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Analysis of Land Cover due to the Construction of the Mandalika Circuit using Remote Sensing Based on Google Earth Engine

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ABSTRACT

The construction of the Mandalika Circuit has caused significant changes in land cover in the surrounding area. This study uses Google Earth Engine (GEE) and Sentinel-2 L2A to analyze land cover changes before and after the construction. The results show that the water bodies experienced a reduction in area of approximately 0.4 km^2, open land experienced a reduction in area of approximately 2.66 km^2, while buildings experienced an increase in area of approximately 3.3 km^2. Vegetation also experienced a relatively small reduction in area of approximately 0.23 km^2. These changes associated eith the development to tourism-related insfratructure and facilities surrounding the Mandalika Circuit. Although the vegetation reduction is relateively small, further investigation is needed to assess the effectiveness of sustainability policies in maintaining vegetation cover amdi ongoing tourism development. The reduction in water body, open land, and vegetation areas may be due to the development of the area around the Mandalika Circuit to support tourist activities. This study emphasizes the importance of continuous monitoring to maintain a balance between development and environmental conservation. Furthermore, this study also shows that the government has made efforts to maintain a balance between development and environmental conservation by implementing sustainable development practices. Therefore, this study can serve as a reference for the government and other stakeholders to implement sustainable development practices and maintain a balance between development and environmental conservation.

Keywords: land cover; Mandalika circuit; remote sensing; Google Earth Engine; sentinel-2 L2A

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3. Introduction

Lombok is a small island with an area of 5,435 km^2, which is part of West Nusa Tenggara (NTB). The island ranks 108th in the list of small islands in the world. Given its status as a small island, development and growth, particularly in the tourism sector, focus on sustainability, encompassing economic, socio-cultural, and environmental aspects. Central Lombok, one of the regencies in NTB with its capital in Praya, has an area of 1,208.39 km^2 and a population of approximately 1,067,682 people. Central Lombok is known for its rich natural and cultural potential. It is one of the regions with significant potential for tourism development. Although tourism in Lombok is generally still lagging behind Bali, this region has unique attractions that deserve to be developed [1].

One of the main attractions in this area is Kuta, located in one of the villages in Pujut District, Central Lombok Regency, West Nusa Tenggara. Kuta is a Special Economic Zone (KEK) for tourism through Government Regulation Number 52 of 2014, with an area of approximately 1,035.67 hectares.

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The Mandalika KEK is designed as an environmentally sustainable (green ecotourism) special economic zone, featuring systems such as reverse osmosis seawater treatment, waste management, solar panels, and green building development. [2]. This area directly faces the Indian Ocean and offers various attractive tourist potentials, such as Kuta Beach and Tanjung Aan. Here, visitors can enjoy activities such as snorkeling and surfing, making it an ideal destination for surfing enthusiasts.

Mandalika is not only renowned for the beauty of its beaches but also for its rich cultural heritage. One unique tradition that draws significant attention is the Bau Nyale ceremony, during which the local community searches for sea worms believed to be the incarnation of Princess Mandalika, a legendary figure from the area. This celebration has become a notable attraction for both domestic and international tourists. In addition, Mandalika hosts a variety of cultural and culinary festivals, further enriching the visitor experience. With its combination of natural beauty and cultural wealth, Mandalika holds great potential to become a premier tourist destination capable of supporting regional economic growth through sustainable tourism. The development of the Mandalika Circuit as a MotoGP venue is also a strategic step to enhance Lombok's visibility on the international stage and attract greater investment to the region [4].

The development of the Mandalika Circuit in Lombok, West Nusa Tenggara, represents a significant project aimed at bolstering Indonesia's tourism sector, particularly through the hosting of international motor racing events such as MotoGP [4]. However, alongside the potential economic benefits, this project also raises concerns regarding its environmental impact, particularly on the land ecosystems surrounding the Mandalika area. Large-scale construction activities, land use changes, and the potential for environmental degradation are critical issues that require ongoing monitoring.

Land cover change analysis can be conducted by utilizing remote sensing technology, specifically satellite imagery [5]. Satellite imagery is commonly used for development planning and natural resource monitoring, as it facilitates the analysis of large areas in a shorter time compared to direct field observations [6].

To obtain satellite imagery data, platforms such as Google Earth Engine (GEE) can be used, which offers high computational power and easy access, enabling more accurate and efficient evaluation of the impacts of development. GEE provides various satellite data and products generated from these datasets [7]. This technology allows for more comprehensive and real-time analysis of land and ecosystem changes, making it possible to identify and manage potential negative impacts more effectively [8],[9].

Through this article, an analysis of land cover changes caused by the development of the Mandalika Circuit will be conducted using GEE with Sentinel-2 imagery. This study aims to identify the changes occurring in the Mandalika area due to the circuit development and emphasizes the importance of continuous monitoring to maintain a balance between development and environmental conservation.

4. Research Methodology

2.1. Type of Research

This study utilizes a quantitative descriptive method for data collection based on satellite image analysis, employing a case study approach with a focus on spatio-temporal aspects.

2.2. Location and Time of Research

This research focuses on the Central Lombok Regency area, specifically in Kuta Village, one of the regions designated as part of the Special Economic Zone (KEK) in West Nusa Tenggara. Kuta Mandalika Village is located at 8°53'06.8" S and 116°16'32.5" E, covering an area of 2,366 hectares. The study is divided into two time periods: before and after the construction of the Mandalika Circuit, which are from July 2018 to July 2019 and from November 2023 to November 2024. The research location was determined using a polygon cutout, as detailed in Figure 1.

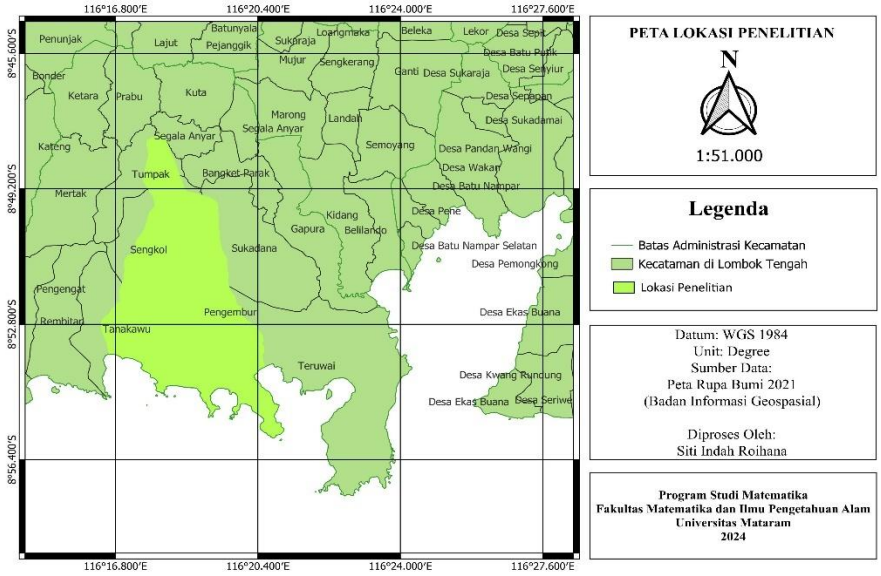

Figure 1. Research Location

2.3. Research Procedure

The flowchart of this research procesure is shown in Figure 2.

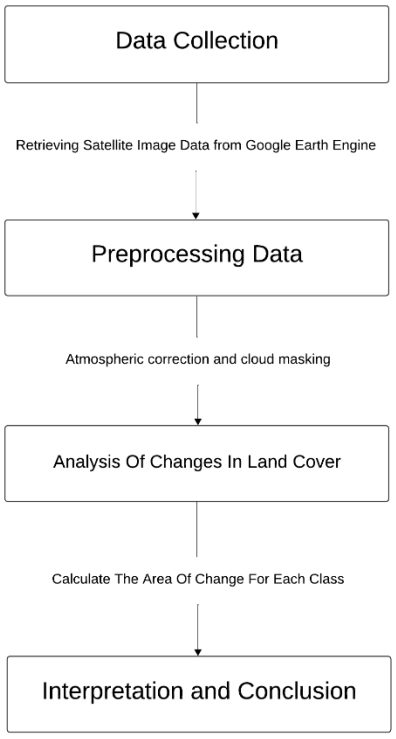

Figure 2. Research Procedure

- Data Collection
  The research was conducted by preparing the Sentinel-2 L2A satellite imagery data to be used. The Sentinel-2 L2A satellite images were cropped according to the study area. The data was then processed using remote sensing index analysis, specifically the Normalized Difference Vegetation Index (NDVI). Sentinel-2 L2A imagery can be accessed through Google Earth Engine (GEE), which provides high-resolution images with accurate surface reflectance due to atmospheric correction processes. Sentinel-2 L2A images have spatial resolutions of 10

meters, 20 meters, and 60 meters, depending on the band type (Nandika et al., 2023). The 10-meter spatial resolution of Sentinel data offers significant potential for detailed exploration of the Earth's surface. This resolution allows for more precise analysis of land features and surface characteristics, enabling better mapping, classification, and monitoring of various environmental conditions (Phiri et al., 2020). Sentinel-2 L2A was chosen because of its high spatial resolution, which allows for more detailed identification of surface features such as vegetation and land use.

- Data Preprocessing
  This research utilizes the NDVI (Normalized Difference Vegetation Index), a remote sensing index used to monitor vegetation changes both spatially and temporally, particularly in land use mapping. A higher NDVI value indicates greater vegetation density (Filgueiras et al., 2019).

$$NDVI = \frac{(NIR - Red)}{(NIR + Red)} \quad [1]$$

NIR or Near Infrared (B08) refers to light reflected in the near-infrared spectrum. Red or Visible Red (B04) refers to light reflected in the red spectrum.

For data collection, Sentinel-2 L2A satellite imagery was used, which has 13 spectral bands, as detailed in Table 1

Table 1. Sentinel-2 L2A Spectral Bands

Name	Common Name	GSD	Center Wavelength	Full Width Half Max	Description
AOT	-	-	-	-	Aerosol Optical Thickness
B01	Coastal	60 mm	0.443 μm	0.027 μm	Coastal aerosol
B02	blue	10 mm	0.49 μm	0.098 μm	Visible Blue
B03	Green	10 mm	0.56 μm	0.045 μm	Visible Green
B04	Red	10 mm	0.665 μm	0.038 μm	Visible Red
B05	Rededge	20 mm	0.704μm	0.019 μm	Vegetation Classification red edge
B06	Rededge	20 mm	0.74 μm	0.018 μm	Vegetation Classification red edge
B07	Rededge	20 mm	0.783 μm	0.028 μm	Vegetation Classification red edge
B08	NIR	10 mm	0.842 μm	0.145 μm	Near Infrared
B8A	Rededge	20 mm	0.865 μm	0.033 μm	Vegetation Classification red edge
B09	-	60 mm	0.945 μm	0.026 μm	Water vapor
B11	SWIR16	20 mm	1.61 μm	0.143 μm	Short-wave infrared, snow/ice/cloud classifiction
B12	SWIR22	20 mm	2.19 μm	0.242 μm	Short-wave infrared, snow/ice/cloud classifiction

- Land Cover Classification
  In this research study, the random forest method is used for sample classification. Random forest is a set of machine learning methods that use decision trees as basic classifiers combined.

There are 3 important aspects in random forest, including bootstrap sampling, each tree predicts with random predictors, and the results of each decision tree are combined using majority vote for classification (Primajaya & Sari, 2018). A decision tree is a classification method that uses a tree structure to assign pixels to different classification categories (Awaliyan & Sulistioadi, 2018). This research uses the random forest classification method since random forest has the best feature capabilities that can work on large data with complex parameters (Devella et al., 2020). The random forest algorithm in this study uses 150 randomly generated decision trees, with 80% training data to build the model and 20% testing data to evaluate the results. The Random Forest model in this study was configured with 150 decision trees. This number was selected as a balance between classification performance and computational efficiency, allowing the ensemble to produce stable predictions without excessive computational costs. The dataset was divided into 80% training data for model development and 20% testing data for evaluating classification performance. Four land cover classes were identified, as detailed in Table 2.

Table 2. Land Cover Classifications

No	Class	Description
1	Water bodies	Water bodies consist of reservoirs, ponds, and small saline lakes.
2	Open Land	Refers to areas of land that are not covered by dense vegetation, buildings, or other significant structures
3	Buildings	Consist of houses, structures, highways, and similar types.
4	Vegetation	Refers to land covered by dense plants, such as rice and corn fields, also plantations.

Accuracy is obtained by creating a contingency matrix or confusion matrix as shown in Table 3.

Table 3. Confusion Matrix

Class	**Sample**					
	A	**B**	**C**	**D**	**Total**	**User's Accuracy (%)**
A	X_{ii}				X_{i+}	$\frac{X_{ii}}{X_{i+}}$
B						
C						
D				X_{ii}		
Total	X_{+i}					
Producer's Accuracy	$\frac{X_{ii}}{X_{+i}}$					

The accuracy test can be mathematically defined by equations [2] and [3].

$$User's\ accuracy = \frac{X_{ii}}{X_{i+}} \times 100\% \quad [2]$$

$$Producer's\ accuracy = \frac{X_{ii}}{X_{+i}} \times 100\% \quad [3]$$

Overall accuracy or total accuracy is used to measure the accuracy of all classes of classification results. This calculation is done by calculating the percentage of total pixels that are classified correctly, then dividing it by the total number of pixels used (Pertami et al., 2022), while kappa accuracy is the percentage of accuracy that uses all elements in the confusion matrix (Muhammad et al., 2016). The calculation can be seen in equations [4] and [5].

$$Overall\ accuracy = \frac{\sum_{i=1}^{r} X_{ii}}{N} \times 100\% \quad [4]$$

$$Kappa\ accuracy = \frac{N\sum_{i=1}^{r} X_{ii} - \sum_{i=1}^{r} X_{i+} + X_{+i}}{N^2 - \sum_{i=1}^{r} X_{i+} X_{+i}} \times 100\% \quad [5]$$

Description:

X_{ii}: The total number of pixels for a sample/class in the i-th row and i-th column.

X_{i+} : The total number of pixels in the i-th row.

X_{+i} : The total number of pixels in the i-th column

N: The total number of samples collected.

Based on the study by Viera and Garet (2005), Kappa accuracy is categorized into several agreement intervals as shown in Table 4.

Table 4. Kappa Accuracy Agreement Categories

Kappa Value **(%)**	**Agreement**
< 0	Less than change agreement
0.01 - 0.20	Slight agreement
0.21 - 0.40	Fair agreement
0.41 - 0.60	Moderate agreement
0.61 - 0.80	Substantial agreement
0.81 - 0.99	Almost perfect agreement

5. Results and Discussion

3.1 Before the Construction of the Mandalika Circuit

The processing results using Google Earth Engine before the construction of Pertamina Mandalika International Circuit with the monitoring period from July 2018 to July 2019 are shown in Figure 3. In this research, four categories of land cover were identified, including water bodies, buildings, open land and vegetation. The characteristics of the land cover types in the image are indicated by different colors, where the water body class is marked in blue, the open land class is marked in yellow, the building class is marked in red, and the vegetation class is marked in green.

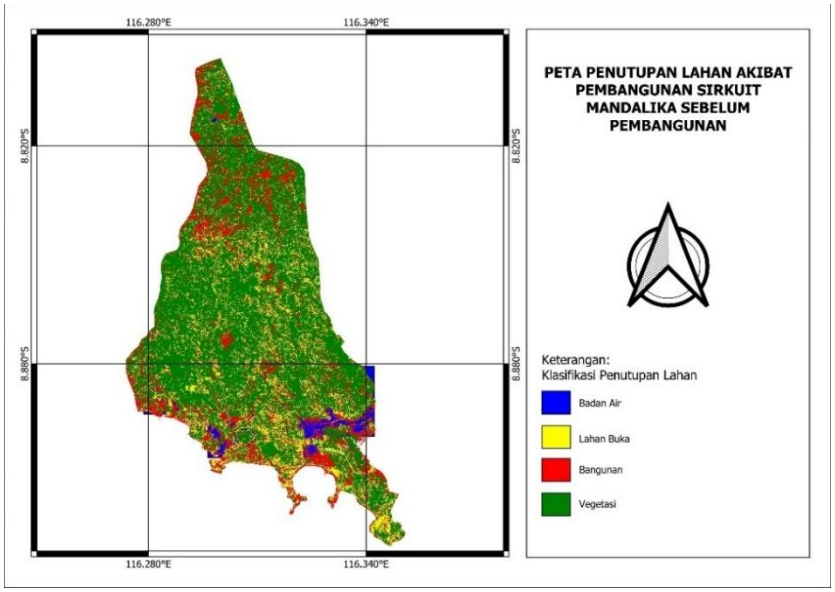

Figure 3. Classification Map Before Construction

The total testing sample collection by Sentinel-2 satellite imagery amounted to 1,732 samples. During the sampling process by the satellite, errors or inaccuracies often occur, which are summarized in the confusion matrix shown in Table 5.

Table 5. Confusion Matrix Before the Construction

Class	Sample					
	Water Bodies	**Open Land**	**Buildings**	**Vegetation**	**Total**	**User's Accuracy (%)**
Water Bodies	50	2	14	0	66	76
Open Land	0	59	29	47	135	44
Buildings	20	23	418	41	502	83
Vegetation	2	103	110	814	1029	79
Total Column	72	187	571	902	1732	
Producer's Accuracy	69%	32%	73%	90%		

According to the examination of the error matrix, the overall accuracy of land cover classification prior to the establishment of Mandalika Circuit was 77.42%, with a kappa accuracy of 61.41%. Based on Table 4, the kappa value prior to construction is classified as Substantial Agreement, indicating a significant degree of reliability in the classification outcomes and making them very trustworthy,however, there remains potential for enhancement.
Overall Accuracy (OA) assesses the proportion of correctly classified pixels relative to the total number of pixels. A score of79% indicates that 79% of the classification outcomes correspond with the referenc e data. However, OA does not consider the possibility of agreement occurring by chance, so Kappa is often considered more informative in classification analysis (Lillesand et al., 2015). The producer's Accuracy values varied from 0% to 32%, where the minimum accuracy was noted in the Open Land class, and reached up to 90%, with the maximum accuracy found in the vegetation class.

The examination of Sentinel-2 satellites images through an ideal band combination quantified land cover classification regions resulting from the circuit's construction from November 2023 to November 2024. The land cover classification area after construction is shown in square kilometers (km^2) and as a percentage. Information regarding these classifications can be found in Table 6.

Table 6. The Area of Land Cover Classification Before the Construction

Class/Sample	Area (km^2)	Percentage (%)
Water Bodies	1.34299786344544	2.446919923
Open Land	8.70395174237874	15.8584563
Buildings	9.35240941401296	17.03993547
Vegetation	35.4858806070279	64.65468831

3.2 After the Construction of the Mandalika Circuit

The results of processing using Google Earth Engine after the construction of the Pertamina Mandalika International Circuit, with a monitoring period from January 2022 to November 2024, are shown in Figure 4.

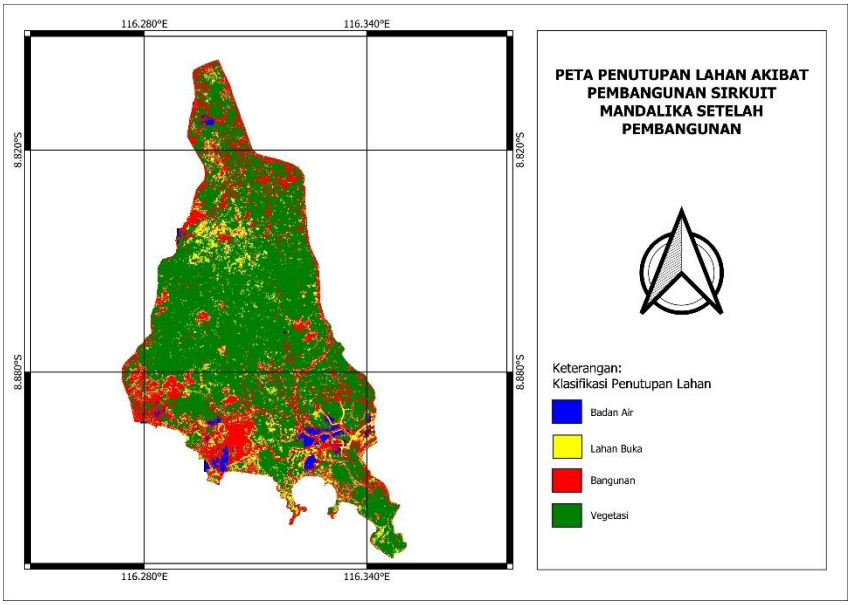

Figure 4. Classification Map After Construction

The total testing sample collection by Sentinel-2 satellite imagery amounted to 1,743 samples. During the sampling process by the satellite, errors or inaccuracies often occur, which are summarized in the confusion matrix shown in Table 7.

Table 7. Confusion Matrix After the Contruction

Class	Sample					
	Water Bodies	**Open Land**	**Buildings**	**Vegetation**	**Total**	**User's Accuracy (%)**
Water Bodies	3	0	0	0	3	100
Open Land	0	109	11	26	146	75
Buildings	2	10	170	7	189	90
Vegetation	1	49	44	1311	1405	93
Total	6	168	225	1344	1743	
Producer's Accuracy	50%	65%	75%	98%		

Based on the analysis of the error matrix, the overall accuracy of land cover classification due to the construction of Mandalika Circuit after its completion was determined to be 91.39%, with a kappa accuracy of 75.85%. According to Table 4, the kappa value post-construction is categorized as Substantial Agreement, signifying a strong level of consistency in the classification results and deeming them highly dependable. The integration of a high OA value (91%) and a considerable Kappa coefficient (75.85%) signifies that the land cover classification model exhibits robust performance and dependability. This indicates that the model successfully differentiates between various land cover types while achieving a high degree of concordance with the reference data. The producer's Accuracy values ranged from 0 – 50%, with the lowest accuracy observed in the water body class, and up to 98%, with the highest accuracy recorded in the vegetation class. The Producer's Accuracy is influenced by the ratio between the referenced class values and the total number of classes. Meanwhile, the User's Accuracy, calculated as the proportion of correctly classified points to the total number of points in each class, reached its highest value of 100% in the water body class. Variations in mapping accuracy were attributed to several factors, including differences in the timing of image acquisition and field data collection, weather conditions during data collection, errors in object recognition, and inaccuracies in reference data (Prabowo et al.,2018).

From the analysis of Sentinel-2 satellite imagery using an optimal band combination, land cover classification areas due to the circuit's construction from January 2022 to November 2024 were quantified. The classification results show that vegetation constitutes the predominant land cover following construction, occupying 64% or about 35.25 km^2. The post-construction land cover classification area is presented in both square kilometers km^2 and percentages. Detail on these classifications is provided in Table 8.

Table 8. The Area of Land Cover Classification After the Construction

Class/Sample	Area (km^2)	Percentage (%)
Water Bodies	0.933678823	1.70115170586874
Open Land	6.04469981	11.0133711229999
Buildings	12.64719736	23.0430430879355
Vegetation	35.25952451	64.2424340831957

Thus, from the data obtained in Table 6 and Table 8, the total land cover change can be calculated, which is presented in Table 9.

Table 9. The total land cover changed

Class/Sample	Area Before the Construction (km^2)	Area After the Construction (km^2)	Land Cover Changes (km^2)
Water Bodies	1.34299786344544	0.933678823	0.40931904044544
Open Land	8.70395174237874	6.04469981	2.65925193237874
Buildings	9.35240941401296	12.64719736	3.29478794598704
Vegetation	35.4858806070279	35.25952451	0.2263560970279

6. Conclusions

Based on the research results in Table 9, it can be concluded that the water body experienced a reduction in area of approximately 0.4 km^2, open land experienced a reduction in area of approximately 2.66 km^2, while buildings experienced an increase in area of approximately 3.3 km^2, and vegetation experienced a slight reduction of approximately 0.23 km^2. The reductions in the water bodies, open land, and vegetation areas may be associated the the development of areas surrounding the Mandalika Circuit to support tourism-related activities such as hotels, restaurants, cafes, and others. Although the vegetation change is relatively small, further investigation is needed to assess the effectiveness of sustainability policies in maintaining vegetation cover amid ongoing tourism development. Considering the potential of the Mandalika Circuit to attract various international and local tourists, this is reinforced by the increase in building area of approximately 3.3 km^2, which indicates the intense development in the surrounding area. As it has become an international attention, the government is certainly trying to make the area around the Mandalika Circuit a comfortable one, and the slight change in vegetation area proves that the government is trying to carry out development without damaging the existing ecosystem. Although vegetation changes are relatively minor, futher investigation is needed to evaluate the effectiveness of sustainability policies.

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