Assessment of tropical forest degradation on a small island using the enhanced vegetation index

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Abstract. The aim of this study was to measure and document the forest degradation on a small forested island in the tropics, that is, Peleng, Central Sulawesi. The forest conditions were observed using Landsat satellite images from 1991 to 2014. To quantify the change in the vegetation cover, a detection technique using Enhanced Vegetation Index (EVI) images was applied. Most parts of the main study area on Peleng are covered by highly degraded forest. However, the degradation decreases with increasing altitude. The EVI application shows that 48% of Peleng’s forests are highly degraded, 28% are moderately degraded, and 24% are less degradation. Highly degraded and poorly managed forests occur at a lower altitude, where the road infrastructure (thus the accessibility) is developed well. Moderately degraded forest is found at borders with cultivation areas. The less degraded areas are found at a higher altitude, far from human habitations, which are mainly in the coastal areas. Local agriculture activities, illegal logging, and wildlife hunting are the main causes of forest degradation. This work represents one of few studies that apply the EVI in tropical forests. The benefit of EVI is discussed.

Keywords: Degradation, enhanced vegetation index, forest

1. Introduction

Tropical forests in Indonesia, especially in Sulawesi, feature diverse flora and fauna with species that are often found nowhere else or are endemic. These forests, however, have long been a target of rampant exploitation and thus are degraded [1]. Forests on Peleng Island, Central Sulawesi, have long been disturbed by anthropological activities, which led to the decline of the ecosystem structure, functions, benefits, and services [2]. Peleng is a small island (± 232,500 hectares) between Sulawesi and the Moluccan Islands, with little explored forests. It is home of several point-endemic species. Among them, Banggai Crow (Corvus unicolor) [3], has long been declared as critically endangered by the International Union for Conservation of Nature and Natural resources (IUCN). It survived in primary forest, which increasingly degrades because of deforestation and other human disturbances. Most of Peleng’s land areas are legally designated as forest estates. Natural resources of these precarious areas serve as important sources for local livelihoods. Illegal logging and wildlife hunting are common due to weak forest management capacities. Although the logging has decreased, timber is still harvested for local needs to build houses, ships and dugout canoes.
This research aims at evaluating vegetation cover changes on spatiotemporal scales. Forest monitoring can be undertaken using a remote sensing approach such as the use of a vegetation index. Today, more than twenty vegetation indices (VIs) have been developed to detect changes and monitor predetermined target species. The Enhanced Vegetation Index (EVI) is suitable for tropical areas and is reasonably accurate [4]. The EVI is used for ecological monitoring, to measure the biomass, vegetation vigour and land cover change and to classify the vegetation [4]. The EVI technique is based on three reflectance bands: red, blue and near-infrared. A geographic information system (GIS) was used to overlay variables and create a map depicting forests at various states or levels of intactness. The work was complemented by ground checking against the local forest vegetation.

2. Experimental

2.1. Research area

Peleng is the largest island of the Banggai Archipelago, located across from the eastern peninsula of Sulawesi at 1°6'30"S–1°35'58"S and 122°37'6.3"E–123°40'1.9"E and belongs to the humid tropical climate zone with average rainfall of ± 898 mm. Peleng is characterized by hilly terrain. The surface topography ranges in elevation from 0 to 1,005 m a.s.l. Geology aspect, the mainland is mainly characterized by karst landforms.

The local forests were differentiated by altitude: lowland forest, lower mountain forest, upper mountain forest and subalpine forest [2]. Lowland forest remnants sporadically occur on Peleng at altitudes up to 500 m a.s.l. The following species probably occur at this altitude according to a study by Indrawan et al. [2]: Ficus spp., Canarium spp., Pigafetta filaris and Lithocarpus havilandii. In more mountainous terrain at altitudes of 500–900 m a.s.l, the following species were detected: Bombaceae, Palaquium sp., Calophyllum sp., Canarium spp., and Syzigium sp. [2]. The vegetation was dominated by shorter trees near the top of the mountain until lichens and epiphyte proliferated. The diversity of trees decreases with increasing altitude.

Indrawan et al. [5] reported that many of the local and endemic faunas, for example, Sula scrubfowl (locally called “kailong”) and Megapodius bernsteini, decreased because of forest conversion and hunting [6]. Peleng cuscus (locally known as “bunges”) Strigocuscus pelengensis, bear cuscus Ailurops ursinus pelengensis, and forest birds, especially fruit doves, have been intensely hunted for food [5]. A very limited number of Banggai crows, locally known as “kuyak” Corvus unicolor, has been found in a limited area, mainly in primary forest at altitudes 500–900 m a.s.l. [2]. The continuous forest conversion is a serious threat to this forest-dwelling point-endemic species.

2.2. Definitions and rationale

Forest degradation is defined as the biogeochemical change of the forest characterized by natural composition and attribute loss caused by fires, forest conversion, and logging [7, 8]. The EVI differencing method has been developed to improve other VIs, such as the widely used NDVI, which is prone to soil background and atmospheric disturbances. The NDVI is also more prone to saturation, which could intensify in areas with dense vegetation such as tropical rainforests. The EVI overcomes these obstacles [9]. The algorithm of the EVI has the capacity to accommodate the soil fitness and uses the blue band to increase the index resistance to aerosol. Because imagery subjected to the EVI does not easily saturate, this index is suitable for monitoring areas with high biomass and growth such as tropical forests [4]. Further, the use of EVI is suitable in tropical areas with variations in local atmosphere conditions due to biomass burning activities [10].

2.3. Data

The satellite data inputs from the Landsat 4 Thematic Mapper (TM) and Landsat 8 Operational Land Imager (OLI) imagery were obtained from the US Geological Survey’s Earth Explorer website (https://earthexplorer.usgs.gov; Landsat data area: path 112 and row 61).
2.4. Methods

2.4.1. Image processing. To fix the position of objects depicted in Landsat 4 TM imagery to the real position on the Earth’s surface, a geometric correction was applied by creating 17 ground control points (GCPs). To reduce atmospheric effects, raw digital number (DN) values from each image were converted to top of the atmosphere (TOA) reflectance using the MODTRAN4 method.

2.4.2. Mapping vegetation cover changes. To detect spatiotemporal vegetation cover changes from 1991 to 2014, the satellite-based EVI algorithm was used [11]:

\[
EV = \frac{G(NIR - Red)}{NIR + (C1 \times Red) - (C2 \times Blue) + L}
\]

where, NIR, Red and Blue are the near-infrared, red and blue spectral reflectance, respectively; C1 is the calibration parameter for red light; C2 is the calibration parameter for blue light; L is the soil factor; and G is the gain factor. For Landsat use, C1 = 6, C2 = 7.5, L = 1 and G = 2.5. The EVI value ranges from 0 to 1. In this study, vegetation was classified into three types: non-vegetation, sparse vegetation and dense vegetation (table 1).

Cloud cover is a major problem when working with optical remotely sensed datasets in humid tropical forest environments such as Indonesia. Furthermore, Indonesia does not have a seasonally cloud-free window [12]. In this research, cloud cover areas were not included in the assessment. The affected areas were reported as “no data.”

2.4.3. Assessing forest degradation. The EVI results were categorized in three classes and analysed using detection change tools. Spectral values were measured for the period from 1991 to 2014. An increased spectral value represents less disturbance and even forest gain. The forest degradation rate was evaluated using two variables: vegetation cover change and existence of local forest tree species. The produced EVI map contains the vegetation cover that was already subjected to a supervised classification of the local vegetation. Subsequently, change detection analysis was conducted on imagery for each year to obtain the spatiotemporal change of the vegetation cover. Sampling was carried out in undisturbed and disturbed forest areas, that is, 35 and 30 random samples were collected from disturbed and undisturbed forests on Peleng, respectively. To obtain a spatial pattern of forest states, the vegetation cover changes over time were overlaid using a GIS application.

3. Results and discussion

3.1. Vegetation cover dynamics

The EVI was derived and classified to produce vegetation maps. The latter were quantified to indicate changes. The results show a drastic decrease in non-vegetation, a slight decrease in sparse vegetation and a large increase in dense vegetation. At any rate, Peleng was dominated by dense vegetation from 1991–2014, as shown by the spectral value of EVI that ranges 0.51–1 (figure 1).

| Vegetation cover type       | Spectral value |
|----------------------------|----------------|
| Non-vegetation             | 0–0.35         |
| Sparse vegetation          | 0.36–0.50      |
| Dense vegetation           | 0.51–1         |
In the EVI maps, dense vegetation is shown in brighter tones compared with more sparse vegetation (figure 2) [13]. Non-vegetation is shown by dark tones. Dense vegetation covered 34% of Peleng in 1991 and increased to 39.5% in 2014. Denser vegetation indicates either primary forest, early degraded forest or old secondary forest, which are usually dispersed in forest areas far away from villages or cultivation areas.

Sparse vegetation has a spectral value ranging 0.36–0.50 and can be detected by lower-intensity bright tones in the imagery. Sparse vegetation tracts are commonly associated with open land areas, which might be severely degraded forest remnants or shrubs. Both in 1991 and 2014, sparse vegetation covered 35% of the total land in highland and lowland areas. Deforestation has resulted in a mosaic of small plots at various stages of clearing and secondary growth, which can be identified by a relatively bright and heterogeneous tones in the imagery.

The last remaining large tracts of primary forest in Peleng are found in the centre of western Peleng. These tracts are not necessarily on steep slopes but at higher elevation with relatively sparse densities of human population and road networks. Large tracts of closed-canopy secondary forest and tree plantations are indistinguishable from primary forest. Field observations and ground checking can help solve this issue.

3.2. Forest degradation rate
The rate of forest degradation on Peleng was estimated on the basis of ground-checked change detection analysis (figure 3). It includes observations of local forest cover that was classified into three types: less degraded, moderately degraded and highly degraded. Less degraded forest dominantly exists in western Peleng and accounts for a 58,300 ha area or 24% of the total area. Moderately degraded forest covers 67,400 ha or 28% of the land and highly degraded forest covers 112,630 ha or 48% of the land.

Moderately degraded forest can be categorized as secondary forest. In our study area, this type of forest is fairly extensive (28%). This type of state sometimes occurs even in the center of forest parts that were cleared by burning and had sparse tree densities and in areas that may be invaded by pioneer vegetation, such as ferns, which may reach heights of 2 m. The forest condition and forest accessibility have a linear relationship. Roads towards the forest were not as crowded in the 1990s as they are now (pers. comm. with Uun Maddus, 2017). Nowadays, new garden and cultivation fields invade higher areas previously vegetated by intact forests. Therefore, roads are constructed. Forests near roads are usually secondary.

Heavy degradation converts forests into cultivation areas or human settlements and roads, especially in coastal areas. Conversions to agriculture mainly occurred in previously sparsely vegetated areas. Highly degraded forest occurs in patches near the coast and roads and in encroached forest areas at higher altitudes. Forested areas formerly cleared by burning for yam/taro/cassava cultivation are often

![Figure 1. Extent of the vegetation cover change from 1991 to 2014.](image-url)
left fallow for 5 years to allow forest regeneration. However, such former cultivation areas are sometimes judged to be unproductive and are then abandoned, making the land available to pioneer plants and maybe even invasive species.

Overexploitation of forest resources is also a challenge. Local farmers enter the forest to collect wood and non-wood products such as timber, rattan, honey and wild animals. Continuous exploitation will cause more degradation, especially if no time for ecosystem restoration is provided. Deforestation on Peleng has significant disaster implications. Soils that are no longer protected by forests are subject to extreme hydrometeorological events such as rapid erosion due to intense rain.

4. Conclusion
This is one of very few studies applying EVI in tropical forests. Based on the ground truthing in western Peleng, the EVI can differentiate the vegetation thickness in a straightforward manner, which confirms that the EVI is practical in the field. The results of this study suggest that forest degradation decreases with increasing altitude. Expansion of agriculture, timber collection and wildlife hunting further
aggravated forest destruction. Accessibility improvements, especially roadwork, play an important role in increasing local forest disturbances; more accessibility means more disturbance. However, it is interesting that, despite global deforestation trends, areas with denser vegetation increase in some locations on Peleng, providing hope for forest rehabilitation. Sustainable agriculture and agroforestry provide local inhabitants with necessary food and resources and are prerequisites for effective tropical forest sustainability. A careful selection of planted species is required in highly degraded forests.

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