of 30 m and path/row 127/046 were collected during the summer of each year to minimize the impact of clouds during the classification process. Ground truth verification was conducted to validate the accuracy of the LULC classification map using samples collected through Google Earth Pro in 2003 as well as through field surveys in 2023. Through on-site surveys, we identified five main types of LULC based on different land uses. These include agricultural land (rice, tea, cashew, and black pepper), cultivated forest (white sandalwood, rosewood, bamboo, and dalbergia), natural forest (rosewood, red sandalwood, ebony, lacquer tree, and ancient tree), waterbodies (ponds, lakes, rivers, and brook), and other land cover (abandoned land, built-up areas, and rocky terrain).

Image pre-processing and supervised classification

To extract meaningful information from satellite data and facilitate interpretation, a series of image pre-processing techniques were applied [21]. These procedures included geometric corrections, image enhancement, noise removal, and topographic corrections, aiming to preprocess the raw data and enhance its interpretability [16]. Composite bands were then generated by combining specific bands to create an image with optimal band combinations. The study area was defined, and the image subset was extracted using ArcGIS 10.8 software. The extract by mask tools were utilized to isolate the image based on the study area boundaries [20]. Following the classification scheme proposed by Anderson et al. (1976) [3] and validated through field surveys, five primary LULC categories were identified: agricultural land, cultivated forest, natural forest, waterbodies, and other land cover.

Training samples were carefully selected for each predefined LULC class by delineating polygons around representative areas [12; 26]. Spectral signatures, which represent the characteristic spectral properties of each land cover type, were derived from the satellite images using these defined polygons. The selection of representative training samples ensured minimal confusion between the mapped land cover classes. For LULC classification of the acquired images from 2003 and 2023, a rule-based supervised classification approach called the maximum likelihood classifier (MLC) was employed [12; 30]. The MLC algorithm allows the analyst to manually select pixels that represent the desired land cover classes. To refine the classification results and improve accuracy while reducing misclassifications, a post-classification refinement technique was applied. The adopted LULC classification approach ensured consistency in defining each land cover category and provided clear boundaries based on variations in natural and anthropogenic features within the study area. Moreover, this classification method is scale-independent, making it applicable at various spatial scales and levels of detail.

Classification accuracy assessment

In change detection analysis involving classification data, it is crucial to assess the accuracy of the classification results. The aim is to determine the quality of spatial classification information obtained from remotely sensed data and its correspondence with reference information [12]. The kappa coefficient is a widely used metric to quantify the classification accuracy and the performance of the analysts involved in the classification process [21]. To assess the classification accuracy, 100 random points were selected using stratified randomization in ArcGIS 10.8 software. These points were distributed across the study area to represent different LULC classes. This approach ensures that each LULC class is adequately represented by reference points, minimizing bias in accuracy estimates. The reference data and the classification results were statistically compared using an error matrix. The kappa coefficient was expressed by the formula below to calculate the degree of agreement between the reference data and the classification results:

$$\mathrm{Kappa} = \frac{\mathrm{Po} - \mathrm{Pe}}{1 - \mathrm{Pe}}$$

where P_o is the agreement ratio between the predicted classification results and the actual classification results. P_e is the random agreement ratio between the predicted classification results and the actual classification results.

Land use/land cover change detection

The post-classification change detection technique, acknowledged as the most accurate approach, compares independently produced classifications of images from different dates to detect changes in LULC. We compiled change maps to illustrate the specific changes observed between each pair of classified images. Utilizing pixel-based comparisons, we generated information that identifies changes on a pixel-by-pixel basis and facilitates a more efficient interpretation of the "from-to" transitions [18]. By performing cross-tabulation, we compared the categories of image pairs to determine qualitative and quantitative differences between the 2003 and 2023 datasets. This analysis enabled us to obtain a two-way cross-matrix, which described the primary patterns of change within the study area.

Results and discussion

The LULC classification map in Ben En National Park for the years 2003 and 2023 was depicted in Figure 2. Table 1 presents the area, proportion, and changes of each corresponding LULC type during the period 2003–2023. From the data in Table 1, it can be observed that significant changes have occurred over the 20 years in the study area. Before using satellite image-based classification results for change detection, we first evaluated their accuracy by checking the results obtained with reference data. The overall accuracy values of the classification results in this study area for the years 2003 and 2023 were 92.0% and 92.8%, respectively. Moreover, the kappa coefficients were 0.901 and 0.910 for the years 2003 and 2023, respectively. The kappa coefficient serves as a quantitative measure of the classification accuracy, providing valuable insights into the agreement between the classified image and the ground truth reference data [11]. Kappa coefficients ranging from 0.81 to 1.00 are considered almost perfect in LULC classification [22; 31]. These results show reliable land cover classification and good consistency between referenced and classified maps.

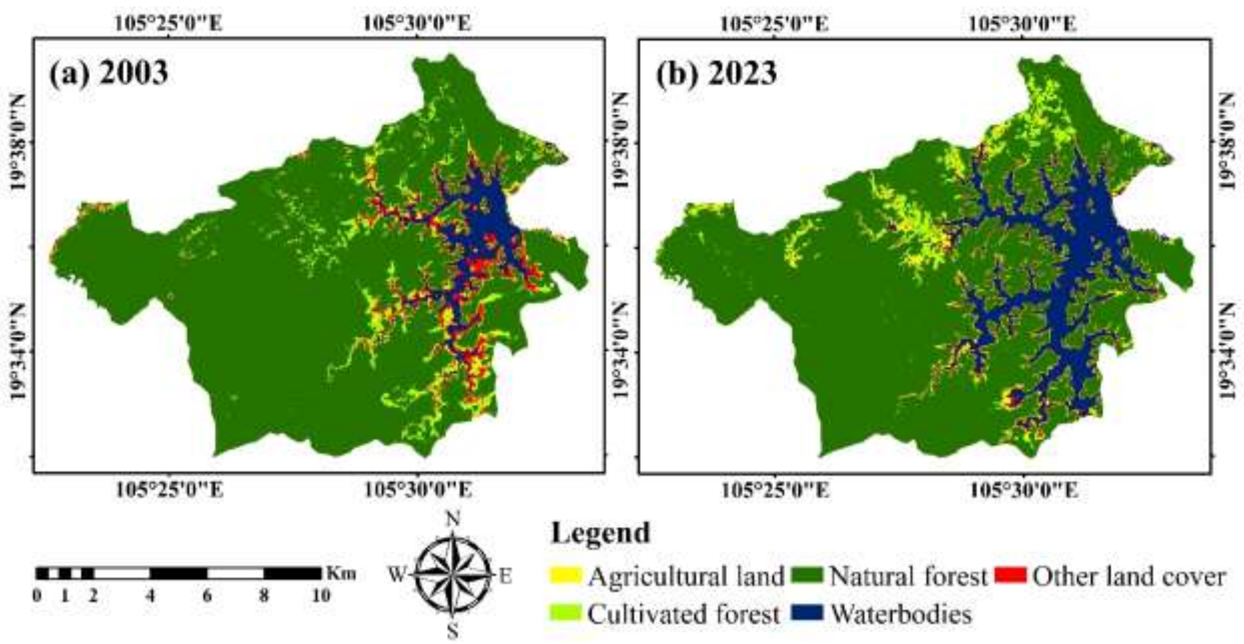

Fig. 2. Land use/land cover maps for Ben En National Park in (a) 2003 and (b) 2023

The classification results have indicated that in 2003, the natural forest class area was the largest area within the research area, accounting for 83.09% (12243.22 ha) (Table 1). Following that, the waterbodies class area accounted for 5.62% (827.95 ha), the cultivated forest class area accounted for 5.24% (772.79 ha), and other land cover classes area accounted for 4.08% (601.79 ha). Lastly, the agricultural land class area had the smallest coverage within the research area at

1.96% (289.25 ha) (Table 1). By the year 2023, the natural forest class area had experienced a reduction in coverage; however, it remained the predominant land cover class within the research area, accounting for 75.00% (11050.80 ha). Furthermore, the cultivated forest and other land cover classes area had also decreased to 5.14% (758.02 ha) and 2.63% (387.24 ha), respectively (Table 1). Meanwhile, the area of agricultural land and waterbodies classes had increased to 3.62% (532.85 ha) and 13.61% (2006.09 ha), respectively of the total research area.

Table 1

The land use/land cover area distribution from 2003 to 2023 in Ben En National Park

Class	2003		2023		Change in 2003-2023	
	Area (ha)	%	Area (ha)	%	Area (ha)	%
Agricultural land	289.25	1.96	532.85	3.62	243.60	1.65
Cultivated forest	772.79	5.24	758.02	5.14	-14.77	-0.10
Natural forest	12243.22	83.09	11050.80	75.00	-1192.42	-8.09
Waterbodies	827.95	5.62	2006.09	13.61	1178.14	8.00
Other land cover	601.79	4.08	387.24	2.63	-214.55	-1.46
Total	14735.00	100.00	14735.00	100.00		

Figure 3 illustrates the changes in land cover classes within the Ben En National Park from 2003 to 2023. From Table 1, it can be observed that, during this period, most of the LULC changes occurred in the natural forest and waterbodies classes. The area of the waterbodies class has increased the most, with a total area increase of 1178.14 ha (8.00%). This significant increase in waterbodies may be due to natural processes like increased rainfall or changes in hydrological patterns [25; 28]. It could also result from human activities such as dam construction or irrigation projects, which may have led to the creation of new water bodies or the expansion of existing ones. In addition, the area of agricultural land class has also increased by 243.60 ha, equivalent to 1.65% of the total area of the study area. The expansion of agricultural land can be linked to factors like population growth, agricultural development, or changes in land-use policies [24]. Conversion of natural areas, including forests, into agricultural land is a common reason for such increases. In contrast, the natural forest area class has been reduced the most with 1192.42 ha (8.09%), along with other land cover classes also reduced with 214.55 ha (1.46%) (Table 1). The substantial reduction in natural forest area may be primarily due to deforestation, logging, and land conversion for agricultural or developmental purposes [8]. Human activities, illegal logging, and forest clearance for infrastructure or agricultural expansion are typical causes of deforestation. Finally, the cultivated forest class from 2003 to 2023 has also been reduced by 14.77 ha (0.10%) (Table 1). The reduction in cultivated forest may be due to factors like shifting agricultural practices, abandonment of cultivated areas, or changes in land management [5]. These factors can lead to a decrease in the extent of cultivated forest over time.

GIS analysis was used for post-classification comparison of the detected changes, with a change map generated for the period 2003–2023 to understand the spatial pattern of change (Fig. 3). The classified maps were overlayed to create a LULC volatility map; a cross-tabulation matrix was also generated for the period 2003–2023 (Table 2) to show the nature of changes in the different cover classes [27]. Among the total agricultural land area of 289.25 ha in 2003, 18.18 ha remained as agricultural land in 2020. However, 199.85 ha were converted into the waterbodies class, 47.71 ha became other land cover, and the remaining 23.51 ha were converted into cultivated forest and natural forest. The cultivated forest class retained only 99.92 ha out of the initial total of 772.79 ha in 2003; the rest was converted to all other classes (Table 2). During the period 2003–2023, the cultivated forest class, with the lowest area loss primarily due to receiving 638.37 ha from natural forest conversion, accounted for most of the loss. In the total natural forest area of 12,243.22 ha in 2003, most of the lost area was converted into cultivated forest, as mentioned above. There was also an additional 665.23 ha converted into other land cover classes, including agricultural land, water bodies, and other land cover. Meanwhile, 10,939.62 ha of natural forest area have been retained by 2023. The waterbodies class increased from 827.95 ha (2003) to 2006.09 ha (2023). Of the initial total area of this class, 824.91 ha were retained, with the most significant increase observed from the other land cover class (530.65 ha), followed by cultivated forest (329.80 ha), agricultural land (199.85 ha), and natural forest (120.88 ha). The other land cover class decreased from 601.79 ha in 2003 to 387.24 ha in 2023. Only 38.85 ha remained as other land cover, while the rest was converted into other classes such as cultivated forest and natural forest (Table 2).

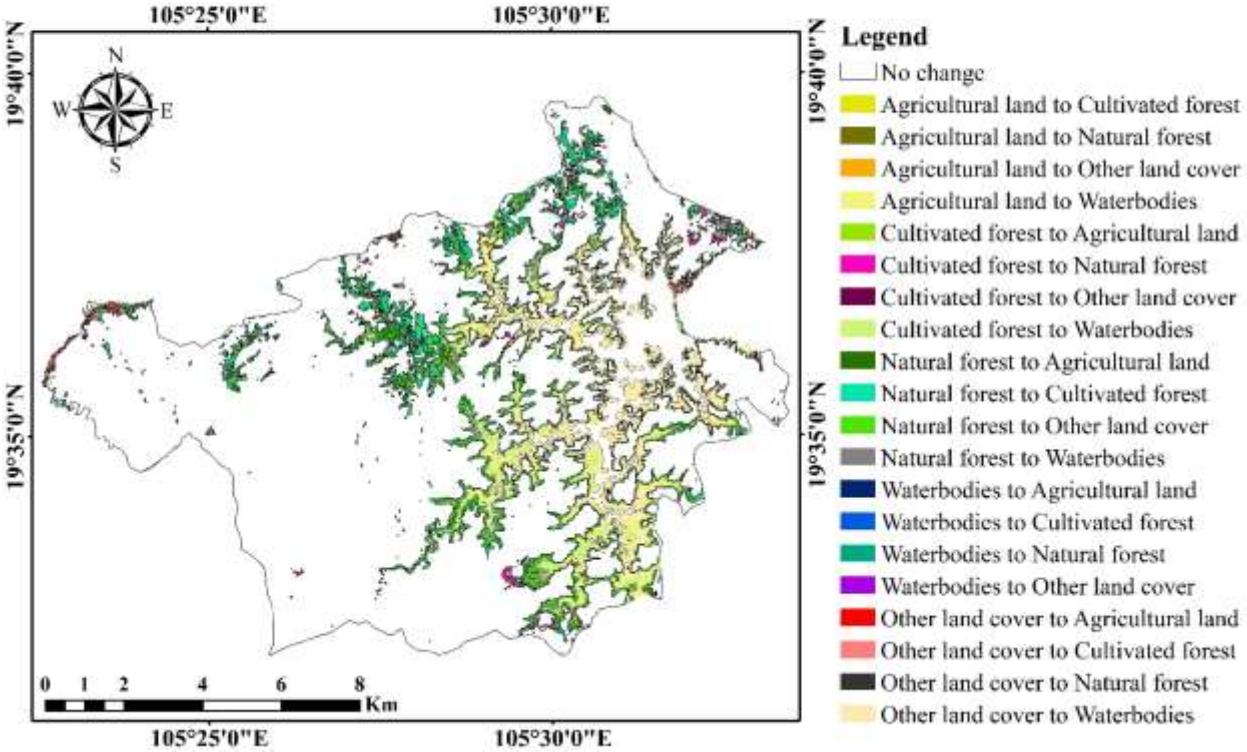

Fig. 3. Land use/land cover changes map from 2003 to 2023 in Ben En National Park

The results of the change matrix analysis (Table 2) indicate a significant reduction in the natural forest and cultivated forest areas during the study period. This reflects that conservation policies for plant biodiversity and the habitats of wildlife within Ben En National Park are facing urgent challenges. The ongoing issue of illegal logging for production and construction materials has resulted in the conversion of a portion of natural forests and sparse forests into other LULC classes, leading to a reduction in green space within the forested area [21; 27]. This negatively impacts the land protective capabilities and water retention, affecting the local ecosystem. Climate change is another factor influencing the development of forested areas within Ben En National Park. Abnormal weather patterns such as prolonged droughts and heavy rainfall have disrupted the forest's condition, hindering the growth of planted species. Additionally, the construction of dams to retain water has also increased the area of water areas, engulfing most of the area of natural forest and cultivated forest.

Table 2

Cross-tabulation of land cover classes between 2003 and 2023 (area in ha)

2003 \ 2023	Agricultural land	Cultivated forest	Natural forest	Waterbodies	Other land cover	Total
Agricultural land	18.18	10.03	13.48	199.85	47.71	289.25
Cultivated forest	132.70	99.92	85.10	329.80	125.27	772.79
Natural forest	370.81	638.37	10939.62	120.88	173.54	12243.22
Waterbodies	0.35	0.24	0.58	824.91	1.87	827.95
Other land cover	10.81	9.46	12.02	530.65	38.85	601.79
Total	532.85	758.02	11050.80	2006.09	387.24	14735.00

Conclusion

In this study, Landsat 5-TM and Landsat 8-OLI/TIRS image data were used to perform supervised classification and LULC maps for the years 2003 and 2023 in Ben En National Park. GIS analysis was then used to overlay the LULC map classes and obtain a change map, with a diagonal matrix created for 2003–2023 to understand the changes in types better. Over the 20 years, the study area has experienced a decline in natural forest, cultivated forest and other land cover classes, with area decreases of 8.09%, 0.10%, and 1.46%, respectively. Additionally, there has been a substantial increase in the extent of agricultural land and waterbodies class areas from 2003 to 2023, with a total increase of 1.65% and 8.00%, respectively. Changes in LULC classes in Ben En National Park, as revealed by this study, are largely associated with human activities. If these LULC trends persist, they are likely to have significant environmental and economic ramifications, impacting the local population's livelihoods. This research underscores the importance of combining remote sensing and GIS in monitoring LULC and forest changes. It provides valuable insights into the spatial distribution and character of land cover changes in Ben En National Park. Based on this research, we recommend that relevant authorities consider implementing solutions such as increasing human resources for monitoring and protecting forest cover from illegal logging activities. Strict enforcement of laws and regulations is also essential for preserving forested areas within the study region. Lastly, we hope that this research can assist national park management agencies in generating the necessary environmental education materials, policy design, and decision-making processes for the conservation and management of forest ecosystems. This includes efforts to protect against illegal logging to prevent loss and degradation of plant biodiversity.

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