Satellite-Based Monitoring of Spatiotemporal Changes in Batudulang Forest in Sumbawa, Indonesia

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Abstract

Space-based earth observation technology applicable to forest inventory and monitoring is well known in the scientific community. High-resolution satellite images form an important data source for forest mapping and change detection at regional and national scales. The value of forest change information derived from remote sensing data is significantly enhanced if this information is integrated into a spatially explicit geographic information system. Satellite-based rapid assessment was conducted to measure spatiotemporal changes in Batudulang forest over the years. The general approach to quantify change in the spatial aspect of the forest involved change detection using moderate-resolution imaging spectroradiometer satellite-based normalized difference vegetation index. A further top–down approach using high-resolution data from Google Earth was used to complement the mapping and specifically identify areas of spatial, temporal, and thematic change on a grid basis (1×1 sq. km). Results from change detection studies revealed that the forest area changed from 287 sq. km in 2008 to 189 sq. km in 2016. Visual image interpretation of high-resolution Google Earth images (2001–2013) analyzed 63 grids, of which 30 showed significant change and 33 exhibited no change.

Abstrak


Keywords: forest change, MODIS, NDVI, satellite image, spatiotemporal analysis

1. Introduction

Sumbawa is part of Indonesian archipelago which located in the middle of the Lesser Sunda Islands chain. The island borders with Lombok to the West, Flores to the East, and Sumba further to the Southeast. The island is part of West Nusa Tenggara province and stretches about 15,400 km². Completing West Nusa Tenggara province, Sumbawa is the biggest one among others, while it ranks the second after Timor in the biogeographic unit...
of the Lesser Sundas [1]. The island is included in the Inner Volcanic Arc (a chain of young volcanic islands from Sumatra in the west to Banda in the east) that evolved around 4 million years ago. Topographically, Sumbawa consists of mountains and irregularly shaped (280 km long, 20–100 km wide). The island is largely volcanic with a limited extent of uplifted limestone in coastal areas, although one major offshore island (Moyo, 330 km) mainly consists of limestone. The South of Sumbawa is structured from old volcanic hills and low mountains to approximately 1,900 m; Meanwhile in Flores, landscapes in the East and North of Sumbawa are dominated by active volcanoes [1]. In Sumbawa, three regencies/subdistricts (kabupaten) exist based on cultural boundaries (old kingdoms). Sumbawa regency in the West is responsible for management of Moyo Island, Dompu in the middle includes approximately half of the Sanggar Peninsula (including the Tambora volcano) and Satonda, and Bima in the East includes part of the northern portion of the Sanggar Peninsula and Sangeang.

**Climatic profile.** Climate in Sumbawa is tropical monsoon with moderate stable temperature and high relative humidity. The wet season (Northwest monsoon) starts in November, peaks in December to January, and could continue until March. From May to September, the Southeast winds (East monsoon) blow relatively dry air to the island. April and October are transitional. Mean daily temperatures vary from 22 °C to 32 °C with average humidity is 85%. Mean annual rainfall spans from 1,000 mm in lowlands to 3,000 mm in highlands. The Eastern part of Sumbawa is considerably drier than the West. The Sumbawa lowlands have a seasonal rainfall pattern with annual totals less than 1,000 mm/year, while the mountains, especially in the Southwest, probably have greater than 3,500 mm/year [2]. The wet season occurs mainly from November to March and the dry season from April to October [3].

**Demographic and socioeconomic profile.** Based on the decennial census in 2010, the number of population in Sumbawa was 1.33 million, made up of 29.58% of the population in West Nusa Tenggara with 4.5 million people. In Nusa Tenggara islands, agriculture becomes the economy motor with the practice of shifting cultivation. Some lowland areas produce rice, but less than 2% of the arable land is appropriate for irrigation. Farming systems are largely based on maize and cassava as staple crops. In dry areas, sorghum or millet alternates maize as the principal grain. The people are practicing extensive grazing of livestock (cattle, water buffalo, horses, goats, and sheep). Different forestry and horticultural species, such as tamarind, candlenut, coffee, and cacao, become primary sources of income during famines and crop shortfalls triggered by long periods of drought. Other growing economic sectors included coastal fisheries, small industries (such as food processing, weaving, and leather making), and tourism. Tourism is a promising sector considering a few surf spots with world-class appeal. Traditionally, the island is known as a source of sappan wood for making red dye, as well as honey and sandalwood. The savanna-like climate and vast grassland on Sumbawa are conducive to horse and cattle breeding. During the 18th century, the Dutch introduced coffee plantations on the western slopes of Mount Tambora, thereby creating the Tambora coffee variant [4].

**Forest conservation in Sumbawa.** It has received attention from the central government and from local and international conservation agencies only in recent years. In the early 1980s, surveys by the Food and Agriculture Organization of the United Nations, in collaboration with the Indonesian Department of Forestry’s Directorate General of Forest Protection and Nature Conservation, identified priority areas for conservation [5]. International conservation agencies, like the World Wide Fund for Nature, Birdlife International, Wildlife Conservation Society, and Nature Conservancy, have become actively involved in sponsoring field programs at selected sites in the region, including biodiversity research, conservation education, and development of regional biodiversity conservation plans [6],[7]. Distinction between rich biological, cultural diversity, and chronic poverty in the area makes significant challenges to decision makers in natural resource management. Settlements are found within and around all forests and designated conservation areas in the region, making land-use conflicts a routine problem. These communities are usually isolated and keep strong traditional values and practices which often strongly linked to land and forest (or coastal) resources. Since humans have an ambivalent relation with forests, immediate needs for exploitation and conservation continue to be a focus to sustain forests in local economies and achieve regional development and environmental protection. Thus, information on forests is as varied as opinions on environmental issues themselves. Under the circumstances, an effective and sustainable approach is required to develop effective programs in monitoring and assessing the effects of human activities on forests.

**Remote sensing and GIS for forest management.** Historically, remote sensing has been important in data collection activities and included black-and-white, color and infrared aerial photography, radar, imaging spectrometer, laser altimetry, and multispectral digital satellite imagery [8],[9]. Satellite imagery consists of varying spectral, spatial, and temporal resolutions and is useful in mapping broad forest types and in detecting and delineating major forest changes over time [9]. Satellite imagery offers several possibilities for inventorization. The use of satellite remote sensing in inventorization of large and sometimes remote areas demonstrated itself
early in the development of the technology. As satellite remote sensing simplified the initial inventory of forest resources, GIS provided the ability to monitor and record the changes. At present, most forest monitoring focuses on activity data, i.e., data on forest cover changes [10] and two approaches are used: top–down and bottom–up. The top–down approach utilizes satellite systems [11],[12] and the bottom–up approach employs ground observation [13]. Satellite data provide systematic coverage and a higher frequency of acquisition at a low cost, which is crucial for forest monitoring [11]-[14]. However, the operational use of these systems is influenced by several factors such as cloud cover, seasonality, and the limited spatial, spectral, and temporal resolution of satellite observations that can lead to an inevitable lag in forest change detection [11]-[15]. The ability to use multiple spatial resolutions of imagery, in conjunction with field data, in multiscale analyses is a burgeoning area for research and applications. However, a perceived mismatch exists between the data needed by ecologists and the data collected with remote sensing instruments [16]. This perception is declining due to the availability of high-resolution data that can be directly linked to traditional field-based ecological measurements [17]. The nesting of data from different scales in an information hierarchy provides opportunities for gathering detailed, site-specific information over increasingly large areas. A new method to detect, characterize, and monitor forest change is by integrating remote sensing and GIS data [18]. Forest change detection analysis, which employs both GIS thematic data and remotely sensed data obtained prior to and following a disturbance, is often conducted to assess specific types of forest damage [19],[20]. Integration of satellite and GIS data substantially improves impact/ damage assessment and map accuracy. The present study is conducted with the objective to design an interactive way that combines Web-based GIS technologies and open-source satellite data to support forest monitoring.

### Study Area

The Batudulang village forms a part of Batu Lanteh subdistrict, Sumbawa district in Nusa Tenggara Barat province. The study area shares a boundary with the villages of Baturotok, Tankan Pulit, Bao Desa, Tepal, and Kelungkung. According to administrative boundary, the village has an area of 43.78 sq. km. The study area extends from −8.5681 to −8.6508 latitude to 117.223 to 117.391 longitude, as shown in Figure 1. Batudulang village faces enormous pressure on its forest resources from the population within and from surrounding villages. This study has attempted to map spatiotemporal changes in the forest of Batudulang through satellite-based observation. The main task is to identify the change in spatial and temporal dimension so that appropriate action is taken by concerned agencies to improve conservation and management of the forest resources in the future.

![Figure 1. Map of Study Area Showing Batudulang Village Overlaid with Observational Grids](image)

### 2. Methods

Time series of NDVI vegetation indices data derived from MODIS satellite images with spatial resolution of 250 m downloaded from NASA’s (Land, Atmosphere Near-real-time Capability) LANCE Rapid Response MODIS images (https://lance.modaps.eosdis.nasa.gov/imagery/subsets?area=sea) was used as direct aid to evaluate any change in forest cover over the 2008–2016 period. The MODIS vegetation indices (VI) is retrieved from daily, atmosphere-corrected, and bidirectional surface reflectance. Accuracy is now within ±0.025, which represents the ability of the 16-day VI products to retrieve a top of canopy (TOC) and nadir VI value when observations are of high quality (clear, no subpixel cloud, low aerosol, and sensor view angle <30°). This estimate is based on comparisons with AERONET-corrected data over a range of biomes and seasonality. The normalized difference vegetation index (NDVI) accuracy is within ±0.025, whereas that of the enhanced VI (EVI) is within ±0.015 and the accuracy of retrieving TOC VI for a good quality day (high quality without the nadir view requirement) is within ±0.020 for NDVI and ±0.010 for EVI [27]. Most of the digital change detection methods are based on change information contained in the spatial and radiometric domain of the image. The requirement of multi-date imagery is crucial when different dates are compared. The data were downloaded and extracted from the administrative layer of Batu Lanteh in Nusa Tenggara Barat province to calculate the change in the forest area over the years. To validate the change interpreted from NDVI vegetation indices showing change, a high-resolution satellite data from Digital Globe available on Google Earth with spatial resolution of 2.4 m for Batudulang village in Batu Lanteh subdistrict was selected to study the exact locations and areas of forest cover change. The validation involved the creation of a spatial framework within which satellite data were observed. The square grid (1 sq. km.) layer for the study areas was created to act as
an observational window. The thematic layer of 63 square grids over Batudulang village was indexed as shown in Figure 1. All thematic data were exported to KML format to be visualized on the Google Earth interface. The changes within the satellite scenes over the study area were observed with the corresponding index numbers within the observational window to track any change within the forest cover in Batudulang and maintain the consistency in the area under observation. The illumination in satellite scenes was set using a time slider to adjust sunlight across the forest landscape within scenes that were more likely to contain evidence of deforestation. The 3D imaging perspective was also employed in visualization and interpretation especially to differentiate standing forest from scrub land, which is often misinterpreted through a vertical perspective. The satellite data for 2010, 2011, 2012, and 2013 from Digital Globe as available on Google Earth were used in the current study. The satellite scenes visualized within a spatial framework (1 sq. km. grid) were exported in a tabular framework for detailed interpretation. The satellite scenes exported were used to interpret any change in the forest cover detected through visual image interpretation of the satellite data. The clips of the corresponding satellite dates were placed side by side to visualize any change over time. The inference drawn from the visual image interpretation of the satellite scenes was provided in textual form.

3. Results and Discussion

Southeast Asia exhibits a striking difference in climate compared with other regions, leading to marked differences in forest types and their appearance on satellite data, thereby affecting the suitability of remote sensing data and monitoring methodologies. In the present study, open-source satellite data on vegetation indices combined with interactive Web-based GIS interface were used to visually interpret and detect changes in the forest of Batudulang region. The change detection based on NDVI vegetation indices for the 2008–2016 period provided insights into the change in spatial extent of the forest cover in the area (Figure 2 A–F). The data revealed that the spatial extent of the forest over the years changed from 287 sq. km. in 2008 to 189 sq. km. in 2016 (Table 1). The dominant drivers of forest cover loss were agricultural expansion, wood extraction, and infrastructure extension [29]. The underlying causes of forest cover loss in Indonesia are related to the expanding global markets for pulp, timber, and oil palm [30],[31]. The results also revealed that the forest cover has decreased by approximately 34.14% since 2008 (Table 1). In addition to forest clearing to establish agroforestry projects, other direct causes include fires [32],[33], illegal logging [31],[33], transmigration programs [34], and smallholder clearance for tree crops [32]. However, forest clearing by small stakeholders was the main reason for forest cover loss in Batudulang.
as evident in the use of high-resolution satellite data. As evaluation of the annual change in forest cover loss between years (2015–2016) showed a significant 16% change compared with the change in 2008–2009 with 5.22%. To improve our understanding of the spatial-temporal change within Batudulang forest, high-resolution satellite data from Google were used and complemented the interpretation by exactly identifying forest change from satellite scenes in 2010–2013. The interactive tabular framework combining Web-based GIS technologies and open-source satellite data and inference of the forest monitoring is shown in Annex 1. Out of 63 observational grids observed, 30 were change grids where forest cover has changed significantly, whereas 33 grids signified no change during the 4-year observational period (2010–2013).

Thus, 47.6% of the grids represent the area that has undergone forest cover change from 2010 to 2013. These data complement the results of annual forest change showing a marked increase in annual change in forest cover from 2015 onwards (Table 1). Spatial analysis of forest change showed that most of the changes occurred in the west, northwest, north, and northeast toward the villages of Sesat, Kelungkung, and Mekong, whereas the southern aspect toward the villages of Tepal, Sempe, and Lenangguar more or less remained unchanged. The agricultural sector in the rural areas of Sumbawa was mainly affected by demographic, political, and economic changes as it simultaneously went through transformation from traditional subsistence farming to modern agricultural practices favoring cash crops such as oil palm, rubber, tea, coffee, and corn. An increase in agricultural production in Sumbawa regency until the end of 2011 was prioritized in improving rice production, secondary crops/palawija (such as soybean, corn, mung bean, and cassava), production and horticulture development, particularly vegetables and fruit crops [28]. This condition has profoundly affected the entire rural landscape, including forest areas. The majority of the original extent of natural forest areas in Southeast Asia have been either logged or cropped with varying intensities, reduced to degraded savanna and grassland, or converted into managed land-cover types while environmental degradation and land-cover changes continue [22]-[26]. With the scale of the observed changes over the study period, large-scale unauthorized logging and agro-industrial development are the main drivers of forest loss. Illegal logging also occurred during the study period, as illustrated by changes in the forest canopy visualized using high-resolution Google images. The 3D satellite clips were used to visualize the change in standing forest canopy and cleared forest (Annex 1). Illegal logging, by certain estimates, accounts for over 50% of total domestic timber production [34]. A high rate of forest degradation within protected forests could have been triggered by the breakdown of centralized political authority in early 2000 and the inability of provincial governments to adequately enforce forest codes [31],[32]. These varying causes have led to different intensities, spatial patterns, and temporal dynamics of the forest degradation phenomenon. To date, synoptic mapping of Indonesian forest cover extent and change using remotely sensed data has been limited due to persistent cloud cover. Thus, achieving an understanding of where, when, and how much the forest cover has changed is difficult [35]. Thus, improved characterization of spatial patterns of change is necessary on various scales (local, regional, and national) and at various resolutions. Thus, a typology of forest/no-forest patterns and of the mechanisms and features of their transformation over time is valuable. The value of forest change information derived from remote sensing data is significantly enhanced when integrated into a spatially explicit GIS, which opens the door for predicting spatio-temporal trends. Thus, by investigating the spatial and temporal patterns of forest change, we can understand its drivers and develop effective policies to reduce deforestation and/or degradation at national and regional scales. Operational satellite monitoring of forest dynamics also serve in detecting displacement and assessing permanence in response to changes in forest governance.

### Table 1. Temporal Change in Forest Area from 2008 to 2016

<table>
<thead>
<tr>
<th>S. No.</th>
<th>MODIS Terra NDVI Vegetation Indices Year</th>
<th>Date</th>
<th>Forest area in sq. km.</th>
<th>Annual change (%)</th>
<th>Percentage change</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>2016</td>
<td>June 13</td>
<td>189</td>
<td>16</td>
<td>34.14</td>
</tr>
<tr>
<td>2.</td>
<td>2015</td>
<td>June 13</td>
<td>225</td>
<td>11.76</td>
<td>21.60</td>
</tr>
<tr>
<td>3.</td>
<td>2014</td>
<td>June 13</td>
<td>255</td>
<td>2.29</td>
<td>11.14</td>
</tr>
<tr>
<td>4.</td>
<td>2013</td>
<td>NA</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>5.</td>
<td>2012</td>
<td>NA</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>6.</td>
<td>2011</td>
<td>NA</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>7.</td>
<td>2010</td>
<td>June 13</td>
<td>261</td>
<td>4.04</td>
<td>9.05</td>
</tr>
<tr>
<td>8.</td>
<td>2009</td>
<td>June 13</td>
<td>272</td>
<td>5.22</td>
<td>5.22</td>
</tr>
<tr>
<td>9.</td>
<td>2008</td>
<td>June 13</td>
<td>287</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

NA: Non-availability of satellite data

Conclusion

This study successfully demonstrated the identification of natural forest distribution in Batudulang for the 2008–2015 period using MODIS-NDVI 250 m multi-temporal imagery. The approach described in this paper provided reliable assessment of change from open-source data comparable to maps derived from higher-resolution data. The study reveals that forest cover over the region has decreased drastically from 287 sq. km. in 2008 to 189 sq. km. in 2016, which amounts to a 34.14% reduction compared with the rate in 2008. The spatial, temporal, and thematic changes were sufficiently mapped by Google Earth satellite data, signifying that 47.6% of observational grids reported changes in the forest cover. The degradation of Batudulang forest is recent and enormous. Thus, prompt action with an improved conservation and management system may prevent or reduce degradation and illegal activities and enhance...
transparency in using forest resources. The magnitude of forest cover change in Batudulang emphasizes the need to reconsider administrative policies for conservation and adoption of improved mechanisms for forest resource management. The present study emphasized the importance of combining technologies, services, and data sources to build credible forest monitoring systems at the appropriate scale (local, provincial, or national) to ensure effective conservation and management.

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