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Research Article

Land Use Change Mapping and Analysis Using Remote Sensing and GIS: A Case Study in Tam Ky City, Quang Nam Province, Vietnam

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Abstract

Changes in land use/land cover (LULC) play a critical role in effective natural resource management, monitoring, and development, particularly within the realm of urban planning. In the examination of Tam Ky city, Quang Nam province, Vietnam, spanning from 2000 to 2020, remote sensing and Geographic Information System (GIS) techniques were employed. The Landsat satellite data (Landsat 7 ETM+ for 2000, Landsat 5 TM for 2010, and Landsat 8 OLI for 2022) underwent analysis using the supervised classification method in ArcGIS 10.8 software to identify and categorize six primary LULC classes: water bodies, agriculture, settlements, vegetation, construction, and bare soil/rocks. The reliability of the classification was evaluated through k values, revealing high accuracy with values of 0.951, 0.953, and 0.950 for the years 2000, 2010, and 2020, respectively. Notable shifts in LULC were observed during the period from 2000 to 2020. The areas covered by vegetation and settlements expanded by 53 and 1300 ha, respectively, while water bodies, agriculture, construction, and bare soil/rocks experienced reductions of 466, 48, 413, and 425 ha, respectively. To facilitate a rapid assessment, the study also incorporated the normalized difference vegetation index (NDVI) and normalized difference built-up index (NDBI). The trends identified in this study are consistently aligned with the results of the supervised classification. The identified changes in LULC pose a substantial environmental threat, and the study's outcomes serve as a valuable asset for future land use planning and management in the area. The method's high accuracy enhances the dependability of the results, making them crucial for well-informed decision-making and sustainable development initiatives.

Keywords: land use/land cover change, remote sensing, geographic information systems, landsat, Tam Ky city

1. INTRODUCTION

Similar to other economies in Southeast Asia, Vietnam has undergone a notable transformation in its economy over the past few decades. Since the implementation of the national economic reform known as Doi Moi in 1986, the country has undergone swift industrialization and urbanization. The urban area in Vietnam has expanded significantly, growing by 8.8 times between 1992 and 2010 [1]. The rapid urbanization and industrialization extending into rural and suburban areas have traditionally been viewed as indicators of national and local economic prosperity [2].

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However, the consequences of urbanization and the accompanying economic development have had adverse effects on the spatial structure and land use/land cover (LULC) patterns. The shift towards urbanization has led to changes in how land is used and covered, impacting the overall landscape. This aspect raises concerns about the potential environmental and social implications associated with the evolving LULC patterns in Vietnam.

Land cover refers to the physical and biological cover over the land surface, whereas land use refers to human activities such as agriculture, forestry, and construction that alter the soil surface processes [3]. In recent decades, LULC changes have become an important area of research globally as they become a major driver of climate change and global warming owing to their interaction with the climate, biodiversity, geochemical cycles, ecosystem processes, and, more importantly, human activities [4]-[6]. LULC changes are believed to be caused by anthropogenic environmental challenges, creating combinations of environmental conditions in an area that may be outside the zone shortly [2]. One of the most important global challenges related to managing the variability of the earth's surface is the

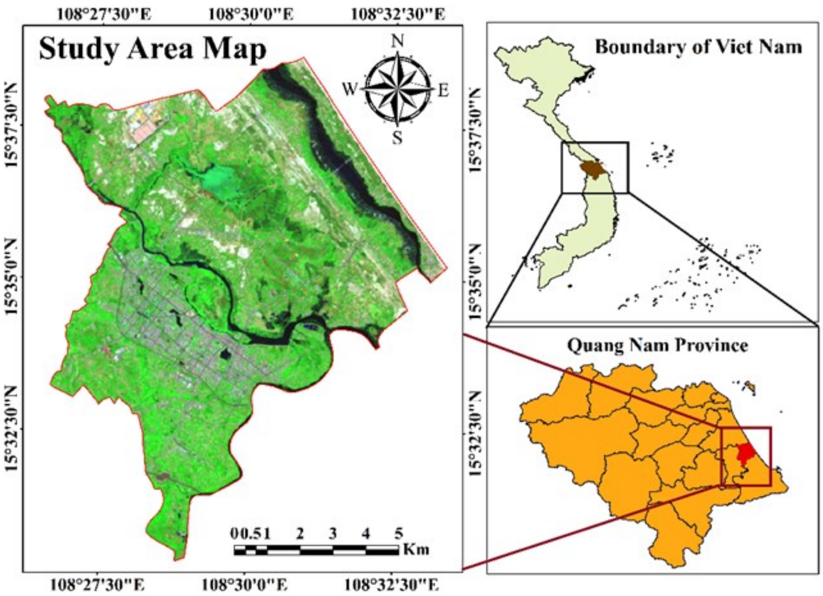

Figure 1. Study area map showing Tam Ky city.

change in land use [6]. Therefore, the study of LULC changes is a fundamental prerequisite for monitoring regional LULC changes, analyzing the driving factors, and forecasting LULC changes [5][7][8].

Remote sensing (RS) plays a pivotal role in supplying precise and timely geospatial insights into urban land cover transformations [3][6][9]. Utilizing data from Landsat Thematic Mapper (TM), Enhanced Thematic Mapper Plus (ETM+), and Operational Land Imager (OLI) images, which furnish moderate-resolution datasets covering extensive geographic areas, RS facilitates a comprehensive understanding of urban landscapes. This information holds significance in both natural and social sciences, aiding the quantification of urban landscape models and the formulation of formal hypotheses about the intricate relationships between urban patterns and physiological as well as biological processes within diverse ecologies. Two key indices commonly employed in RS analysis are the normalized difference vegetation index (NDVI) and the normalized difference built-up index (NDBI). NDVI is an indicator of vegetation health and density, calculated from the contrast between visible and near-infrared light, providing valuable insights into the vegetative cover within urban areas [10]-[12]. On the other hand, NDBI is a measure of built-up areas, emphasizing the ratio of the difference between the shortwave infrared and the middle-infrared bands, aiding in the identification and monitoring of urban development [13]-[15]. In conjunction with Geographic Information Systems (GIS), RS fosters the generation of scientifically reliable outcomes [16][17]. This synergy allows the formulation of policy recommendations that support sustainable development initiatives, especially in rapidly expanding urban environments. As a result, the combined application of RS and GIS stands as a widely adopted approach for the detection and monitoring of changes in land cover across various scales, producing actionable results that contribute to informed decision-making by policy-makers and planners [2][6][18].

At the regional scale, the categorization and mapping of LULC rely on RS data from satellite images, employing various classification techniques. Unsupervised classification, supervised classification, hybrid classification, and fuzzy classification stand out as the most commonly utilized methods [19]. In comparison to other disciplines, these techniques heavily hinge on a combination of foundational knowledge and personal expertise within the specific field of study. Presently, there is a paucity of research concerning the rate, trends, and extent of mantle fluctuations, as well as the potential application of satellite data to monitor and map LULC changes in Quang Nam province, Vietnam. This gap underscores the need for further investigation and exploration in understanding how satellite imagery and classification techniques can be effectively employed to assess and document changes in land use and cover within the specified region.

The main objective of this study was to analyze LULC changes in Tam Ky city, Quang Nam province, over two decades, during two main phases: 2000–2010 and 2010–2020 using GIS and RS. The overall goal of this study was: (1) to identify and classify LULC types and to quantitatively analyze LULC changes from 2000 to 2020; (2) to estimate, map, and analyze NDVI and NDBI changes using Landsat satellite images; and (3) to evaluate the factors affecting the change of LULC in the study area in the period 2000–2020. To monitor and analyze the soil cover in the research area over time, a specific dataset of Landsat images is required to respond to various local changes in land use. This is one of the first and most important tasks of any land use planning and evaluation project. Additionally, coating monitoring can also provide valuable information to land users, decision makers, and land planners to develop a reasonable land use development strategy in the short and long term.

2. MATERIALS AND METHODS

2.1. Study Area

Tam Ky is a city in Quang Nam province, Vietnam encompassing 13 communes and wards with a total natural area spanning 9,396 ha and a population of 123,560 humans [20]. Geographically situated in the middle of Vietnam, the study area exhibits a latitudinal range of 15°30'23.25"N–15° 38'37.17"N and a longitudinal range of 108° 26'43.36"E–108°33'23.53"E (Figure 1). Positioned between the prominent economic hubs of Vietnam—Ha Noi and Ho Chi Minh City—Quang Nam province shares borders with Da Nang city and the Dung Quat economic zone in Quang Ngai province. Functioning as a vital contributor to the economic development of the central region, Tam Ky city has positioned itself as an economic, political, cultural, and scientific center within Quang Nam province, which has a rich tradition of patriotism and revolution. The study area falls within the tropical monsoon climate region, characterized by hot and humid weather with distinct seasonal patterns of rain. The average annual temperature stands at 26 °C, while the average annual rainfall measures around 249 mm. The rainy season predominately spans from September to December, witnessing 70–75% of the annual rainfall, whereas the dry season extends from January to August, with only 25–30% of the annual rainfall occurring during these months.

2.2. Data Collection

To assess changes in LULC, we utilized satellite imagery from TM, ETM+, and OLI. The images for the years 2000, 2010, and 2020 were acquired at no cost through the United States Geological Survey (USGS) Earth Explorer data portal at www.earthexplorer.usgs.gov. Specifically, Landsat satellite images for the study area were chosen across three years, encompassing path 145 and row 20, with a spatial resolution of 30 m (Table 1). In addition to the satellite imagery, ancillary data incorporated ground-based information regarding LULC classes and aerial images encompassing the study and its surroundings. Point reference data were identified and positioned through a random stratification process utilizing ArcGIS 10.8 software. Furthermore, high-resolution RS image data from the Google Earth Pro application for the years 2000, 2010, and 2020 were selected to aid in the image classification process and assess the overall accuracy of the classification results.

2.3. Image Preprocessing and Classification

After the data collection phase, the RS images

Table 1. Satellite data specifications.

Data	Data type	Spatial Resolution (m)	Date of Acquisition	Data Source
Landsat 7 ETM+	Imagery	30	07/05/2000	USGS
Landsat 5 TM	Imagery	30	24/03/2010	USGS
Landsat 8 OLI	Imagery	30	09/07/2020	USGS

Table 2. Description of land use/land cover categories in Tam Ky city.

Classification Scheme	Description
Water bodies	Rivers, open water, lakes, ponds, and reservoirs
Agriculture	Cultivation, rice fields, and other farming lands
Settlements	Residential, commercial, industrial, transportation, and mixed urban
Vegetation	Shrub forests, perennial forests, and grassland
Construction	Construction built-up, project planning land, and cemetery land
Bare soil/rocks	Land areas of exposed soil and barren areas influenced by human influence

underwent processing, involving the integration of scenes and the alignment of images with the administrative boundaries of Tam Ky city. The processing tasks were executed using ArcGIS 10.8 software, incorporating the red, green, blue, and near-infrared channels. The classes identified in the study area include water bodies, agriculture, settlements, vegetation, construction, and bare soil/ rocks (Table 2). For each of these predetermined LULC classes, training samples were carefully selected by delineating polygons around representative sites [8][15]. The spectral signatures of the respective land cover classes, derived from the satellite imagery, were recorded using the pixels enclosed by these polygons. A satisfactory spectral signature was ensured to minimize confusion between the mapped land covers [21]. Subsequently, the maximum likelihood algorithm was applied to classify the supervised images [18][22]. This image classification technique is primarily controlled by the analyst who selects pixels representing the desired classes. Following the classification, a refinement process was implemented to enhance the simplicity and effectiveness of the method, aiming to boost classification accuracy while minimizing misclassifications [4][23]. The chosen LULC classification method ensures consistency in defining each category and establishes clear boundaries between classes by considering variations in both natural and anthropogenic features within the research area. Moreover, this classification approach is scalable and can be seamlessly applied across different spatial scales or levels of detail. Figure 2 provides a detailed illustration of the methodology employed in this research.

2.4. Accuracy Assessment

To evaluate the categorical accuracy of the Landsat images over three years, the study employed reference data consisting of 220, 231, and 239 randomly selected pixels from the maps of 2000, 2010, and 2020, respectively. These selections were made based on ground-based truth data and visual interpretation. The reference data and the classification results underwent a statistical comparison using a matrix analysis [24]-[26]. Additionally, a nonparametric k parameter test was conducted to gauge the accuracy of the classification, considering all elements in the error matrix [18][22]. The kappa coefficient (k) serves as a measure of consistency between the classified map and the reference values. The k value of 1 signifies a perfect match, while a value of 0 indicates no accuracy. As per Cohen (1960) [27], the calculation of k is as follows:

$$k = \frac{Po - Pe}{1 - Pe} \quad (1)$$

where *Po* is the number of times the k raters agree, and *Pe* is the number of times the k raters are expected to agree only by chance.

2.5. Estimation and Correlation between NDVI and NDBI

By leveraging satellite imagery, we can approximate the NDVI and NDBI, offering valuable insights into monitoring the health of vegetation and urbanization trends [26][28]. The NDVI acts as a vegetation index, using the near-infrared (NIR) and red (RED) bands from satellite images to distinguish vegetation [15][29]. As vegetation cover expands, the NDVI value rises, whereas it decreases with diminishing vegetation cover. Conversely, the NDBI functions as an urban index, employing the shortwave infrared (SWIR) and NIR bands to identify built-up areas [13]. The NDBI value increases with expanding built-up areas and decreases with a reduction in built-up areas [13][14]. Formulas (2) and (3) are employed to calculate the NDVI and NDBI indices, respectively.

$$\text{NDVI} = \frac{\text{NIR} - \text{RED}}{\text{NIR} + \text{RED}} \quad \textbf{(2)}$$

$$\text{NDBI} = \frac{\text{SWIR} - \text{NIR}}{\text{SWIR} + \text{NIR}} \quad \textbf{(3)}$$

Regression analysis was applied to quantify the correlation between NDVI and NDBI in Tam Ky city for the years 1992, 2003, and 2022. The correlation coefficient values obtained through regression analysis fall within the –1 to +1 range [3]. To execute the regression analysis, the random point generator feature in ArcGIS 10.8 software was utilized to create 300 random point data within the study area boundaries. The extract multi values to points tool was then used to extract a value for each point data from the NDVI and NDBI pixels. Subsequently, these values were exported to Microsoft Excel 2016 software (Microsoft, USA) for estimating the regression equation between NDVI and NDBI.

2.6. Land Use/Land Cover Change Detection

The post-classification change detection technique was implemented using ArcGIS 10.8 software to map fluctuations in land cover and compare changes between the classified images [5][30]. This process resulted in a two-dimensional cross-matrix, providing a descriptive summary of the primary LULC changes in the study area. To ascertain the number of transitions from one specific land cover type to another and their respective areas during the assessment period, a pixel-by-pixel cross-matrix analysis was conducted. This analysis allowed for the detailed detection of post-classification changes, offering insights into the specific nature of alterations between the classified images and presenting various combinations of "from–to" change classes [30].

3. RESULTS AND DISCUSSIONS

3.1. Land Use/Land Cover Classification

The LULC classification maps for Tam Ky city in 2000, 2010, and 2020 can be observed in Figure

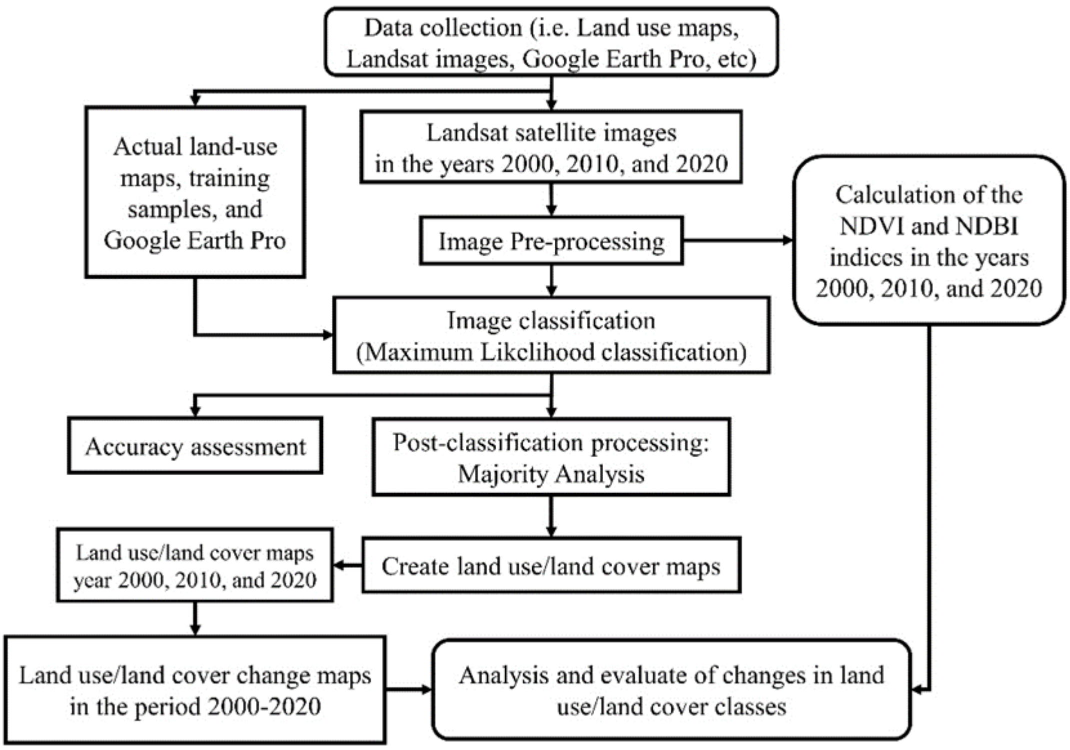

Figure 2. Overall workflow diagram of the study.

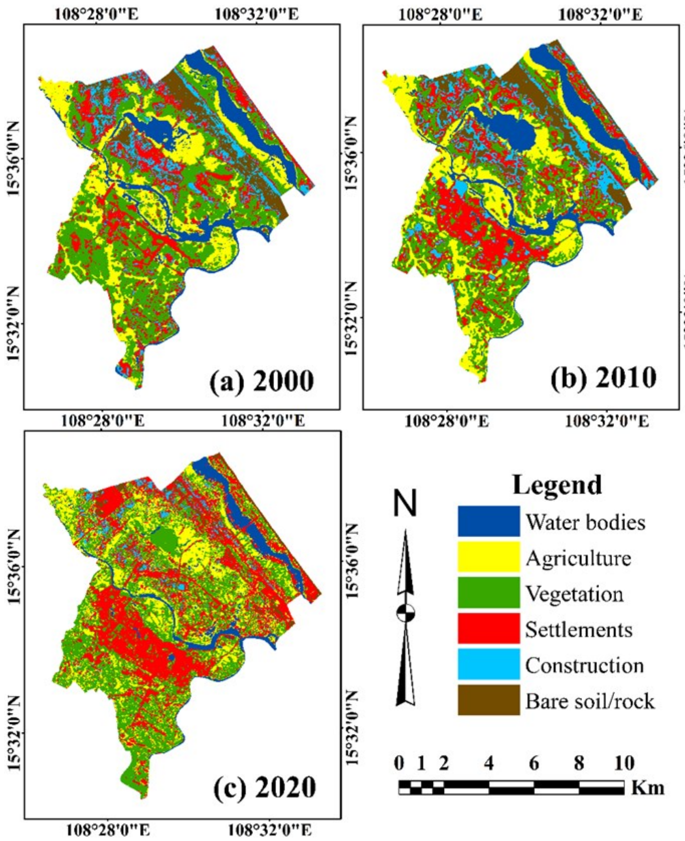

Figure 3. Land use/land cover map of Tam Ky city in (a) 2000, (b) 2010, and (c) 2020.

3. Utilized to gauge the categorical precision of both the model and the classification user, the k value is commonly employed for this purpose [26][31]. To assess the consistency or accuracy between the reference data and the LULC values within the classified image, representative k values ranging from −1 to +1 are employed [21]. Numerous studies have effectively applied k values. About the maps corresponding to 2000, 2010, and 2020, the overall classification accuracy attained 95.9%, 96.1%, and 95.8%, respectively. Simultaneously, the overall k values were measured at 0.951, 0.953, and 0.950 for the respective years. These values signify a consistently high level of accuracy in the classification [22][24]. A classification accuracy exceeding 90% and a k value equal to or greater than 0.9 are indicative of a successful endeavor in the study of LULC fluctuations, encompassing classification, detection, and prediction [22].

Based on the classification results, the statistics for each of the three years of the types of land area and the percentage of each class are shown in Table 3. Table 3 and Figure 3 indicate that vegetation and settlements are the prevalent LULC class in the spatial distribution model. The area covered by vegetation was 35.08%, 27.98%, and 35.64% of the total area in 2000, 2010, and 2020, respectively, whereas the settlement land accounted for 17.77%, 22.01%, and 31.60% of the total area in 2000, 2010, and 2020, respectively (Table 3). The area of agricultural land was approximately 20.35%, 21.00%, and 19.84% of the total area in 2000, 2010, and 2020, respectively (Table 3). The results also revealed that the LULC classes of water bodies, construction land, and bare soils/rocks slightly increased during 2000–2010. During 2010–2020, these LULC classes—water bodies, construction, and bare soil/rocks—reduced from 11.66 to 6.70%, 7.79 to 3.39%, and 7.35 to 2.83%, respectively (Table 3).

3.2. Land Use/Land Cover Change

During 2000–2010, the real fluctuations in the area covered by vegetation were relatively large, and more than 7% of the land area, which corresponds to 667 ha, changed to other types of land use (Table 4). The settlement land area increased the most from 1669 ha, accounting for 17.77% of the total area in 2000, to 2068 ha, accounting for 22.01% of the total area in 2010; this represents an increase of 399 ha, corresponding to a percentage increase of 4.24% (Table 4). During this period, the economy in Tam Ky city continued to rely primarily on agricultural production and consequently, the area covered by agricultural land increased slightly by 0.65% (Table 4). In addition, owing to policy directives and investment from the central government and Quang Nam province, Tam Ky city announced the allocation of some land to construction, for constructing infrastructure that contributes to the socio-economic status of a developed provincial capital. Accordingly, the area of construction land increased from 732 ha, accounting for 7.79% of the total land area in 2000, to 873 ha, accounting for 9.29% of the total land area in 2010. The area occupied by water bodies also increased during this period, although not significantly; nevertheless, the surface water sources in the study area were enough for agricultural irrigation. Tam Ky city borders the sea, and the primary land type in the coastal areas is sandy land, which cannot be used for agriculture. In some areas covered by vegetation, the primarily perennial trees were cut down, resulting in a 0.25% increase in the total area covered by bare soil/rocks (Table 4).

During 2010–2020, Tam Ky city experienced faster and stronger development, with more dynamic and comprehensive development directions that are associated with constructing smart and environmentally friendly cities [32]. This development along with population growth led to clear changes in LULC. The area of settlement land increased from 2068 ha, accounting for 22.01% of the total area in 2010, to 2969 ha, accounting for 31.60% of the total area in 2020; this represents an increase of 9.59% in the total settlement land area over 10 years (Table 4). During this period, as the city developed, various socio-economic infrastructure works were completed and numerous commercial centers were constructed to improve the lives and economy of the local population; consequently, the area covered by construction land and bare soil/rocks reduced significantly by 554 and 449 ha, respectively, which correspond to a reduction of 5.90% and 5.77%, respectively (Table 4). According to research by Lan and Son (2013) [33], Quang Nam province in general, and Tam Ky, city in particular, have relatively favorable climatic conditions. However, during 2010–2020, owing to climate change coupled with an increase in drought and the construction of hydroelectric dams upstream to store water, the area covered by water bodies reduced considerably from 1139 ha, accounting for 12.12% of the total land area in 2010, to 630 ha, accounting for 6.70% of the total land area in 2020. The land area covered by vegetation increased during 2010–2020 to 720 ha, accounting for 7.66% of the total land area in 2020 (Table 4). During 2000–2010, agricultural production was the main economic driver; however, during 2010–2020, there was a general shift toward an industrially-oriented economy, partly due to increased drought and climate change, which resulted in a lack of water available for irrigation. Consequently, the agricultural land area decreased by 1.16%, with a total area of 109 ha [34].

GIS was used to perform a post-classification

Table 3. Results of land use/land cover classification in Tam Ky city from 2000 to 2020.

Classes	2000		2010		2020	
	Area (ha)	%	Area (ha)	%	Area (ha)	%
Water bodies	1096	11.66	1139	12.12	630	6.70
Agriculture	1912	20.35	1973	21.00	1864	19.84
Vegetation	3296	35.08	2629	27.98	3349	35.64
Settlements	1669	17.77	2068	22.01	2969	31.60
Construction	732	7.79	873	9.29	319	3.39
Bare soil/rocks	691	7.35	714	7.60	266	2.83
Total	**9396**	**100.00**	**9396**	**100.00**	**9396**	**100.00**

Table 4. Change statistics of land use/land cover in Tam Ky city from 2000 to 2020.

Classes	2000–2010		2010–2020		2000–2020	
	Area (ha)	%	Area (ha)	%	Area (ha)	%
Water bodies	43	0.46	–509	–5.44	–466	–4.96
Agriculture	61	0.65	–109	–1.16	–48	–0.51
Vegetation	–667	–7.09	720	7.66	53	0.56
Settlements	399	4.24	901	9.59	1300	13.83
Construction	141	1.50	–554	–5.90	–413	–4.40
Bare soil/rocks	23	0.25	–449	–4.77	–425	–4.53

comparison of the detected changes by creating a map of the LULC changes to understand the spatial pattern of the changes during 2000–2020 (Figure 4). The two classification maps for 2000 and 2020 were intersected to create the LULC change map. The map shown in Figure 4 represents the transformation of different types of land use between 2000 and 2020, wherein each color represents a conversion type.

Cross-tabulation matrices are utilized for assessing the transformation from one LULC class to another [35]. To ascertain the status of land encroachment across various land types, a matrix depicting changes, derived from an inherent post-classification comparison of LULC in Tam Ky city, was formulated for the timeframe 2000–2020 (Table 5). Within the diagonal matrix, pixels exhibiting no change were positioned along the main diagonal, while conversion values for the classes were organized in descending order. This matrix facilitates a comparison between diagonal cells and others, yielding insights into whether the area of a specific class remains constant or has transitioned to a new classification.

The cross-tabulation matrices (Table 5) illustrate the nature of the change in land cover in Tam Ky city between 2000 and 2020. Of the 3296 ha that were vegetation areas in 2000, only 1527 ha remained as such by 2020, whereas 1675 ha were transferred to agricultural and settlement land areas, with the rest changing to construction land, water bodies, or bare soil/rock. The increase in the vegetation area from 2000 to 2020 was primarily due to agriculture (730 ha) and settlement land (558 ha) (Table 5). Out of a total of 1669 ha of settlement land in 2000, only 769 ha was retained as such in 2020, with the rest primarily lost to vegetation (as discussed earlier, owing to an increase in agriculture) and bare soil/rock. The agricultural land area decreased from 1912 ha in 2000 to 1864 ha in 2020 (Table 5). Approximately 827 ha of agricultural land was replaced primarily by vegetation and settlements. Agricultural land primarily replaced areas covered by vegetation in 2020 (580 ha) (Table 5). Considering water bodies, out of 1096 ha in 2000, only 548 ha retained in 2020. The area covered by water bodies was reduced by 630 ha and was primarily replaced by vegetation, agricultural, and settlement land by 2020. The construction land area was reduced from 732 ha in 2000 to 319 ha by 2020, with only 89 ha area retained as construction land in 2020 (Table 5). It was primarily replaced by settlements (345 ha), vegetation (163 ha), agricultural land (72 ha), and bare soil/rocks (54 ha). Finally, considering the area covered by bare soil/rocks, 458 ha were replaced by settlements and vegetation, whereas 107 ha area remained as unchanged (Table 5).

3.3. Analysis of NDVI and NDBI Indices

The analysis of NDVI values over the years reveals notable changes in vegetation density and health in Tam Ky city [22][29]. In 2000, the NDVI index ranged from –0.43 to +0.63, indicating varying levels of vegetation cover (Figure 5a). By 2010, there was a noticeable shift with NDVI values ranging from –0.23 to +0.47, suggesting changes in vegetation patterns (Figure 5b). In 2020, the NDVI values exhibited further fluctuations, ranging from –0.20 to +0.63 (Figure 5c). The observed increase in positive NDVI values over time suggests an overall improvement in vegetation health, while the fluctuations may indicate dynamic environmental changes. The study also employed the NDBI index to assess urban development trends [13]. In 2000, the NDBI values ranged from –0.55 to +0.44, signifying the extent of built-up areas (Figure 5d). By 2010, there was a slight shift in NDBI values, ranging from –0.52 to +0.48, suggesting changes in urban development (Figure 5e). In 2020, the NDBI values were further adjusted, ranging from –0.44 to +0.29 (Figure 5f). The observed decrease in positive NDBI values may indicate a reduction in built-up areas or alterations in the urban landscape [13][14].

The LULC analysis complements the NDVI and NDBI findings, providing a comprehensive understanding of landscape changes [11][14]. Over the years, the area covered by vegetation exhibited fluctuations, accounting for 35.08%, 27.98%, and 35.64% of the total area in 2000, 2010, and 2020, respectively. This indicates dynamic changes in vegetation cover within the study period. In contrast, settlement land expanded from 17.77% in 2000 to 31.60% in 2020, suggesting significant urbanization and development. Furthermore, agricultural land occupied approximately 20.35%, 21.00%, and 19.84% of the total area in 2000, 2010, and 2020, respectively, showcasing relatively stable land use for agriculture. The LULC classes of water bodies, construction land, and bare soils/rocks underwent shifts during the studied periods. Notably, water bodies, construction, and bare soil/ rocks increased from 2000 to 2010 but experienced reductions from 2010 to 2020, indicating changing dynamics in these land cover categories. Overall, the combined analysis of NDVI, NDBI, and LULC provides a comprehensive perspective on the evolving landscape and land use patterns in the study area [10]-[12].

Figure 6 depicts the relationship between NDVI and NDBI across the three years of the study (2000, 2010, and 2020). A regression line highlights the distinctive association between these indices. The correlation coefficients (R^2) resulting from linear regression analysis for 2000, 2010, and 2020 were 0.1556, 0.0850, and 0.6284, respectively (Figure 6). Throughout all three years, the regression line

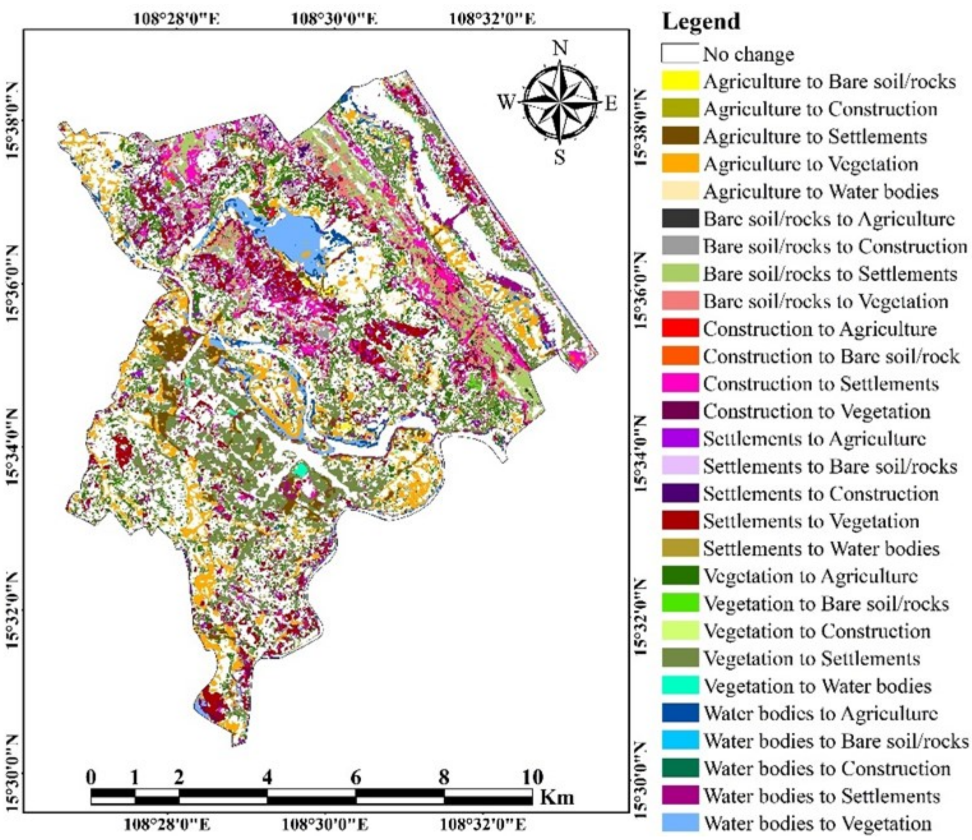

Figure 4. Major land use/land cover conversion in Tam Ky city from 2000 to 2020.

Table 5. Cross-tabulation of land cover classes between 2000 and 2020 (area in ha).

2020 \ 2000	Water bodies	Agriculture	Vegetation	Settlements	Construction	Bare soil/rocks	**Total**
Water bodies	**548**	63	18	1	0	0	**630**
Agriculture	151	**827**	580	203	72	31	**1864**
Vegetation	268	730	**1527**	558	163	103	**3349**
Settlements	122	274	1095	**769**	354	355	**2969**
Construction	1	8	60	66	**89**	95	**319**
Bare soil/rocks	6	10	16	72	54	**107**	**265**
Total	**1096**	**1912**	**3296**	**1669**	**732**	**691**	

consistently demonstrates a negative correlation between NDVI and NDBI. In instances where NDVI values are high, NDBI values tend to be low, and vice versa. Figure 6 provides additional clarity on the relationship between the vegetation index (NDVI) and the composite component derived from NDBI. The regression analysis not only affirms the negative correlation but also unveils insights into the spatial distribution of NDBI values [13][18]. Notably, areas with the highest NDBI values coincide with those exhibiting the lowest NDVI values, while regions with the lowest NDBI values showcase the highest NDVI values. This spatial interconnection underscores that locale characterized by increased built-up areas and barren land witness a decline in vegetation coverage. This analytical methodology deepens our comprehension of the complex interplay between changes in land use and vegetation health [14][25][29]. It provides valuable insights for sustainable land management and environmental conservation initiatives.

A crucial role is played by multi-temporal RS data and GIS technology in the analysis and association of data, with a particular focus on the detection, extrapolation, interference, area calculation, and monitoring of LULC changes [3][17][36]. The effectiveness of detecting and monitoring LULC changes, even within a brief time series, has been demonstrated through the utilization of RS data [2][37][38]. The significance of GIS is emphasized in this study as a powerful tool for spatial processing and analysis, making use of numerical models and the combined analysis of data layers. Simultaneously, GIS proves to be instrumental in supporting the examination of landscape changes amid the urbanization process. The integration of multi-temporal RS data and GIS technology provides a robust framework for comprehensively understanding and managing dynamic environmental changes, offering valuable insights for sustainable land use planning and effective environmental conservation strategies [39][40].

3.4. Assessment of Future Land Use/Land Cover Changes

Based on the comprehensive analysis of past LULC dynamics in Tam Ky city, Quang Nam province, several implications and predictions for future developments can be derived. Firstly, the observed trends suggest a continued shift towards urbanization and economic development, characterized by the expansion of settlement areas and infrastructure development. This trajectory indicates the need for proactive urban planning strategies to manage land resources efficiently and sustainably. Emphasizing smart growth principles, such as compact development and preservation of green spaces, will be crucial in mitigating the negative impacts of urban sprawl and ensuring the livability of the city. Secondly, the decline in agricultural land area highlights the ongoing transition from agrarian to industrialized economies. As Tam Ky city evolves, diversification of economic activities beyond agriculture will become increasingly important. Policies and initiatives to support the growth of non-agricultural sectors, such as manufacturing, services, and tourism, can help stimulate economic development while reducing pressure on agricultural land. Furthermore, the observed changes in vegetation density and urban development, as indicated by NDVI and NDBI indices, underscore the intertwined relationship between land use dynamics and environmental health. Future efforts should focus on balancing economic growth with environmental conservation, promoting sustainable land management practices, and enhancing resilience to climate change impacts. Overall, proactive planning, sustainable development practices, and interdisciplinary collaboration will be essential in shaping the future trajectory of Tam Ky city towards a resilient, prosperous, and environmentally sustainable urban center.

Although the utilization of Landsat satellite imagery is advantageous for large-scale analyses, it may not sufficiently capture the intricate details of LULC changes occurring at a smaller scale. In future studies, integrating socioeconomic data could enhance the understanding of the drivers behind the observed LULC changes, providing a more comprehensive perspective. To further advance research in this field, the development of long-term monitoring and prediction models could be explored. These models would enable the forecasting of future LULC changes, offering insights into their potential impacts on local climate and biodiversity. By incorporating such predictive tools, studies could better anticipate and prepare for the evolving dynamics of LULC. These recommendations, if implemented, have the potential to yield more robust and comprehensive insights into LULC changes. Additionally, such an approach could contribute significantly to understanding the implications of these changes for sustainable urban development.

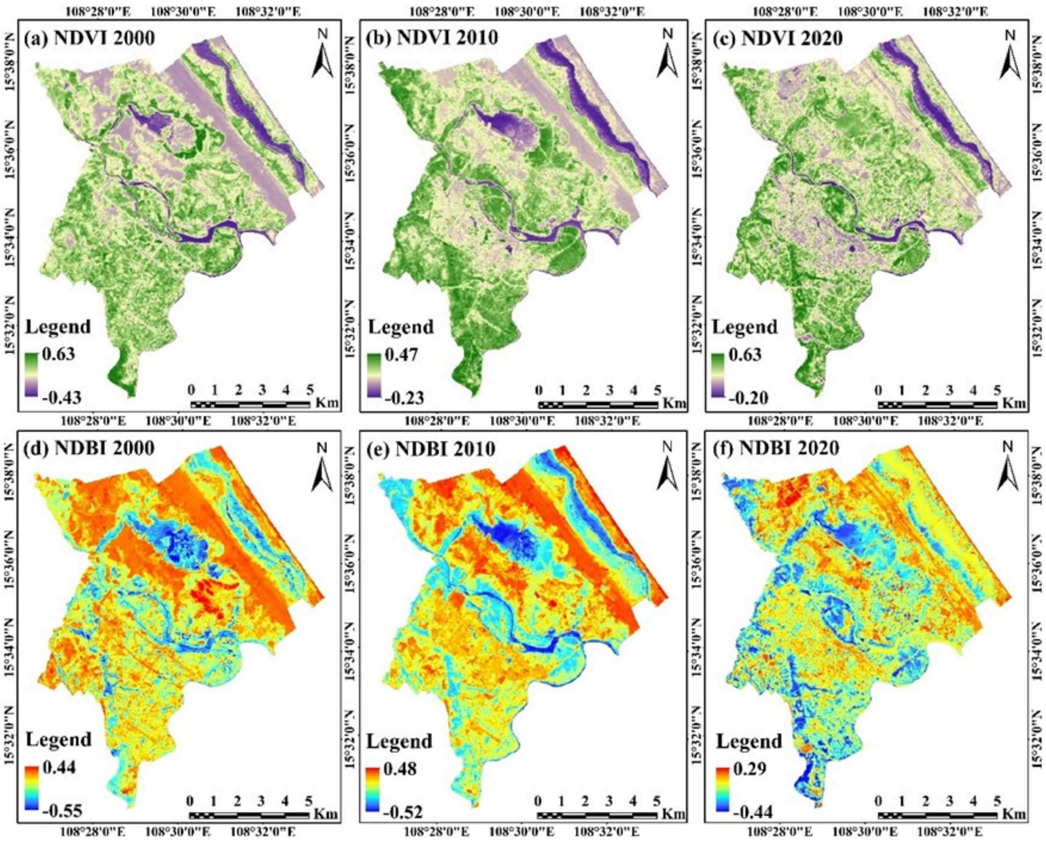

Figure 5. NDVI and NDBI maps for Tam Ky city in 2000, 2010, and 2020.

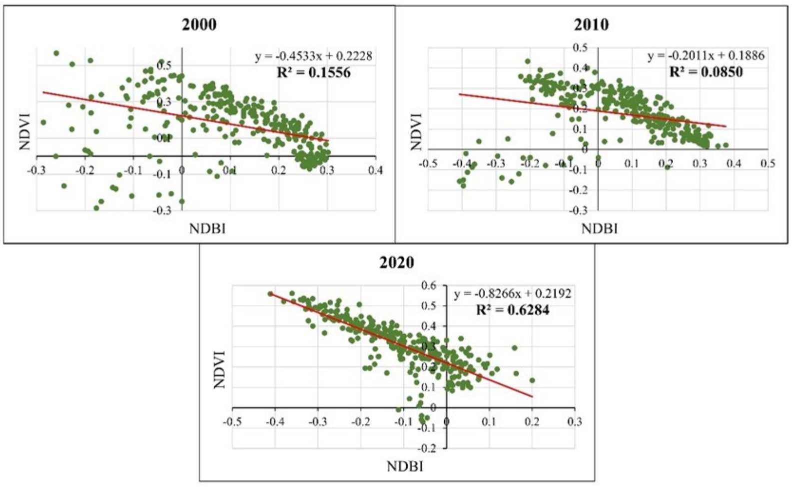

Figure 6. Regression analyses between NDVI and NDBI in Tam Ky city in 2000, 2010, and 2020.

4. CONCLUSIONS

The integration of RS and GIS technology has provided valuable insights into the LULC changes in Tam Ky city, Quang Nam province, over the period from 2000 to 2020. The study has revealed significant transformations in the landscape, highlighting the dynamic nature of land use dynamics within the region. The findings indicated a notable decline in water bodies, agricultural land, construction, and bare soil/rock classes, with respective decreases of 4.96%, 0.51%, 4.40%, and 4.53% over the two-decade period. Conversely, there has been a substantial increase in vegetation and settlement class areas, with a combined total increase of 0.56% and 13.83%, respectively, from 2000 to 2020. This change in land use patterns has highlighted the impact of many different factors, including population growth, urbanization, and economic development, on the landscape of Tam Ky city. The analysis of NDVI and NDBI indices has further elucidated changes in land cover characteristics, revealing a strong correlation between impervious surfaces and vegetation cover. These findings suggest a complex interplay between human activities, urban expansion, and environmental factors, influencing the distribution and health of vegetation within the study area. The study emphasizes the urgency in land use planning and management by policymakers and stakeholders in Tam Ky city due to rapid development and changing land use patterns. Therefore, appropriate measures to ensure the proper use of natural resources and efficient land usage are crucial for sustainable development in Tam Ky city, Quang Nam province.

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Conflicts of Interest

The authors declare no conflict of interest.

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