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Exploring Bali's Tourism Dynamics through Nighttime Light Satellite Imagery

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ABSTRACT

This study explores the growth of the tourism sector in Bali, Indonesia, over the period 2015 to 2023 using Nighttime Light (NTL) satellite imagery as an indicator of economic activity and urbanization. Tourism, as the main sector driving Bali's economy, shows a pattern of development that is reflected by an increase in nighttime light intensity. VIIRS DNB imagery processed through Google Earth Engine provides an effective and cost-effective method to map tourism development. Findings show that high-intensity zones have expanded significantly in Denpasar, Kuta, and Nusa Dua, while medium-intensity areas such as Gianyar and Tabanan have also increased. Correlation analysis confirms a strong positive relationship between light intensity, the number of tourists, and hotel development, validating the use of NTL as a tourism indicator. In contrast, the area of low-light-intensity areas continues to decline, indicating urbanization is happening. However, this growth also brought significant environmental challenges, such as light pollution, land use change, and increased energy consumption. Therefore, the adoption of sustainable tourism practices, including the use of green lighting, transition to renewable energy, and conservation of green spaces, is crucial to maintain the balance between economic growth and environmental sustainability.

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1. INTRODUCTION

Bali's tourism sector has grown significantly over the past few decades and is becoming a major driver of economic activity. However, this rapid growth brings challenges in terms of sustainability, urbanization, and environmental impact (Ridwana et al; 2020). The increase in tourist numbers has led to the expansion of infrastructure, such as hotels, restaurants, and entertainment venues, often concentrated in major tourist hubs like Denpasar, Kuta, and Nusa Dua. As a result, urbanization has accelerated, with both positive and negative consequences for local communities and ecosystems.

While tourism plays a key role in the local economy, its growth also leads to concerns about the environmental impact, particularly in terms of light pollution (Hrelja and Pecar, 2024; Rodrigues and Loureiro, 2024), energy consumption (Batool et al., 2023; Nagabhooshanam et al., 2025), and land-use changes (Iemaaniah et al., 2023; Iskandar and Abdurrahman, 2025). The increasing intensity of night lights in tourist areas reflects not only the growth of the tourism sector but also the rising demand for resources, contributing to urban sprawl (Iskandar, et al., 2025). For example, many areas of Bali, especially those outside the primary tourist zones, are seeing shifts in land use that threaten natural habitats and biodiversity.

Despite these concerns, there is a lack of comprehensive and effective monitoring systems that can track the extent of these changes and their impact on the environment. Traditional methods of measuring economic and urban development, such as surveys and direct observation, can be resource-intensive and time-consuming. That's why nighttime light (NTL) satellite imagery is an important tool for studying night lighting patterns around the world. It's more effective, efficient, and free.

Nighttime Light (NTL) satellite imagery is satellite imagery that shows the amount of light emitted by lights in urban areas, industries, and large vehicles such as ships. These images can be used to track patterns of urbanization (Sanjaya and Fianty, 2023; Zheng et al., 2023), economic activity (Ivan et al., 2020; Jean et al., 2016), light pollution (Hidayat et al., 2021; Katz and Levin, 2016), and for environmental monitoring (Yang et al., 2020; Yuan et al., 2023). VIIRS DNB (Visible Infrared Imaging Radiometer Suite Day/Night Band) is a satellite sensor designed to collect radiance data at night. It can detect various light sources such as city lights, fishing boats, and other combustion sources. VIIRS DNB is an important tool for analyzing nighttime activity due to its high resolution and ability to capture small details. It has been widely used for urbanization analysis, economic activity monitoring, and artificial light emission mapping in various regions (NOAA, 2020).

Previous studies have demonstrated the strong relationship between NTL and economic activities, including tourism. In the context of tourism, NTL has proven to be a useful tool for monitoring the intensity of human activity in tourist areas. Krikigianni (2019) and Chang (2022) found that NTL imagery is closely linked to the tourism economy, with tourist hotspots showing higher light intensity due to increased human activity and infrastructure development (Chang et al., 2022; Krikigianni et al., 2019). Therefore, understanding the relationship between NTL intensity and tourism growth can offer valuable insights into the spatial dynamics of tourism development.

This study examines the connection between NTL intensity and tourism growth in Bali for the years 2015, 2019, and 2023. Using Google Earth Engine (GEE), we analyzed VIIRS DNB data

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to explore the patterns of tourism development. The findings of this study will help improve our understanding of how tourism affects Bali's urbanization and environment and provide a cost-effective and efficient way to monitor these changes.

2. METHODS

This study adopts a quantitative descriptive approach to analyze the spatial dynamics of tourism development in Bali using Nighttime Light (NTL) satellite imagery. The research integrates remote sensing analysis with statistical data to observe changes over three time periods: 2015, 2019, and 2023. We utilize primary data from VIIRS DNB (Day/Night Band) Stray Light Corrected monthly composite imagery, obtained through Google Earth Engine (GEE), and secondary data such as the number of tourists, population, and number of hotels from official statistics provided by Badan Pusat Statistik (BPS) Bali.

We used VIIRS Stray Light Corrected Nighttime Day/Night Band Composites Version 1 imagery on the Google Earth engine. Google Earth Engine is a cloud-based computing platform designed to process and analyze geospatial data at scale. It leverages global satellite data collections and allows users to run analyses using simple scripts. In the context of this research, Google Earth Engine was used to process VIIRS DNB's data, including data collection invocation, average radiance analysis, and image processing based on specific locations.

The imagery was provided by the Earth Observation Group, the Payne Institute for Public Policy, and the Colorado School of Mines. The Earth Observation Group (EOG) specializes in observing light and combustion sources at night around the world. The group began working with Defense Meteorological Satellite Program (DMSP) data in 1994 and has produced a series of annual cloud-free nighttime light composites. EOG's current focus is on deriving products from nighttime Visible Independent Imaging Radiometer Suite (VIIRS) data. As of 2019, these products are available to the public through the academic department at the Colorado School of Mines, a public university in Golden, Colorado, and additional data are available through the Payne Institute for Public Policy (NOAA, 2019). VIIRS Stray Light Corrected Nighttime Day/Night Band Composites Version 1 imagery is a monthly averaged radiance composite, and cloud cover is determined using the VIIRS Cloud Mask (VCM) product (NOAA, 2020). This product is an alternative configuration of the VIIRS DNB that uses a scatter correction procedure (NOAA, 2020). This image has a spatial resolution of 463.83 meters and the unit of the mean DNB radiance is nanoWatts/sr/cm^2 (NOAA, 2020).

The image is processed using Google Earth Engine with a simple script that sets the time range and location, calls the image collection, calculates the brightness of the light, combines the images per year using the mean function, crops the images by location, and exports the images to Google Drive. Post-processing continued using ArcGIS software. The image was cropped according to the boundaries of Bali province using the extract by mask tool, then the brightness level classification was performed using the reclassify tool. This classification is divided into 3 classes namely low, medium and high using the natural breaks (Jenks) classification type. Natural breaks are the best way to divide areas. The best range is one in which similar ranges are grouped together. This method minimizes the variation within each range so that the areas within each range have values that are as close to each other as possible (Hou et al., 2022).

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To see the change in area of each light level, use the Raster to Polygon tool to convert the raster image format to polygons. To obtain an area value in square kilometers, the Project to UTM tool is used to change the coordinate system to UTM 50S and then select Calculate geometry in square kilometers in the Attribute table. The results of the area calculation and the results of the visual classification of light intensity can then be analyzed using Pearson correlation and descriptive analysis along with other supporting data such as data on the number of tourists, population, and data on the number of hotels from the Badan Pusat Statistik (BPS) of Bali Province, which is shown in Table 1.

Table 1. Data on the number of tourists, population, and number of hotels

Year	Tourists (million)	Hotels (units)	Population (million)	Information
2015	11	281	4.1	Bali tourism began to grow rapidly with a focus on cultural and natural destinations.
2019	17	501	4.3	Tourism activity reached its peak before the COVID-19 pandemic.
2023	15	541	4.4	Domestic tourist visits gradually improved after COVID-19 with the addition of tourism infrastructure.

Source: Badan Pusat Statistik Provinsi Bali

3. RESULTS AND DISCUSSION

3.1 Tourism Growth

The analysis of Nighttime Light (NTL) imagery reveals significant changes in the intensity of night lights in Bali from 2015 to 2023, reflecting shifts in land use and tourism development. Figure 1 shows the distribution of nighttime light intensity in Bali, with red representing high-intensity areas, yellow indicating medium intensity, and green indicating low intensity. In 2015, high-intensity areas were concentrated in Denpasar, but by 2019, this spread to Kuta and Seminyak, and by 2023, extended to southern Badung. Meanwhile, Gianyar and Tabanan, which were predominantly low-intensity areas, have increased to medium intensity, signaling the growth of new tourist destinations. As shown in Figure 1, low-intensity areas have decreased since 2015 due to expanding human activities and infrastructure development.

There has been a notable increase in medium-intensity areas, while high-intensity areas have continued to grow, particularly in major tourist hubs. The uneven distribution of light intensity suggests that infrastructure needs to be more evenly spread across Bali, especially in the northern and western regions, which still have many low-intensity areas. This pattern is a direct reflection of urbanization, defined as the shift from less-developed areas to urban ones with greater infrastructure and population density due to tourism growth. Urbanization is marked by the spread of urban areas and the expansion of infrastructure, such as hotels and roads (Iskandar, et al., 2025). Changes in night light intensity are closely linked to urbanization, where higher light intensity reflects faster infrastructure development and more concentrated human activity, both of which are key features of urbanization.

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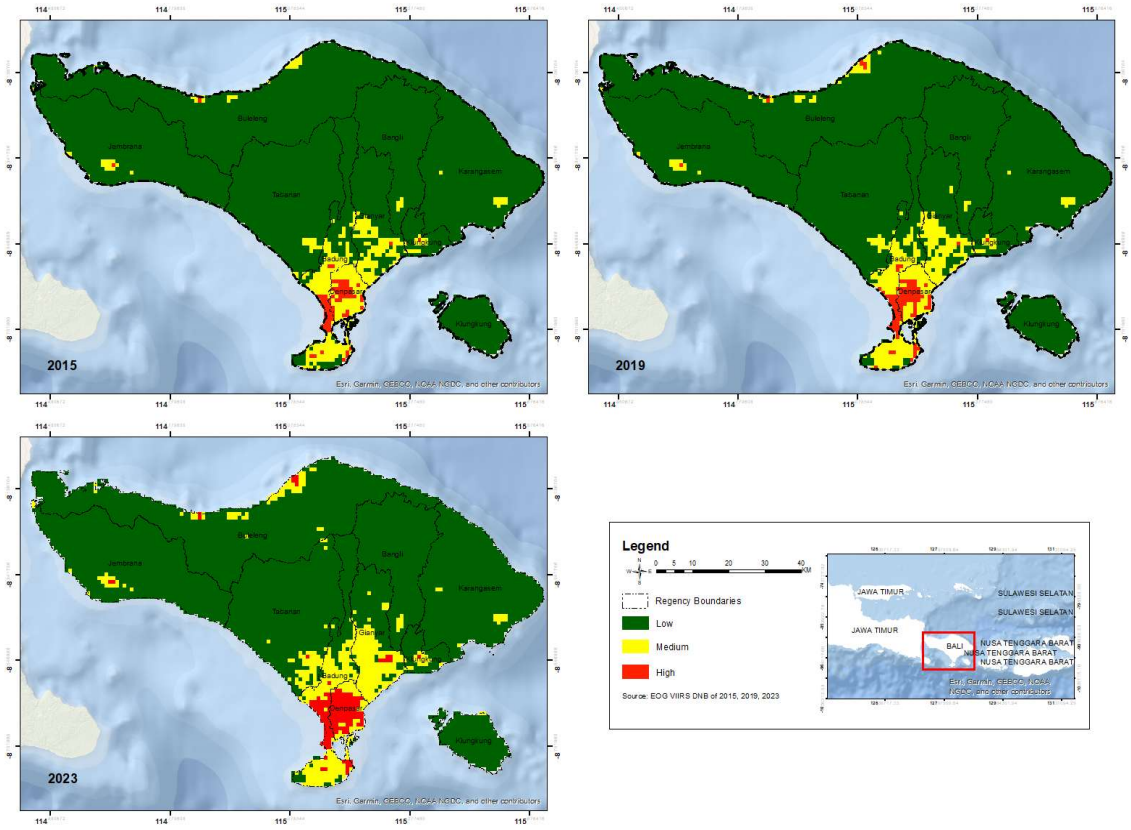

Figure 1. Distribution of night light intensity in Bali in 2015, 2019, and 2023

In 2015, 11 million domestic tourists visited Bali, with 281 star-rated hotels. The number of tourists increased rapidly in 2019, reaching 17 million, as the number of star-rated hotels increased to 507. Although the COVID-19 pandemic affected the tourism industry, the sector began to recover in 2023, with 15 million tourists and 541 star-rated hotels. In line with the development of tourism, the area of highlight intensity has also increased. In 2015, this area was recorded at 75 km², then increased to 99 km² in 2019 and significantly increased to 151 km² in 2023 (Figure 2). Meanwhile, the population of Bali also continues to grow, from 4.1 million in 2015 to 4.3 million in 2019 and reaching 4.4 million in 2023.

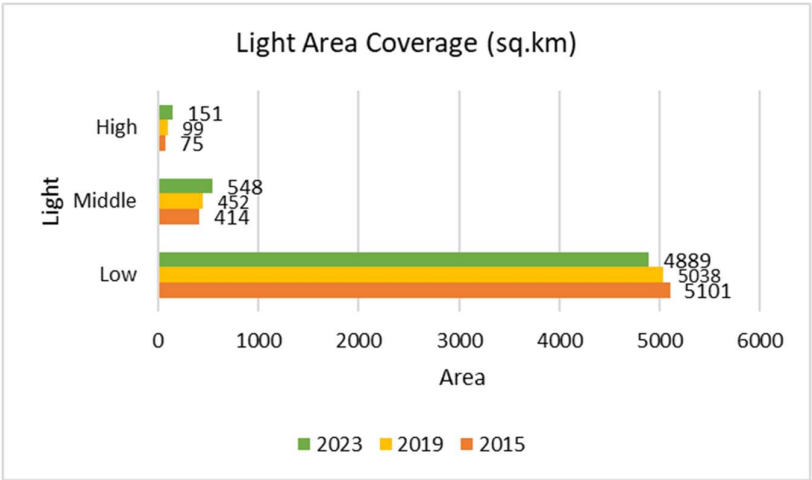

Figure 2. Light area coverage in square kilometers

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The correlation analysis between the number of tourists, the number of hotels, the area of high luminous intensity, and the total population in Bali for the period of 2015 to 2023 shows a close relationship between the growth of the tourism sector and the expansion of urbanization (Figure 3). The results of the correlation calculation show that the area of highlight intensity has a strong positive relationship with the number of tourists and the number of hotels. This indicates that the development of highlighted areas, which represent urbanization and infrastructure development, is directly related to the increase of tourism activities. The larger the highlight area, the more hotels are built to accommodate tourists, further contributing to local economic growth.

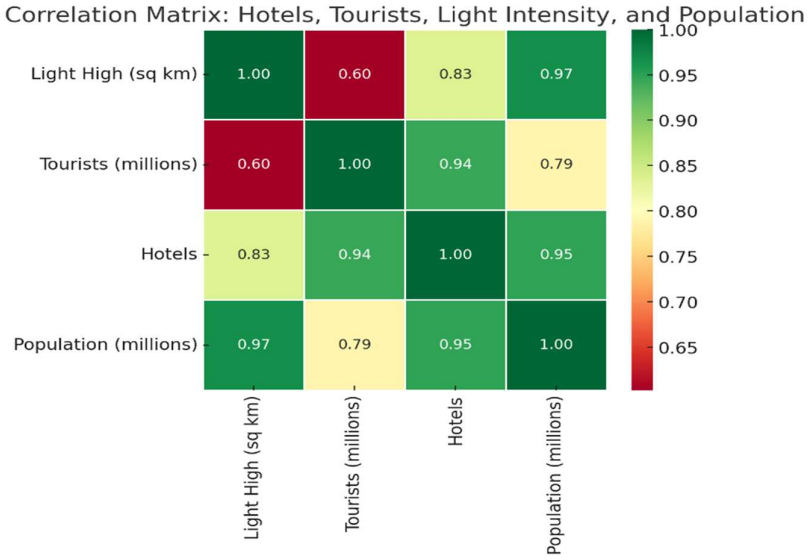

Figure 3. Correlation matrix: hotels, tourists, high-light intensity, and population

In addition, population also shows a positive correlation with the area of high-light areas, the number of hotels, and the number of tourists. This correlation indicates that population growth has contributed to the expansion of urban areas, both through the development of tourism support infrastructure and the increase in residential settlements around major tourist areas. However, the correlation between population and the number of tourists is not as strong as the relationship between the number of tourists and highlight intensity or the number of hotels. This suggests that the increase in the number of tourists is more influenced by external factors such as tourist attraction, tourism promotion, and accessibility than by local population growth alone. The results of this analysis support the hypothesis that Nighttime Light (NTL) satellite imagery can be an effective indicator in monitoring the development of the tourism sector and urbanization.

3.2 Environmental Impacts and Sustainability Challenges

The increase in night light intensity in Bali over the period 2015 to 2023, as shown in the NTL satellite image analysis, reflects the significant dynamics of tourism and urbanization. However, this development also has environmental consequences that require attention. One of the impacts is light pollution, especially in major tourist areas such as Denpasar, Kuta and Nusa Dua, which experience high light intensity. This light pollution can disrupt natural

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ecosystems, especially for nocturnal animals such as sea turtles that lay their eggs on the beach, as well as migratory birds that depend on natural light patterns (Hidayat et al., 2021). In addition, increased night lighting intensity is directly related to increased energy consumption in these tourist areas, which could increase Bali's carbon footprint if it continues to rely on fossil fuel-based energy sources. Urbanization, as evidenced by the expansion of highlight intensity areas, also indicates land use change that can damage natural habitats and reduce biodiversity. Areas with low light intensity, such as Gianyar and Tabanan, indicate the risk of habitat degradation in protected areas and traditional agricultural lands.

Bali's trend is in line with other global tourism regions. For example, the Maldives is experiencing increased resort island development intensity, supported by data showing that tourism generates approximately 28% of GDP and 60% of foreign exchange (King et al., 2022). Thailand shows a similar pattern, with areas such as Phuket and Pattaya experiencing significant growth in tourism infrastructure, resulting in deforestation, pollution, and littering in some areas (Agarwal et al., 2019; Moukomla, 2025). The rapid expansion of Bali's medium and high light intensity zones highlights the urgent need for a balanced development strategy to prevent overtourism and ecological degradation.

A sustainable approach to tourism management is needed to address these environmental impacts. Green lighting regulations, such as reducing light intensity in ecologically sensitive areas, can help reduce light pollution (Katz and Levin, 2016). In addition, the transition to renewable energy, such as the use of solar energy and energy efficient lighting, can reduce energy consumption (Jean et al., 2016). The protection of green spaces and conservation areas should be a top priority, especially in areas prone to land use change. Environmental awareness campaigns for tourists are also needed to reduce pressure on Bali's unique ecosystems. With these measures in place, Bali's tourism growth can continue to contribute to the local economy without damaging the environmental balance.

4. CONCLUSIONS

This study highlights that the growth of tourism in Bali from 2015 to 2023 has significantly shaped urbanization patterns and night light intensity. Areas with high light intensity, such as Denpasar, Kuta, and Nusa Dua, reflect the concentration of major tourism activities, supported by an increase in tourists, hotels, and attractions. In contrast, regions with medium light intensity, like Gianyar and Tabanan, show the potential for new tourism developments. While these expansions boost Bali's economy, they also bring challenges, including pollution, higher energy consumption, and land-use changes. To ensure the long-term sustainability of tourism, Bali must adopt policies focused on sustainable tourism practices, such as green lighting, renewable energy use, and conservation. By prioritizing responsible development, Bali can continue to thrive as a leading tourist destination while preserving its unique environment and cultural heritage.

5. RECOMMENDATIONS

To ensure that Bali's tourism remains sustainable, it is necessary to decentralize tourism development to the north and west, regulate light pollution, and transition to renewable energy to reduce environmental impacts. Further research is needed to assess the long-term impacts of tourism-related urbanization on water resources, air quality, and biodiversity,

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using more advanced remote sensing techniques to strengthen environmental monitoring and policy implementation.

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