THESIS

SPATIO-TEMPORAL ASSESSMENT OF VEGETATION REGENERATION IN AREAS AFFECTED BY PYROCLASTIC FLOWS AND SURGES

A Case of Gunung Merapi National Park

Thesis submitted to the Double Degree M.Sc. Programme, Universitas Gadjah Mada and Faculty of Geo-Information Science and Earth Observation, University of Twente in partial fulfillment of the requirement for the degree of Master of Science in Geo-Information for Spatial Planning and Risk Management

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I certify that although I may have conferred with others in preparing for this assignment, and drawn upon a range of sources cited in this work, the content of this thesis report is my original work.

Yogyakarta, 27 March 2013

Dedy Humaidi

Abstract

Merapi Volcano eruptions have impact on the surroundings including Gunung Merapi National Park (GMNP). Pyroclastic flows and pyroclastic surges are able to cause serious damage to vegetation and causing land cover changes. Concerning the function of GMNP as conservation area, the information of what was the impact of volcanic eruptions to the vegetation and how the vegetation regeneration after the eruptions are important. The main aim of this research was to study the vegetation regeneration in GMNP areas after the 2006 and 2010 eruptions using remote sensing and GIS. This research used vegetation indices to detect changes in canopy cover which were then used as indicator of vegetation regeneration. The results showed that vegetation types affected in 2006 and 2010 eruption were mixed forest and shrub. GMNP zones affected in 2006 eruption were: sanctuary, mitigation, wilderness and traditional zones, while the 2010 eruption affected all zones: sanctuary, intensive use, mitigation, rehabilitation, religious and cultural, wilderness, and traditional. There were four vegetation indices tested (RVI, NDVI, SAVI, $MSAVI_2$) for their correlations with canopy cover. Results from simple regression model concluded that NDVI with power regression model gave the highest R^2 value. This model can explain 70% of variance in canopy cover. From the ANOVA analysis of vegetation regeneration after 2006 and 2010 eruptions, there were differences of vegetation regeneration within different landcover types and different GMNP zones. This study also found that the vegetation regeneration after 2006 eruption was influenced by four factors: distance to crater, aspect, elevation, and rainfall. While the vegetation regeneration after the 2010 eruption was influenced by two factors: rainfall and elevation.

Keyword: remote sensing, GIS, vegetation regeneration, NDVI

Intisari

Erupsi Gunungapi Merapi menimbulkan dampak terhadap lingkungan di sekitarnya termasuk Taman Nasional Gunung Merapi (TNGM). *Pyroclastic flows* dan *pyroclastic surges* dari letusan Merapi dapat menimbulkan kerusakan vegetasi dan menyebabkan perubahan tutupan lahan. Berkaitan dengan fungsi TNGM sebagai kawasan koservasi, maka informasi mengenai dampak dari erupsi Merapi terhadap vegetasi dan regenerasi vegetasi menjadi penting. Tujuan dari penelitian ini adalah untuk mempelajari regenerasi vegetasi di areal TNGM setelah erupsi tahun 2006 dan 2010 dengan menggunakan penginderaan jauh dan sistem informasi geografis (SIG). Penelitian ini meggunakan indeks vegetasi untuk mendeteksi perubahan penutupan tajuk yang dijadikan indikator regenerasi vegetasi. Hasil yang diperoleh menunjukkan bahwa tipe vegetasi yang terdampak pada erupsi tahun 2006 dan 2010 adalah hutan campuran dan semak. Zona TNGM yang terdampak pada erupsi 2006 dan 2010 adalah zona inti, mitigasi, rimba dan tradisional. Dalam thesis ini ada empat jenis indeks vegetasi yang digunakan yaitu RVI, NDVI, SAVI dan $MSAVI_2$. Indeks tersebut diuji korelasinya dengan penutupan tajuk. Hasil dari model regresi linear menunjukkan bahwa indeks vegetasi NDVI dengan *power regression* memberikan nilai koefisien determinasi (R^2) yang paling tinggi. Model ini mampu menjelaskan 70% dari variasi penutupan tajuk. Hasil analisis ragam (ANOVA) terhadap regenerasi vegetasi setelah erupsi 2006 dan 2010 menunjukkan bahwa terdapat perbedaan regenerasi vegetasi di dalam jenis tutupan lahan dan zonasi TNGM yang berbeda. Penelitian ini juga mendapatkan hasil bahwa regenerasi vegetasi setelah erupsi 2006 dipengaruhi oleh empat faktor, yaitu jarak dari kawah, aspek, ketinggian dan curah hujan. Sedangkan regenerasi vegetasi setelah erupsi 2010 dipengaruhi oleh dua faktor yaitu curah hujan dan ketinggian.

Kata kunci: penginderaan jauh, regenerasi vegetasi, NDVI

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March 2013

Dedy Humaidi

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List of Abbreviations

ANOVA	:	Analysis of Variance
ASTER	:	Advanced Spaceborne Thermal Emission and Reflection Radiometer
Bakosurtanal	:	Badan Koordinasi Survei dan Pemetaan Nasional (*National Coordination Agency for Survey and Mapping*)
Bappenas	:	Badan Perencanaan Pembangunan Nasional (*Indonesian National Bureau for Development Planning*)
BNPB	:	Badan Nasional Penanggulangan Bencana (*Indonesian National Board For Disaster Management*)
BPPTK	:	Balai Penyelidikan dan Pengembangan Teknologi Kegunungapian (*Indonesian Agency for Investigation and Technological Development on Volcanism*)
CC	:	Canopy Cover
DN	:	Digital Number
ETM	:	Enhanced Thematic Mapper
GMNP	:	Gunung Merapi National Park
MSAVI	:	Modified Soil Adjusted Vegetation Index
NDVI	:	Normalized Difference Vegetation Index
RVI	:	Ratio Vegetation Indices
SAVI	:	Soil Adjusted Vegetation Index

1. Introduction

1.1. Background

In 2004, through the Decree of the Minister of Forestry Number 134/Menhut-II/2004, an area of total ± 6,410 ha in Yogyakarta and Central Java Provinces was designated as a national park (Gunung Merapi National Park/GMNP). According to Regulation Number 5/1990 about the conservation of natural resources and its ecosystems, GMNP as a national park has three functions namely protection of life support system, preservation of biodiversity and its ecosystems, and sustainable utilization of natural resources.

The national park is managed using a zoning system, in which each zone has its own specific function. GMNP zoning system consists of seven zones: a sanctuary zone, a wilderness zone, an intensive use zone, a rehabilitation zone, a traditional zone, and a religious and cultural zone, and a reconstruction and mitigation zone

The GMNP is located in the surrounding area of Merapi Volcano. Merapi is one of 129 active volcanoes in Indonesia and is considered as the most active and most dangerous volcano in Indonesia (Camus, Gourgaud, Mossand-Berthommier, & Vincent, 2000). In the last century, Merapi erupts regularly once in 2-5 years.

In General, volcanic eruption can be seen as an ecological disturbance to the ecosystem. This disturbance can also be considered a part of ecological dynamic that has effect in shaping the composition, structure and function of ecosystems (Hobbs & Huenneke, 1992; Dale, Swanson, & Crisafulli, 2005). Volcanic activity can have impact on vegetation through six types of disturbances, namely lava formation, pyroclastic flow, debris avalanches, lahar, tephra and blowdown (Dale, Delgado-Acevedo, & MacMahon, 2005). Pyroclastic flows and surges are considered as the most dangerous hazards from Merapi volcanic eruption (Widiwijayanti, Voight, Hidayat, & Schilling, 2009). Both have a destructive effect on vegetation. One study of the effect of Merapi pyroclastic flows on vegetation mentioned that after 1994 Merapi eruption there were four types of effects to vegetation: singed trees; broken trees, blown down trees, and buried trees (Kelfoun, Legros, & Gourgaud, 2000).

Most areas of GMNP have been affected by pyroclastic flows from previous eruptions (Figure 1.1). In the last decade Merapi has erupted twice. In 2006, Merapi eruption caused 1,246 hectares of Merapi and Merbabu National Park severely damaged. Some area lost their main function as protection forest. Economic value of that loss was estimated to be 6 billion rupiahs, and would at least need 100 thousands of new seed and 30 years of time for replanting (Sohirin, 2010). In the last eruption event of 2010, at least 1,128 hectares of vegetation was destructed by pyroclastic flow which caused an economic loss of 157 billion rupiah (Bappenas and BNPB, 2011).

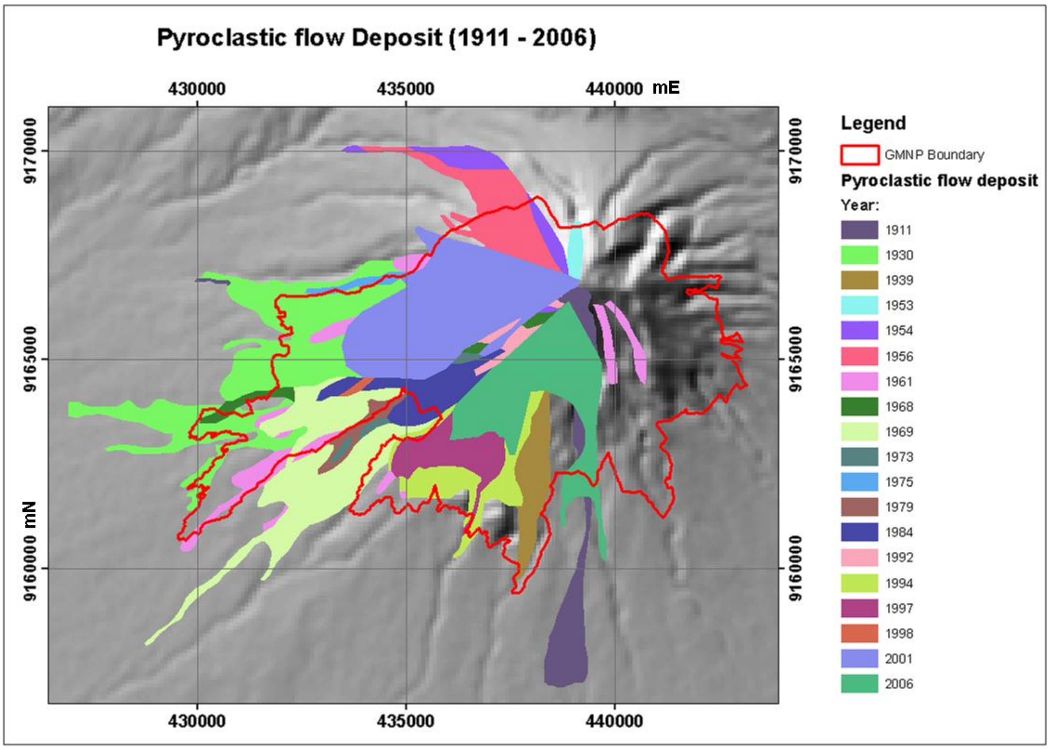


Figure 1.1 Pyroclastic flow deposit of Merapi Volcano eruption 1911-2006 (source: BPPTK, 2010)

However, the vegetation in GMNP has the natural ability to regenerate. As reported by Sutomo (2010) that the ecosystems in GMNP are resilient to disturbance. He used chronosequence approach by comparing vegetation structure and composition in different areas which were affected by pyroclastic flows and surges of 1994 to 2006 eruptions. From the statistical analysis he concluded that there was a rapid colonization by vascular plants in both primary and secondary succession area. In primary succession area (affected by pyroclastic flow) the species richness and diversity reach their peak fourteen years after disturbance, while in secondary succession (affected by pyroclastic surge) the species richness became close to reference (unaffected) site after two years, but the peak of richness and diversity was also after fourteen years.

The development of remote sensing instrument has given the opportunity to monitor vegetation recovery. Satellite imagery has been used many times as an alternative for extensive field sampling in studying vegetation response after disturbance. The most widely used approach is using vegetation indices, especially Normalized Difference Vegetation Index (Riaño et al., 2002). Several studies of vegetation regeneration have used NDVI data to be correlated to relevant parameter in vegetation regeneration such as fractional vegetation cover, fraction of Absorbed Photosynthetically Active Radiation (fAPAR), Net Primary Production (NPP), and Leaf Area Index (LAI), these relationship are develop based on calibration with the ground data (Gitas et al., 2012).

The temporal evolution of vegetation recovery derived from remote sensing data has been validated in several ways. These include the use of aerial photography and field studies. For instance the values of different indices from imageries were correlated to vegetation cover as an indicator of regeneration (Riano et al., 2002).

Forest recovery after disturbance can also be assessed using changes in canopy structure (such as canopy cover) as a measure of ecosystem function (Chazdon, 2003). Canopy cover or canopy density can be used as one of the indicators of forest condition and the use of remote sensing is ideal to monitor canopy cover because it can cover wide area (Wang, Qi, & Cochrane, 2005).

1.2. Problem Statement

Merapi Volcano eruptions have impact on the surroundings including GMNP. Pyroclastic flows and pyroclastic surges are able to cause serious damage to vegetation and causing land cover changes. Concerning the function of GMNP as conservation area, the information of what was the impact of volcanic eruptions to the vegetation, and how the vegetation regeneration after the eruptions is important.

Satellite sensor derived data is a very potential source to study changes in the vegetation at regional or even global scales (Pettorelli et al., 2005). Many studies have explored the use of vegetation indices to assess vegetation regeneration after disturbance, mostly after forest fire events (Diaz-Delgado et al., 1998; Riaño et al. 2002; Mutanga, 2007).

According to Gitas et al. (2012), theoretically the same approach can also be used to other disturbances in which there are external forces that caused damage to the vegetation (e.g. volcanic eruptions, landslides, hurricanes, tsunamis, etc.). But not many studies have applied this approach to volcanic eruption cases.

Vegetation regeneration is also influenced by environmental factors such as topographic and climate factor (Diaz-Delgado, Salvador & Pons, 1998). Remote sensing technology has been proven to be a suitable tool to understand vegetation regeneration and offers possibility to conduct spatio temporal analysis at landscape scale to determine the environmental factors (topographic and climatic) influencing the vegetation regeneration.

1.3. Research Objectives

The main aim of this research was to study the vegetation regeneration in GMNP areas after the 2006 and 2010 eruptions using remote sensing and GIS.

The specific objectives of this study were:

1. To assess the effect of pyroclastic flows and surges on vegetation after the 2006 and 2010 eruptions in GMNP areas.
2. To evaluate the relationship between selected vegetation indices and canopy cover.
3. To compare the vegetation regeneration within the different landcover types and different GMNP zones.
4. To determine environmental factors influencing vegetation regeneration after eruption.

1.4. Research Questions

The research questions were:

Nr	Research objectives	Research questions
1	To assess the effect of pyroclastic flows and surge of 2006 and 2010 eruptions on vegetation in GMNP areas.	1. What was the vegetation cover before the eruptions in 2006 and 2010? 2. Which vegetation types were affected in the 2006 and 2010 eruptions? 3. Which GMNP zones were affected in the 2006 and 2010 eruptions?
2	To evaluate the relationship between selected vegetation indices and canopy cover.	4. What is the relationship between selected vegetation indices and canopy cover?
3	To compare the vegetation regeneration within the different landcover types and different GMNP zones	5. Is there a difference in vegetation regeneration within the different landcover types and GMNP zones?
4	To determine the environmental factors influencing vegetation regeneration after the eruption	6. Which environmental factors influence vegetation regeneration?

1.5. Research Hypotheses

1. H_0 : There is no correlation between vegetation indices and canopy cover
   H_1 : There is correlation between vegetation indices and canopy cover
2. H_0 : There are no significant differences of vegetation regeneration within different landcover types and different GMNP zones
   H_1 : There are significant differences of vegetation regeneration within different landcover types and different GMNP zones
3. H_0 : The selected environmental factors do not explain the variability of vegetation regeneration
   H_1 : The selected environmental factors explain the variability of vegetation regeneration

1.6. Research Benefit

This research was the first that utilized the use of remote sensing in assessing vegetation regeneration in GMNP areas which were affected by pyroclastic flows and surges of Merapi Volcano eruptions. This approach would lessen the time needed to assess the vegetation response if compared by the direct field measurement approach. Moreover, in relation to the GMNP function as conservation area, this research also assessed the vegetation regeneration in different conservation zones.

2. Literature Review

2.1. Merapi Volcano

Merapi volcano is a Strato-volcano type with andesitic-basaltic magma, reaching height as 2978 m with a diameter of 28 km, covering an area of 300-400 km2 and occupying 150 km^3 volumes. Eruptions of Merapi are generally preceded by lava dome growth followed by pyroclastic flows, lava avalanches and pyroclastic fallout. These primary hazards coupled by secondary lahars hazard that can occur during the rainy season are threatening its surrounding.

Hartini (2012) did a study on morpho–chronological of Merapi volcano domes and summarized the history of Merapi eruptions recorded in the period 1902-2006 (Table 2.1).

Table 2.1 Summary of Merapi eruptions in period 1902-2006
(Source: Hartini, 2012)

Year	Type of eruption	Direction	River flowed and extent distance
1902 -1904	Dome collapse	E	Woro (6 km)
1905 - 1906	Undifferentiated	E	Woro
1909 - 1913	Dome collapse	SW	Batang
1920 – 1923	Undifferentiated	W – SW	Blongkeng
1930	Undifferentiated	NW, W – SW, SW	Senowo, Blongkeng (12 km), Batang
1933 – 1934	Fountain collapse	NW	Senowo
1939 – 1941	No collapse		-
1942 – 1945	Dome collapse	NW, SW	Senowo, Blongkeng, Batang
1948	No collapse		-
1953 – 1956	Dome collapse	N	Apu (5km)
1957 – 1958	Dome collapse	SW	Batang (4km)
1961			
17 – 18 April	Dome collapse	NW, SW	Batang (6.5 km), Senowo
7 – 8 May	Fountain collapse	NW, SW, SE, E	Senowo, Batang (12 km), Gendol, Woro
27 – 28 Nov	Dome collapse	SW	Batang (8 km)
1967 – 1969			
1967 - 1968	Dome collapse	SW	Batang (7 km)

Year	Type of eruption	Direction	River flowed and extent distance
1969	Fountain collapse	SW, W – SW – S	Bebeng (13.5 km), 9 km to Blongkeng, Batang , Krasak
1972 – 1974			
1972	Fountain collapse	SW	Batang (3 km)
1973	Dome collapse	W – SW	Blongkeng (5.5 km), Bebeng (7 km), Batang (6 km)
1976 – 1979	Dome collapse	SW	Batang (6km)
1980 – 1983	Dome collapse	SW, SW – S	5 – 7 km to Batang, Bebeng, Putih, Krasak
1984 – 1991	Dome collapse	SW	Sat/Putih
1992 – 1993	Dome collapse	W	Sat/Putih (4 – 5 km)
1994 - 1998			
1994	Dome collapse	SW, SW– S, S	Bebeng, Krasak, Bedog, Boyong (6.5 km)
1995	Dome collapse	SW, S	3.5 km to Krasak, Boyong
1997 (14 Jan)	Dome collapse	SW, SW– S	Bebeng, Krasak, Bedog
(17 Jan)	Fountain collapse	SW– S, S	Krasak, Bedog, Boyong (6.5 km)
1998	No collapse		-
2001	Dome collapse	NW,W – SW, SW	Senowo, Lamat, Bebeng (4.5 km) and Sat/Putih (6 km)
2006 (15 May)	Dome collapse	SW – S , S, SE	4.5 km to Krasak, Boyong, Gendol
(14 June)	Dome collapse	SE	Gendol (7 km)

Note: E: east, SE: southeast, S: south, SW: southwest, W: west, NW: northwest, N: north

In the last ten years, Merapi volcano has erupted twice in 2006 and 2010. The 2006 eruption caused two casualties, while in the 2010 eruption approximately 368 people died and more than a hundred thousand people were evacuated within a radius of 25 km from the crater (Darmawan, 2012).

As reported by Gertisser et al. (2011) the latest eruption in 2010 was the most powerful eruption since 1900s, and also its eruptive behaviour was significantly different from previous eruptions. After two centuries of volcanic activity dominated by lava dome growth and intermittent gravitational or explosive dome failures that produce pyroclastic flows, the 2010 Merapi eruption type was explosive (Figure 2.1).

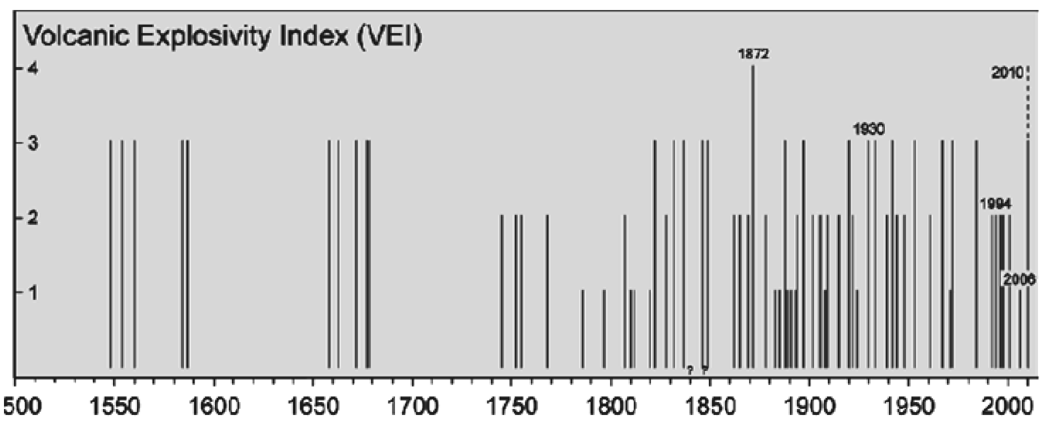


Figure 2.1 Merapi historical eruption record
(Source: Gertisser et al., 2011)

2.2. Pyroclastic Flows and Surges of Merapi

Merapi volcano has different characteristic of pyroclastic material flow compared with other volcanoes so it is referred as "Merapi type". It is resulted from the collapsed lava dome at the summit and significantly influenced by gravity (Takahashi & Tsujimoto, 2000; Bardintzeff, 1984).

Merapi Volcano eruption generally starts with the growth of basaltic andesite lava dome that after reaching a certain size may collapse and generate pyroclastic flows (Gertisser et al., 2011). This pyroclastic flow is also known block-and-ash flow (BAF), nue´es ardentes, or glowing clouds.

Merapi pyroclastic flow is a mixture of volcanic material from different size (from ash to several meters size) and hot gasses (Gertisser et al., 2011). It moves rapidly on land surface following the topography with great speed up to 200 km/hour (Dale, Delgado-Acevedo & MacMahon, 2005). Another definition of volcanic hazard also include pyroclastic surge, pyroclastic material consisting of gasses and rock debris with lower density (Crandell, 1984).

The difference between pyroclastic flows and surges is their movement along the ground. Pyroclastic flows are influenced by gravitational force so they follow the topography, while pyroclastic surges movements are more intricate because besides gravity and topography, aerodynamic drag is also influencing (Burt, Wadge & Curnow, 2001).

2.3. Vegetation Indices for Vegetation Monitoring

Remote sensing is related to the activities of recording, observing, and perceiving objects or events from a distance. It can be defined as science and technology to acquire information about the earth's surface and atmosphere using sensors onboard airborne or space borne platforms (Weng, 2010).

Based on the scope, remote sensing can be divided into (1) satellite remote sensing (when satellite platforms are used), (2) photography and photogrammetry (when photographs are used to capture visible light), (3) thermal remote sensing (when the thermal infrared portion of the spectrum is used), (4) radar remote sensing (when microwave wavelengths are used), and (5) LiDAR remote sensing (when laser pulses are transmitted toward the ground and the distance between the sensor and the ground is measured based on the return time of each pulse) (Weng, 2010).

One of the most important applications of remote sensing is in vegetation monitoring. Comparison of vegetation index changes over time has been used to assess the condition of forest and plant species (Lawrence & Ripple, 1999), and the most-used vegetation index is the Normalized Difference Vegetation Index (NDVI) formulated by Rouse et al. in 1973. It has been applied in many vegetation studies using remote sensing. This index is developed based on the observation that chlorophylls a and b in green leaves strongly absorb light in the Red, with maximum absorption at about 690 nm, while the cell walls strongly scatter (reflect and transmit) light in the NIR region (about 850 nm) (Glenn et al., 2008). NDVI normalizes values between -1 to +1; dense vegetation has a high

NDVI, while soil values are low but positive, and water is negative due to its strong absorption of NIR (Glenn et al., 2008).

Many studies have used NDVI in monitoring vegetation response or regeneration after experiencing disturbance especially forest fires. Diaz-Delgado et al. (1998) studied the vegetation responses to fire variability by evaluating the rates of recovery after fire in different Mediterranean plant communities. In this study the regeneration processes were monitored by the NDVI response. He concluded that use of NDVI seems to be adequate to monitor the plant regeneration processes.

Lawrence (2005) has also studied vegetation response 20 years after the 1980 Mount St. Helens eruption. He used changes in spectral index related to vegetation amount (NDVI) in multi temporal satellite imageries as surrogate variables to see vegetation regeneration in affected area. NDVI difference values near to 0 represent little or no vegetation changes and the increasing positive values represent increasing vegetation amounts.

$$NDVI\ Difference\ =\ NDVI_t - NDVI_{t-1}, \text{ where t = analysis time}$$

Vegetation indices can be calculated from different satellite sensors. Buhe et al. (2002) compared the vegetation index at different spatial and spectral resolutions, i.e. MODIS, AVHRR and ASTER; they found that in the area with a complicated vegetation and topographical distribution it is found that ASTER-NDVI is very useful.

However, there are many optional vegetation indices that are developed as alternative to reduce some errors associated with NDVI such as its sensitivity to soil reflectance, and its linear or non linear relationship with ecological properties measured (Kerr & Ostrovsky, 2003). In general these vegetation indices can be categorized into two types: ratio-based indices e.g. RVI and NDVI, and soil-adjusted indices e.g. SAVI and $MSAVI_2$ (Lawrence & Ripple, 1999)

Ratio Vegetation Index (RVI) is one of the earliest vegetation indices proposed by Pearson and Miller in 1972. It has been found to show high correlation with vegetation cover (Lawrence & Ripple, 1999).

Several modified versions of NDVI have been developed, with increasing complexity, to reduce the in sensitivity of NDVI to varying substrates. Soil Adjusted Vegetation Index (SAVI) was proposed by Huete in 1988 aiming to reduce effect of soil background variations by the use of a soil-adjustment factor. He found that any adjustment factor between 0.5 and 1 considerably eliminated background influences over a range of vegetation densities (Veraverbeke et al., 2012).

An attempt to account for differences in soil background was proposed by Qi et al. in 1994. They formulate the modified SAVI (MSAVI) by replacing constant L in SAVI formula with a dynamic soil-adjusting factor. They showed that MSAVI better accounted for soil variability than SAVI when applied to a cover measure of cotton (Purevdorj, Tateishi, Ishiyama, & Honda, 1998). In this study, the second proposed versions (MSAVI2), which does not require an empirically determined soil line was used (Lawrence & Ripple, 1999).

3. Study Area

3.1. Location

Gunung Merapi National Park (GMNP) is an area of nature that has authentic ecosystems of Volcanic Mountain of Merapi and a high mountain forest, managed with the zoning system exploited for the purpose of research, science, education, support breeding and cultivation, recreation and tourism. GMNP covers ± 6,410 hectares of areas surrounding the Merapi Volcano. It is administratively located in two provinces, Central Java (Magelang, Boyolali and Klaten Regency) and Yogyakarta (Sleman Regency). It is approximately 30 kilometres north of Yogyakarta City (Figure 3.1).

This study took the southern part of GMNP as study area, because this area was the most affected in the 2006 and 2010 eruptions. The study area comprises two regencies: Sleman and Klaten, with total area of ± 2,835 hectares.

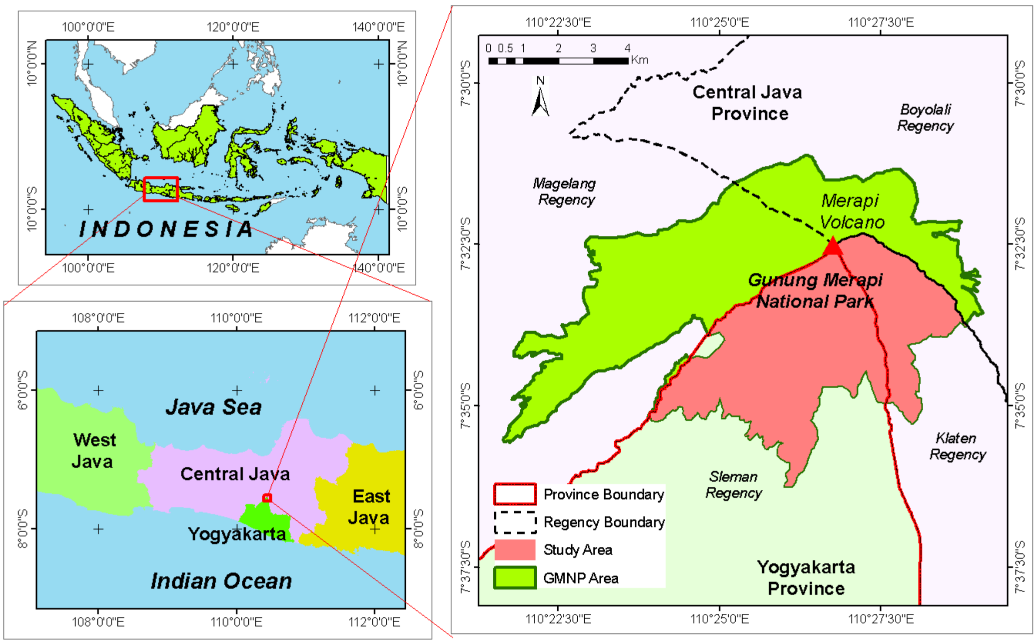


Figure 3.1 Location of Gunung Merapi National Park and study area

GMNP is located at an altitude between 600-2968 m above sea level. Topography is ranging from gently sloping to the hilly and mountainous. Merapi is the source for three watersheds, Progo in the western part, Opak in the southern part and Bengawan Solo River Basin in the eastern part. Overall, there are about 27 rivers around Merapi

3.2. GMNP Zones in Study Area

According to the regulation stated in the Ministry of Forestry Decree number P.56/Menhut-II/2006 about Guidance of National Park Zoning System, a national park zoning system must consist of three main zones: sanctuary, wilderness, and intensive use zone. Besides those main zones, a national park can have additional zones namely traditional, rehabilitation, religious and cultural zone, and specialized zone.

GMNP zoning system in the study area consists of seven zones (Figure 3.2). As regulated in the aforementioned regulation, each zone has its specific function.

- Sanctuary zone is functioning as area for the protection of ecosystems, preservation of flora and fauna and their habitat, genetic resources of plants and wildlife, for research and development, and education.
- Wilderness zone is functioning as area for preservation activities and utilization of natural resources and environment for the purposes of research, conservation, limited tourism, wildlife habitat and support the sanctuary zone.
- Intensive use zone is functioning as area for nature tourism and recreation, environmental services, education, and also for research and development.
- Rehabilitation zone is functioning for restoring ecosystems of damaged areas to close to its natural ecosystem condition.

- Traditional zone is functioning as area for sustainable utilization of certain national park resources by the local community in order to meet their needs.
- Religious and cultural zone is functioning as area for protection the value cultural, historical, archaeological and religious heritage, and also for research and education.
- Reconstruction and mitigation zone is specialized zone in GMNP. It is designated to support effort to make improvement of mitigation measure in watershed in Merapi Volcano surrounding to prevent natural disasters such as floods and landslides in the future.

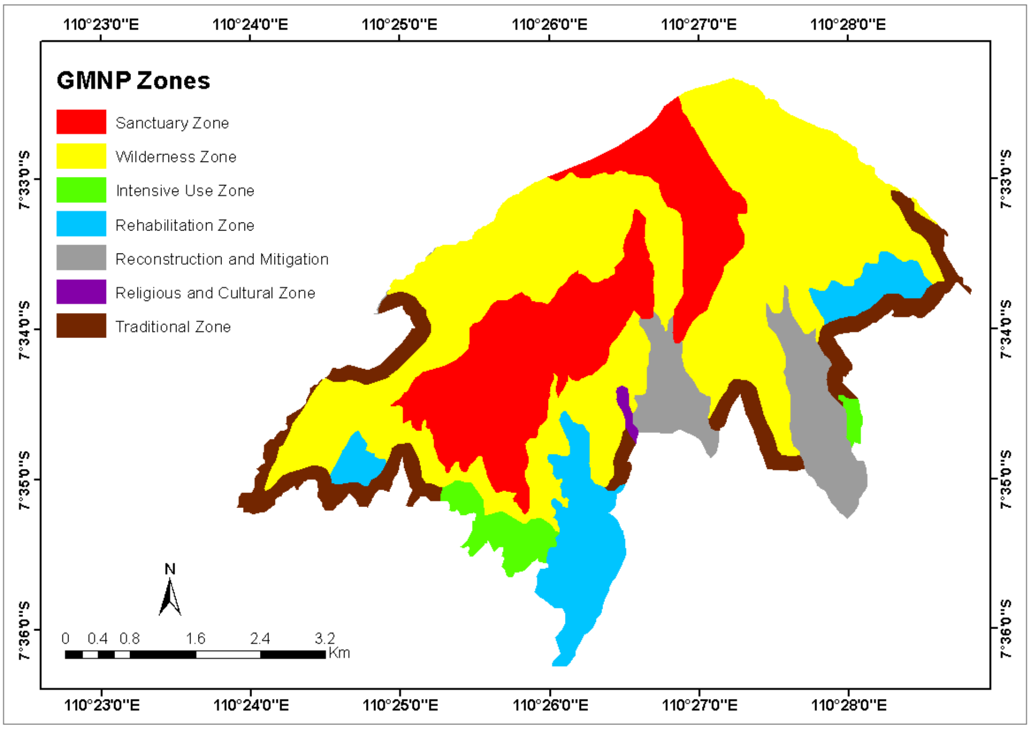


Figure 3.2 GMNP zones

The study area is mostly designated as wilderness zone and sanctuary zone. The area size of each zone is given in Table 3.1.

Table 3.1 Zonation of GMNP in study area

Zone	Area (hectares)
Sanctuary zone	628
Wilderness zone	1,366
Intensive use zone	81
Rehabilitation zone	263
Mitigation and reconstruction zone	230
Religious and cultural zone	8
Traditional zone	257
Total	2,835

(Source: Data processing, 2013)

3.3. Vegetation Condition of GMNP after 2010 Eruption

In 2011, one year after the latest eruption, GMNP bureau did a comprehensive survey on park condition, including the damage on vegetation. By using post eruption ASTER image and accompanied by field survey, the damage on vegetation is classified into high, medium and low damage (Table 3 2).

Table 3.2 Vegetation damage class in GMNP area after 2010 Merapi Volcano eruption

Vegetation damage class	Area (ha)	%
High	1.242	19.38
Medium	1.208	18.85
Low	2.544	39.69
Lava field	1.416	22.09
Total	6.410	100

(Source: GMNP Bureau, 2011)

High damage is defined as area directly affected by pyroclastic flows and surges where no vegetation remained, and the deposit of pyroclastic materials was clear. Medium damage is area affected by pyroclastic surge, the deposit of pyroclastic materials was visible on the ground, trees were burnt and broken but the remaining stand still can be seen. Low damage is defined as an area that is not affected by the pyroclastic flow and surge so the vegetation was still in good condition. Lava field is barren area surrounding the crater which has been without vegetation before the 2010 eruption.

The study also discovered that part of GMNP area that is still relatively safe from the eruption, located in the Southern and Eastern flanks of Merapi Volcano, in Plawangan and Turgo (South), and Musuk and Cepogo (East).

4. Materials and Methods

4.1. Materials

There are two types of data used in this study, satellite images and maps.

4.1.1. Satellite Images

This research used remotely sensed data from different years (Table 4), to compare the condition before and after two eruptions (2006 and 2010). ASTER images of four different years were used: 2003, 2006, 2009 and 2012; and two Landsat images of 2011 which were processed to make one mosaic image (Table 4.1 and Figure 4.1).

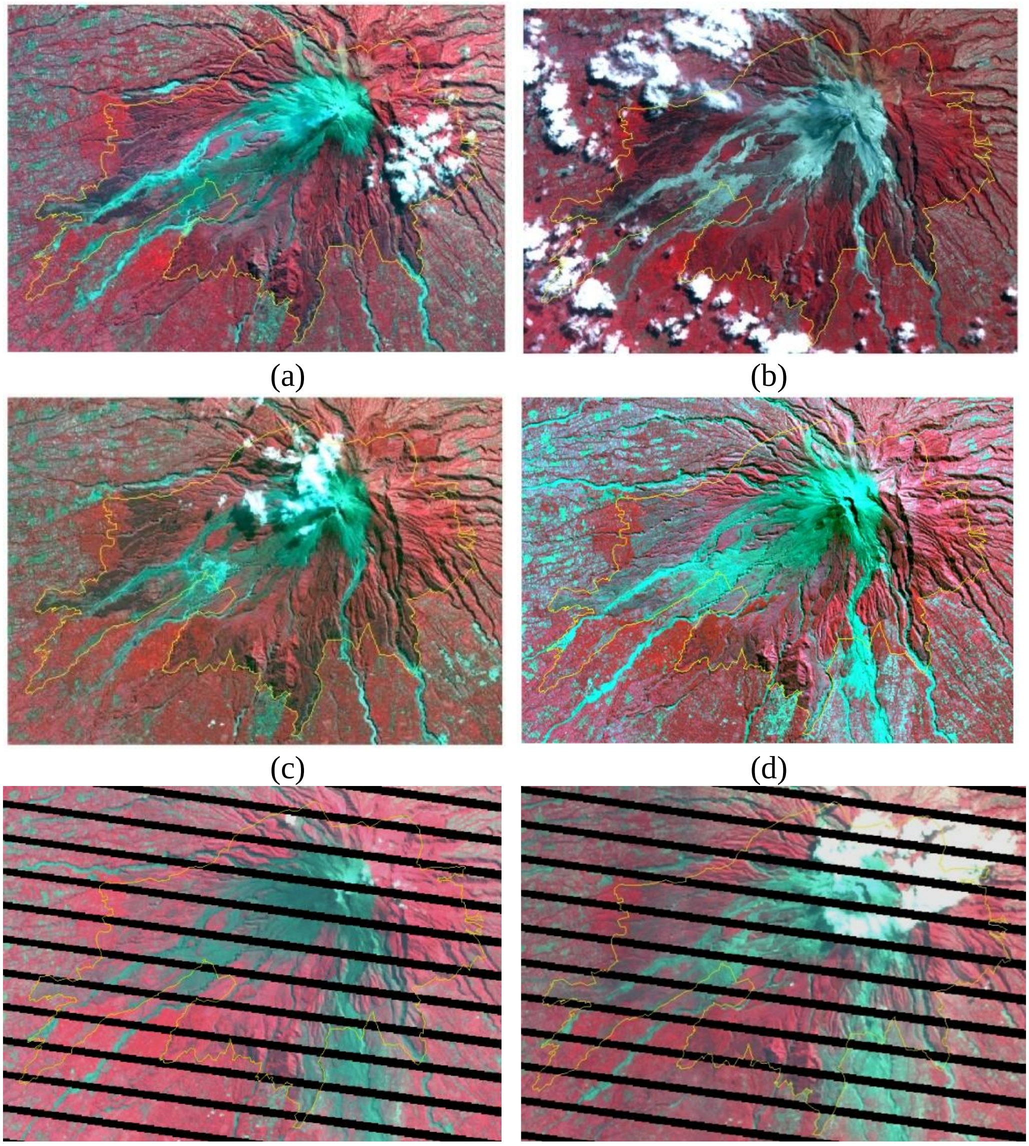
Table 4.1 Satellite Images used in the study

Year	Sensor	Acquisition Date	Note
2003	ASTER	30-06-2003	Before 2006 eruption
2006	ASTER	25-08-2006	After 2006 eruption
2009	ASTER	07-07-2009	After 2006 eruption, and before 2010 eruption
2011	Landsat ETM+	11-06-2011 10-05-2011	After 2010 eruption
2012	ASTER	13-06-2012	Recent image, after 2010 eruption

The ASTER images used were AST14OTH (registered radiance at the sensor-orthorectified). These ASTER products are terrain-corrected, provide radiometrically calibrated radiance, and are mapped to the Universal Transverse Mercator coordinate system and are resampled using cubic convolution method. These ASTER images were obtained from NASA Land Processes Distributed Active Archive Center (LP DAAC) via ITC RSG Lab.

Landsat imageries were obtained from USGS Earth Resources Observation and Science Center (USGS EROS), downloaded from USGS Global Visualization

Viewer (Glovis) web site (http://glovis.usgs.gov/). These Landsat images are processed with the Standard Terrain Correction (Level 1T), which provides systematic radiometric and geometric accuracy by incorporating ground control points while employing a Digital Elevation Model (DEM) for topographic accuracy.



(e) (f)

Figure 4.1 Satellite images used in the study
the yellow line is GMNP boundary
ASTER images recorded in: (a) 30-06-2003, (b) 25-08-2006,
(c) 07-07-2009, (d) 13-06-2012
Landsat ETM images recorded in (e) 10-05-2011 and (f) 11-06-2011

These images were selected because of the minimum cloud coverage in the GMNP areas, and also because they represent the condition before and after the eruptions. All images were recorded in the dry season therefore the seasonal variability of NDVI can be neglected.

4.1.2. Maps

Maps used in this research are listed in Table 4.2.

Table 4.2 Maps used in the study

Nr	Map	Source
1	GMNP zonation map	GMNP Bureau scale 1:25,000, Year 2012
2	Pyroclastic flow and surge map of 2006	Previous study of Gertisser et al. (2012)
3	Pyroclastic flow and surge map of 2010	Previous study of Darmawan (2012)
4	Contour map, used to generate: elevation, slope, aspect, and distance to crater maps	Bakosurtanal, contour interval 12.5 meters, Year 2000
5	Digital Topographic Map	Bakosurtanal, Scale 1:25,000 Year 2000
6	Average annual rainfall intensity map	SABO DAM Office, average annual rainfall in period of 2002-2010

The pyroclastic flows and surges maps used in this study were the results of several studies on Merapi. Since it was not possible to obtain the digital vector format of the pyroclastic flows and surges data, therefore these data was obtained by digitizing from the previously published studies.

The pyroclastic flows and surges map of 2006 (Figure 4.2) was taken from Gertisser et al. (2012), although only for the southern part of pyroclastic flows, while the south-western flows was not available. But since that part of flows was relatively small and only affecting already barren area, the absence of this data was not significant for the aim of studying vegetation regeneration. The 2010 pyroclastic flows and surges map (Figure 4.3) was taken from study by Darmawan (2012). This map was made based on a visual interpretation of

GeoEye and SPOT 5 images of year 2010 coupled by pyroclastic flow modelling and field survey.

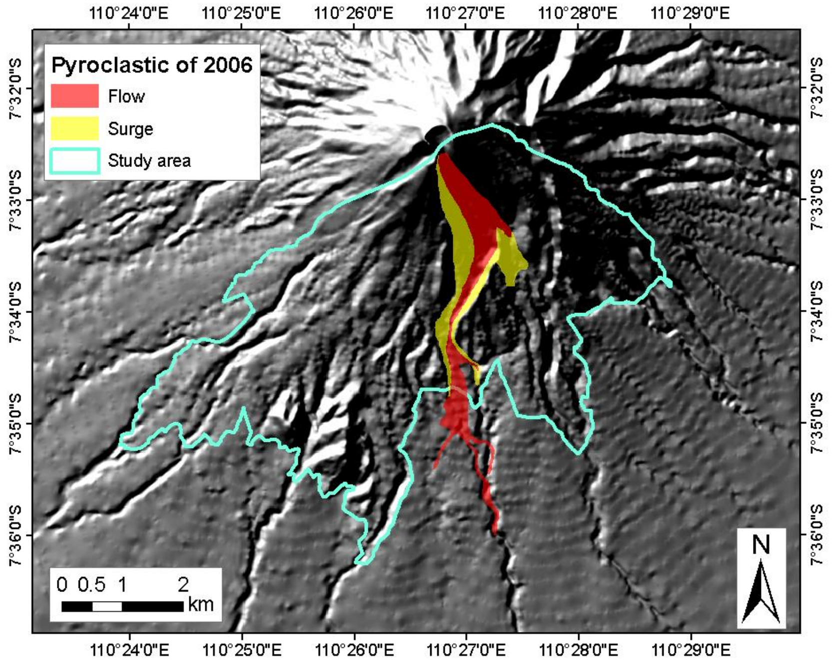


Figure 4.2 Pyroclastic flow and surge of 2006 eruption
(Source: Gertisser et al., 2012)

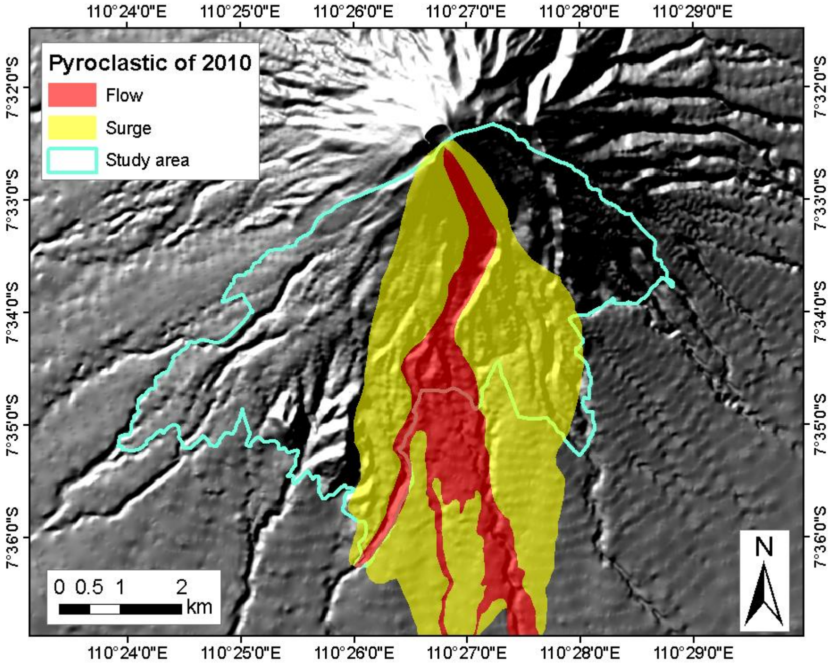


Figure 4.3 Pyroclastic flow and surge of 2010 eruption
(Source: Darmawan, 2012)

4.2. Method

This research was divided into six parts as follows:

4.2.1. Image Pre-processing

Image pre-processing is required before the image analysis. The aim of this step was to bring all images to the same comparable format. It consisted of two activities: geometric correction and radiometric corrections (Figure 4.4).

First step in pre-processing was geometric correction. It is a transformation process of image so that image has planimetric characteristic or conventional map (Jensen, 2005). The process includes determining projection and datum that were used for the images. In this research, Projected Coordinate System uses UTM, datum WGS 1984, and zone 49 S.

Although the ASTER images used (AST14OTH) were supposed to be orthorectified, there were still some differences between the ASTER imageries and the underlying GIS base layer (Indonesian Topographic Map). Therefore, all images were georeferenced to the map using ground control points. The resulting RMS errors were below 0.5 pixels.

Radiometric correction is recommended for analysis using different sensors or multi temporal data because different sensors and different recording time may give different digital value even for the same area (Khoiriah, 2012). Comparison using data from several sensors that have different spatial resolutions and or spectral bands can be very important for some application such as monitoring natural disasters (Dinguirard & Slater, 1999).

This study used multiple images from different satellite sensor. Images used come in different format, ASTER images were delivered in term of scaled radiance in DN and Landsat images were also in DN. To perform analysis of multiple sensors it is required to have the spectral data in the same unit and values.

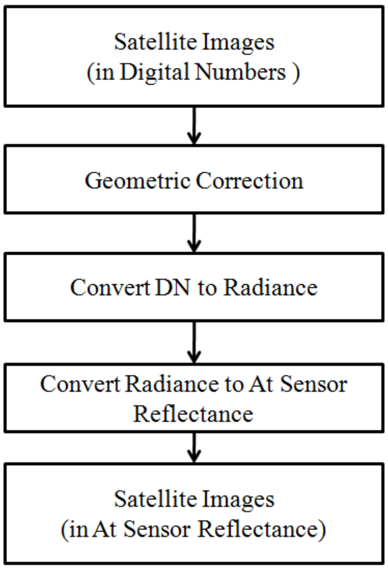


Figure 4.4 Flowchart of image pre-processing

Radiometric correction was done by converting DN into at sensor Reflectance. This step was done to convert the DN into calibrated data (at sensor reflectance) that better represent surface features within the landscapes of interest. The correction was done to allow the use of multiple images from the different sources (e.g., different dates, times of day, and sensor settings). The method can be differentiated into two parts, which are: convert the digital number to spectral radiance/at-sensor-radiance, and then from at-sensor-radiance to at-sensor-reflectance.

Radiance is precise scientific term used to describe the power density of radiation. At sensor reflectance is unitless planetary reflectance. It has the benefit of correcting for planetary variables such as the solar elevation angle and earth-sun distance.

The formulas used in converting DN to at-sensor radiance for ASTER and Landsat images were:

- For ASTER images: $L_{sat} = (DN-1) * UCC$
- For Landsat images: $L_{sat} = Gain \times DN + Bias$

Where:

L_{sat}= at-sensor spectral radiance
DN= digital number (the pixel values in the original files)
Gain = $(L_{max} - L_{min}) / 255$= slope of response function
Bias = L_{min} = intercept of response function
L_{max} = radiance measured at detector
L_{min} = lowest radiance measured by detector
UCC = Unit Conversion Coefficient for ASTER. This is different for each ASTER band, and depends on the gain setting that was used to acquire the image. Information of gain setting was obtained from the metadata files. The appropriate UCC for each band was selected from the Table 4.3

Table 4.3 Unit conversion coefficient for ASTER

Band	Coefficient (W/m2*sr*um)/DN)			
	High Gain	Normal	Low Gain 1	Low Gain 2
1	0.676	1.688	2.25	N/A
2	0.708	1.415	1.89	
3N	0.423	0.862	1.15	

Source: ASTER User Handbook, 1999

The formula used in converting radiance value to at sensor reflectance for both ASTER and Landsat images was:

$$\rho_{TOA} = \frac{(\pi * L_{sat} * d^2)}{(ESUN_\lambda * \cos(\theta_s))}$$

Where:

ρ_{TOA} = at-sensor reflectance (or top-of-atmosphere reflectance)
L_{sat} = at-sensor radiance
d = earth-sun distance (in astronomical unit)
θ_s = solar zenith angle = (90- solar elevation angle). Solar elevation angle obtained from the metadata file
$ESUN_\lambda$ = mean solar exoatmospheric spectral irradiance, this value is different for ASTER and Landsat (Table 4.4)

Table 4.4 Mean solar exoatmospheric spectral irradiance for ASTER and Landsat

ASTER Band	$ESUN_\lambda$	Landsat Band	$ESUN_\lambda$
B1	1845.99	2	1812
B2	1555.74	3	1533
B3N	1119.47	4	1039
Source: Smith 2007		Source: Landsat 7 Handbook	

Additional step was done to the Landsat images, because of the scan line corrector (SLC) failure these images contain gaps that need to be filled for further use. Process of gap filling was done using free software that is distributed by NASA (*Frame and Fill software* v 1.0) by utilizing Landsat image of 10 May 2010 as the anchor scene and Landsat image of 11 June 2010 as the filling scene. The selection of anchor scene was based on minimum cloud coverage in the study area (Figure 4.5).

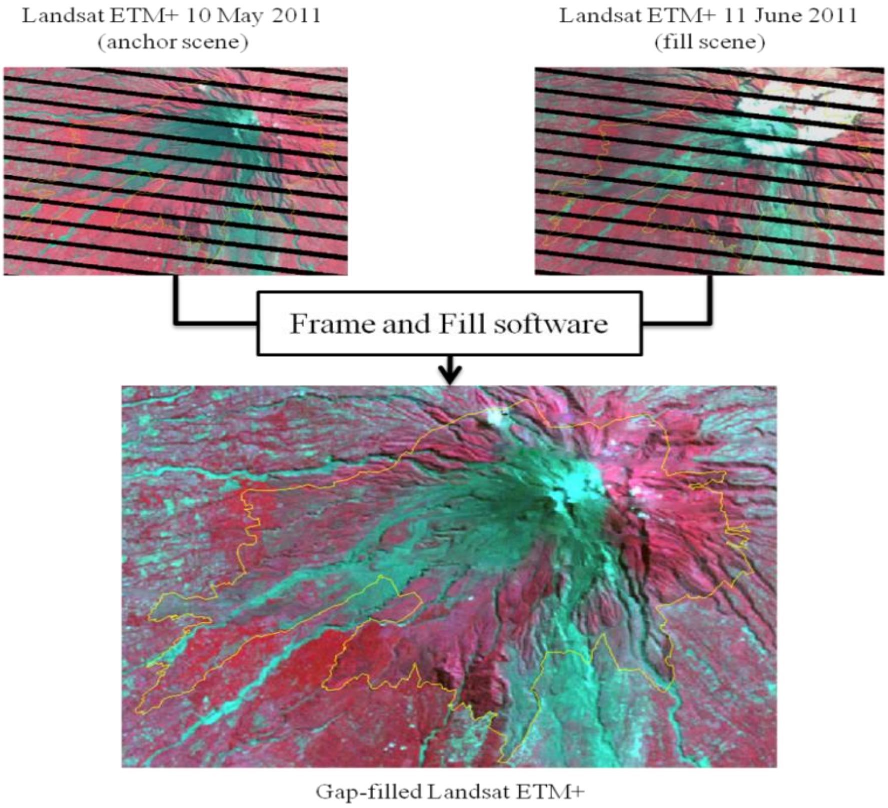


Figure 4.5 Gap-filling process of Landsat images

In summary, this study used image differencing technique. There are some prerequisites that need to be completed prior the image subtraction (Vanstraaten, 2003).

(1) All images must be geometrically aligned and overlap so that the pixels for a corresponding area will have the same geographical coordinates in all images. This issue is addressed by performing geometric correction.
(2) The areas outside the study area are masked out and also the areas that are covered by clouds and clouds shadow were masked out.
(3) All images must be radiometrically corrected to ensure they are comparable. This issue is addressed by converting all images from digital value to reflectance at sensor.

4.2.2. Field Data Collection

Field data collection was done in October-December 2012. The aim of the fieldwork was to collect information of landcover type and vegetation cover in GMNP areas. And also in relation with the use of vegetation indices as variables, the field visit was done to collect canopy cover to be tested for correlation with selected vegetation indices. Canopy cover is defined as the vertical projection of the crown area to the ground surface (Jennings, Brown, & Sheil, 1999). Canopy cover can be expressed as fraction or percent (Figure 4.6).

Figure 4.6 Example of canopy cover definition
(Source: Jennings, Brown, & Sheil, 1999)

Sampling scheme used was stratified representative sampling. Stratification was based on the GMNP zonation and volcanic hazards (flows and surges). Besides that, the plot locations were also decided to represent different NDVI values across the study area. In total there were 60 plots sampled in the field (Appendix 1 and 2). The sample plot is a rectangular plot with size of 20 m x 20 m.

This study used the change of canopy cover as indicator of vegetation regeneration. Canopy cover was collected by calculating the crown projection area of a tree by measuring the diameter from of the canopy crown in the maximum and minimum direction. The sum of crown projection area from all trees in a plot was then divided by the plot size, so the canopy cover was presented in percentage.

4.2.3. Assessment of Pyroclastic Flows and Surges Effect on Vegetation

This phase was conducted to answer the first objective. It focussed on assessing the effect of pyroclastic flows on vegetation by using time-series satellite imageries. The effect of pyroclastic flows and surge to the vegetation was monitored by creating the landcover map of study areas from satellite images in different years, to see the changes in landcover before and after eruption events, and also to see the affected landcover types and GMNP zones as the impact of pyroclastic hazards.

To see the landcover changes, landcover classification was done by visual interpretation. It is the most intuitive way to extract information from remote sensing images based on human's ability to relate colours and pattern in an image to real world features (Kerle et al., 2004). Visual interpretation was chosen considering that the condition and characteristic of the study area were relatively known.

Recognition of image objects was based on interpretation elements which are tone/hue, shape, texture, size, pattern, site, and association. Land cover types were determined based on information from field data and ancillary data. This ancillary data included results from previous studies or GMNP's project reports, and also high resolution image. The ancillary data was useful in determining land cover types in areas that were not visited during the fieldwork due to the difficulties in accessing the location and also time constraint.

Landcover classification first was done using the most recent image of 2012. The resulting landcover classification was then used as ancillary information to classify image of 2009 and 2003. The resulting landcover classes of GMNP before and after 2006 and 2010 eruption events were combined to see the changes.

Merapi eruptions were also affecting different landcover types and GMNP zones. To know what landcover types and zones affected in 2006 and 2010 eruptions, map of pyroclastic flows and surges, landcover, and zonation were combined (Figure 4.7).

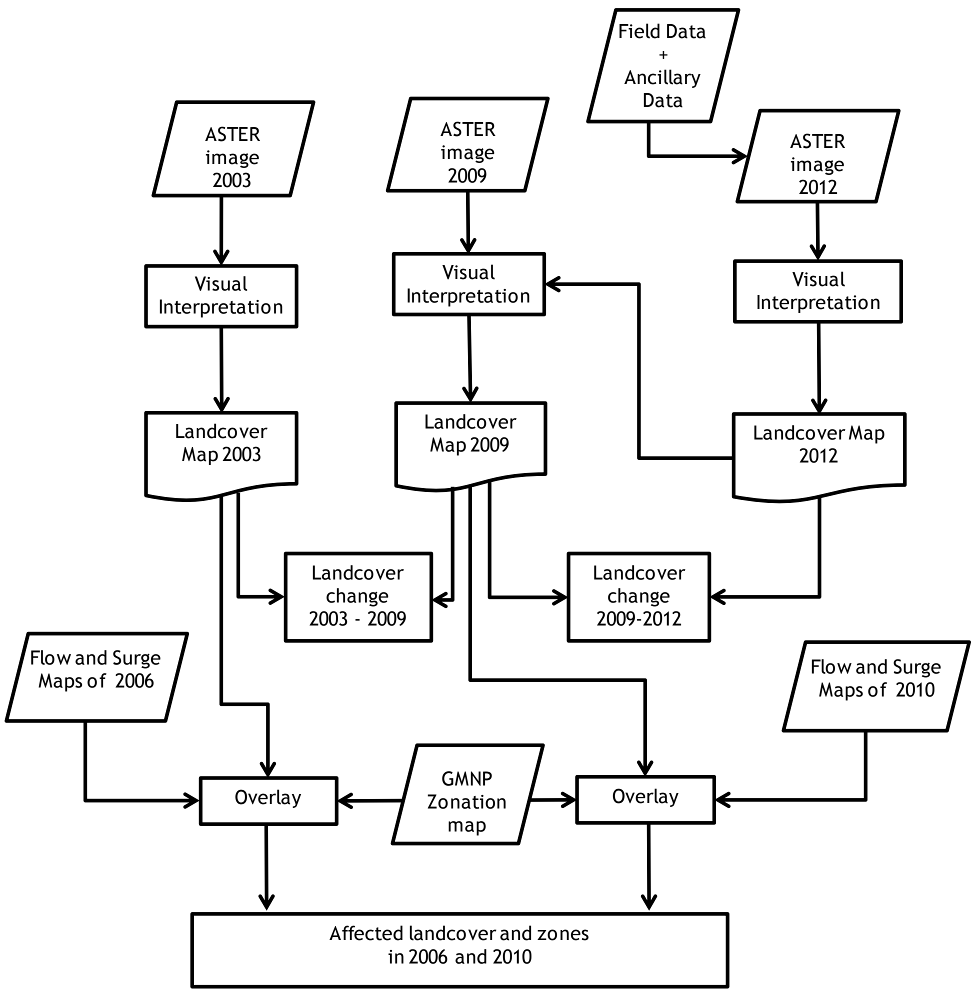


Figure 4.7 Flowchart for assessment of pyroclastic flows and surges effect on vegetation

Landcover Classes Definition

Landcover classes were developed based on the GMNP's project reports, which classified GMNP areas into seven landcover classes: mixed forest, pine forest, damaged pine forest, shrub, grass, barren land and farmlands. But the pine forest, damaged pine forest, and farmland area are located outside the study area. Therefore there are only four landcover classes in the study area. The definitions of each landcover class are:

Mixed forest: This class is the secondary forest in GMNP areas (Figure 4.8). According to the GMNP report, this forest is composed by some species: pine (*Pinus merkusii*), *Schima wallichii, Erythrina lithosperma* and acacia *(Acacia decurens).* Before established as national park, part of GMNP was used as production forest owned by Perhutani (a state-owned forestry company). The pine and acacia were planted in the GMNP so they are not the native species (GMNP, 2011)

Figure 4.8 Mixed Forest in study area

Shrub: This is the area which is covered with woody vegetation generally with low height (about 6 meters). In the study area, there were areas affected in 2010 eruption by pyroclastic surges but have been re-vegetated, dominated by *Acacia decurrens* species (Figure 4.9). In this study, these areas were also classified as shrub.

Figure 4.9 Shrub in study area

Grass: this class is areas that dominantly covered by grass or herbaceous (Figure 4.10). Type of dominant grass in GMNP is *Brachiaria mutica* (GMNP, 2011) which is used by the local people as forage.

Figure 4.10 Grass in study area

Bareland: this is area which is not covered by vegetation. It consisted of barren area surrounding the crater and other non vegetated areas including gullies (Figure 4.11)

Figure 4.11 Bareland in study area

4.2.4. Relationship between Vegetation Indices and Canopy Cover

In this study four vegetation indices (RVI, NDVI, SAVI and $MSAVI_2$) were selected to be evaluated for their relationship with canopy cover. The formula of each vegetation index is given in Table 4.5.

Table 4.5 Formula of vegetation indices used in this study

Vegetation Index	Formula
Ratio Vegetation Index	$RVI = \frac{\rho NIR}{\rho Red}$
Normalized Difference Vegetation Index	$NDVI = \frac{(\rho NIR - \rho Red)}{(\rho NIR + \rho Red)}$
Soil-Adjusted Vegetation Index	$SAVI = 1.5 \times \frac{(\rho NIR - \rho Red)}{(\rho NIR + \rho Red + 0.5)}$
Modified Soil-Adjusted Vegetation Index 2 ($MSAVI_2$)	$MSAVI2 = \frac{(2 \times \rho NIR) + 1 - \sqrt{(2 \times \rho NIR + 1)^2 - 8 \times (\rho NIR - \rho Red)}}{2}$

ρ_{Red} *: reflectance values of Red spectrum*
ρ_{NIR} *: reflectance values of Near Infrared spectrum.*

Vegetation indices transformations were performed to all images which already converted into reflectance at sensor (Figure 4.12). The relationship was developed is based on the deterministic mathematical model or statistics models based on correlation analysis. Simple regression was used to examine the relationship between canopy cover and vegetation indices. Regression model used were linear and non linear including quadratic, polynomial, power and exponential (Veraverbeke et al., 2012; Lawrence & Ripple, 1999).

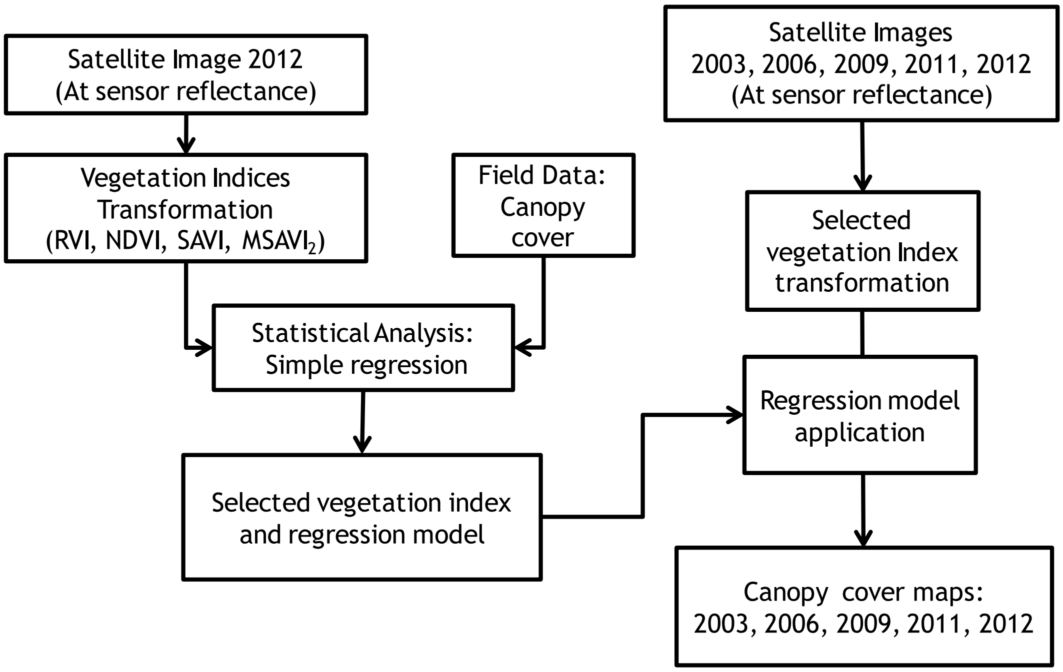


Figure 4.12 Flowchart for selection of vegetation index

Some plots have canopy cover of 0%, therefore to avoid infinite values in power and exponential regression model, a small value 0.001 was added to canopy cover data. So for sample plots with no vegetation the value of 0.001 was used (Lawrence & Ripple, 1999).

The coefficients of determination (R^2) of regression models were used as indicator to select the best relationship (Veraverbeke et al., 2012; Lawrence & Ripple, 1999). The coefficient of determination is an estimate of the proportion of the total variation in the data that is explained by the model.

This study used satellite images from different sensors (ASTER and Landsat ETM+). Some studies reported that there are some differences between vegetation indices (i.e. NDVI) between ASTER and ETM+ data. In general, the Landsat ETM+ has higher NDVI value for the same land surface compared to ASTER (Xu & Zhang, 2010). To address this issue, an additional step was taken to do intercalibration between Landsat NDVI and ASTER NDVI using formula created by Steven, Malthus, & Baret (2007).

$$NDVI\ ETM_{Adjusted} = -\ 0.002 \times NDVI\ ETM + 1.971$$

Where:

NDVI ETM adj : Adjusted Landsat ETM NDVI (intercalibrated)
NDVI ETM : Landsat ETM NDVI

4.2.5. Comparison of Vegetation Regeneration in Different Landcover Types and Zones

Many studies of vegetation regeneration after forest fires use changes of vegetation index (mostly NDVI) as indicator of regeneration. They used vegetation indices from different time to assess the change in vegetation cover by using image differencing technique. The positive value of vegetation index difference was then used as indicator of the increase of vegetation cover or regeneration.

In this study, regeneration was assessed using difference in canopy cover as indicator. Areas which have not regenerate would have values close to zero while areas that have changed will have positive or negative values based on the direction of change.

After masked from clouds, canopy cover map from different years after 2006 and 2010 eruptions (canopy cover of 2006, 2009, 2011, and 2012) were subtracted from each other and the resulting images give the amount of canopy cover changes after eruption. Using image differencing technique, new variables (canopy cover change) were created as indicator for vegetation regeneration after eruption, namely:

$$\Delta CC09\text{-}06 = \text{canopy cover 2009} - \text{canopy cover 2006}$$

$$\Delta CC12\text{-}11 = \text{canopy cover 2012} - \text{canopy cover 2011}$$

To compare the vegetation regeneration in different landcover types and different zones, statistical analysis was performed. Analysis of variance (ANOVA) was used to evaluate differences in canopy cover change between different landcover types and different zonations. Post hoc analysis was performed using Tukey-Kramer's multiple comparison procedure to determine differences at the different landcover types and different zones (Casady & Marsh, 2010).

ANOVA procedure is based on the assumption of independence of observations. In spatial analysis study, one method to eliminate spatial dependency is by using a random sampling technique to derive response variables (Orgil, 2007). In this study, 2000 sample points were randomly generated for modelling using "Create Random Points" tool in ArcGIS software (Appendix 3). The random points were then used to extract response variables (ΔCC09-06 and ΔCC12-11), and also the attribute of landcover type, zonation and pyroclastic hazards in all random points using "Extract Values to Points" tool in ArcGIS.

The main objective of the study was to assess the vegetation regeneration, therefore random points were limited only in areas that have positive canopy cover changes, and cloud covered areas were also excluded. Consequently the samples number was reduced to 1764. These point data were then imported to SPSS software for statistical analysis. The flowchart of this step is presented in Figure 4.13.

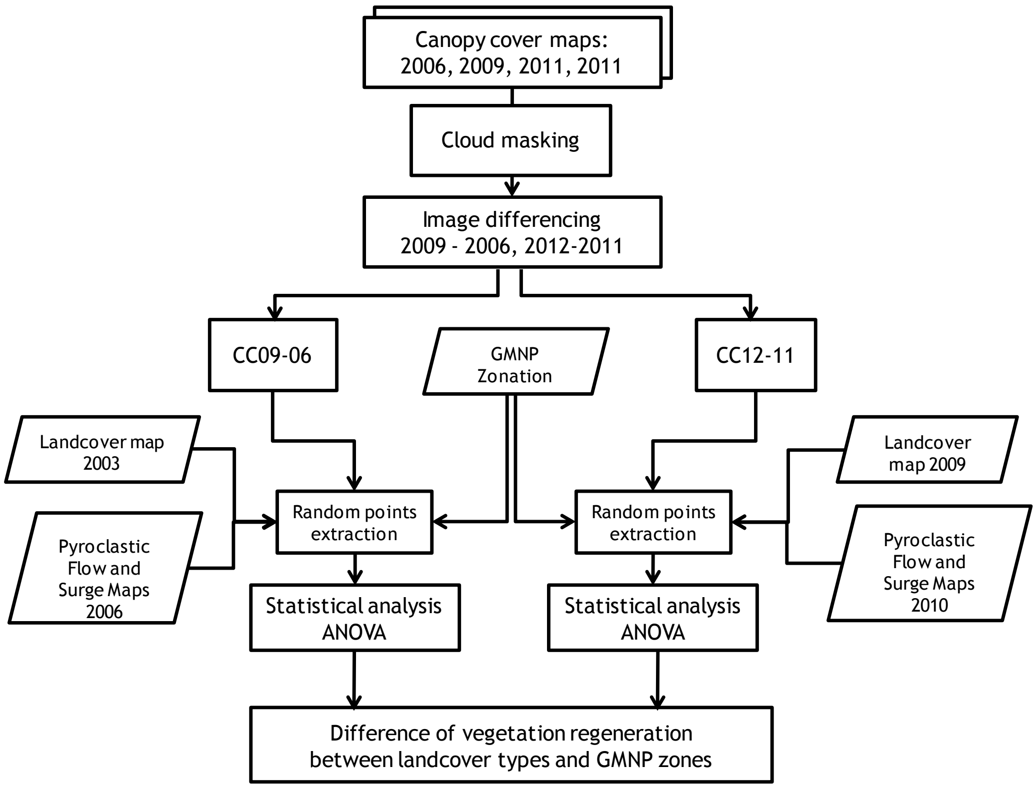


Figure 4.13 Flowchart for assessment vegetation regeneration

4.2.6. Determination of Influencing Factors to Vegetation Regeneration

Influencing factors for vegetation response were examined. As suggested by Lawrence (2005) these factors can be differentiated into three broad categories: (1) direct effect of eruption, such as distance from crater, (2) physical forces such as slope, and (3) other habitat conditions such as elevation, aspect and rainfall.

To evaluate the relationships between the environmental factors and the vegetation regeneration multiple linear regression was used. A stepwise evaluation procedure was used. It started with an empty model then variables were added to the model if they were significant at $\alpha = 0.05$, and removed from the model if their contribution to the model was not significant at $\alpha = 0.1$ (Casady & Marsh, 2010). The abovementioned random points were used to extract response variables (ΔCC09-06 and ΔCC12-11), and the predictor variables (distance from crater, elevation, slope, aspect, and rainfall).

The analysis of influencing factor to vegetation was conducted using the random point extraction. Attributes of these point data were then imported to SPSS software for statistical analysis. Steps are presented in Figure 4.14.

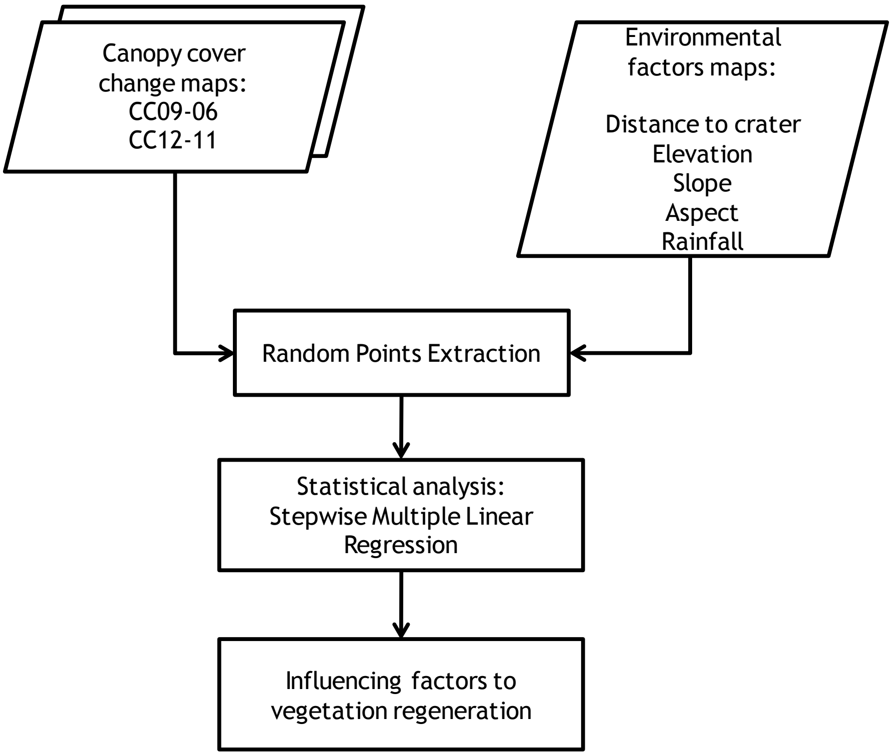


Figure 4.14 Flowchart for determining influencing factors

5. Results and Discussion

5.1. Assessment of Pyroclastic Flows and Surges Effect on Vegetation

5.1.1. Landcover Classification

Landcover types in study area were classified into four classes: mixed forest, shrub, grass, and bareland. The results of classification from 2003, 2009 and 2012 images are presented in Table 5.1 and Figure 5.1, 5.2, and 5.3.

Table 5.1 Landcover classes in 2003, 2009, and 2012

	2003		**2009**		**2012**	
LC	**Hectares**	**%**	**Hectares**	**%**	**Hectares**	**%**
Bareland	485.87	17.14	563.90	19.89	670.16	23.62
Grass	67.91	2.40	77.45	2.73	176.47	6.22
Mixed Forest	1959.98	69.13	1852.11	65.33	1086.08	38.33
Shrub	321.35	11.33	341.64	12.05	902.39	31.83
Sum	2835.09	100.00	2835.09	100.00	2835.09	100.00

In general it can be seen that there was a large decline in mixed forest in GMNP area and increase other landcover types. The decrease of mixed forest area in period 2009-2012 was much larger than the decrease in period 2003-2009. Conversely, there was a large increase of shrub area in 2009-2012, which was much larger than the increase in 2003-2009. Bareland and grass classes also showed similar trends, there were larger increases in period 2009-2012 compared to period 2003-2009.

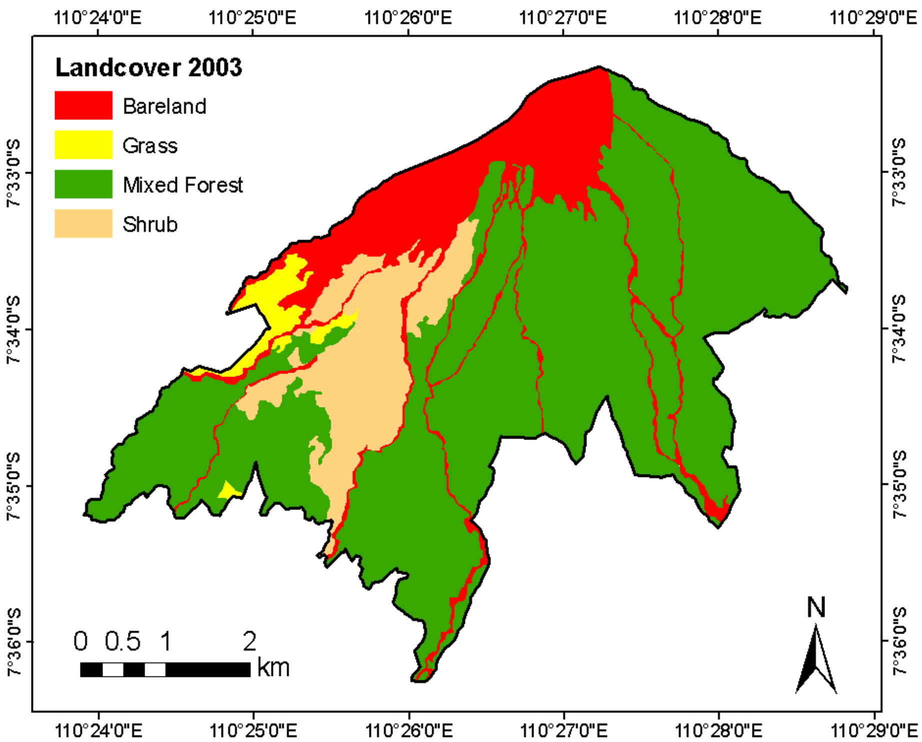


Figure 5.1 Landcover classification of 2003

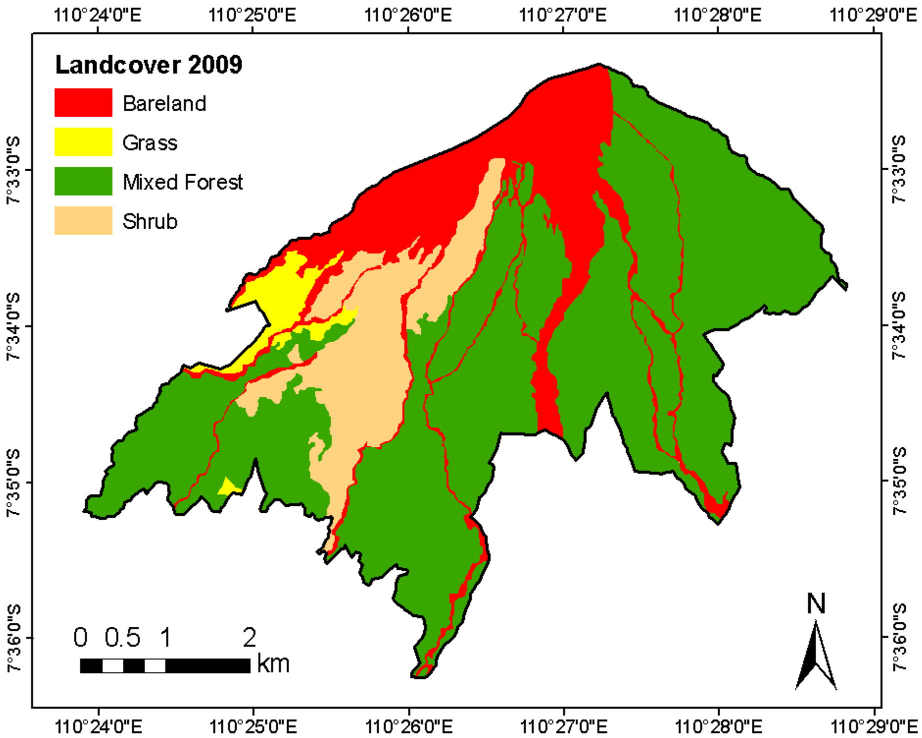


Figure 5.2 Landcover classification of 2009

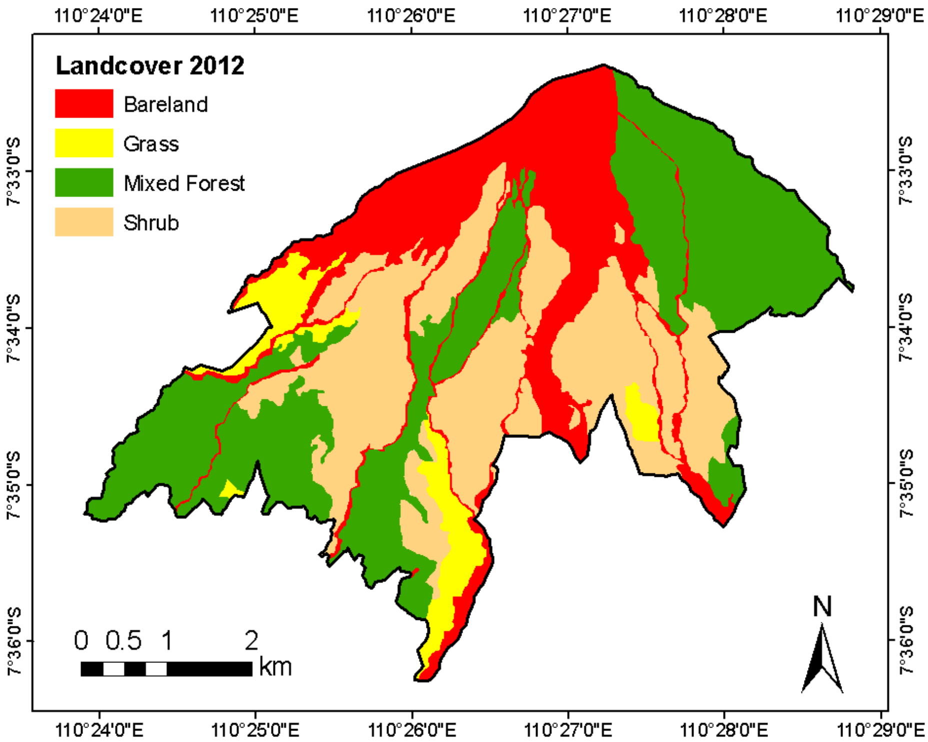


Figure 5.3 Landcover classification of 2012

5.1.2. Landcover Types Affected by Pyroclastic Flows and Surge

Merapi eruptions in 2006 and 2010 have caused landcover changes due to the pyroclastic flows and surges. The most affected landcover types in 2006 and 2010 eruptions were mixed forest, as presented in Table 5.2.

Table 5.2 Landcover types affected in 2006 and 2010 eruptions

Landcover	Pyroclastic 2006			Proclastic 2010		
	Not Affected (ha)	Flow (ha)	Surge (ha)	Not Affected (ha)	Flow (ha)	Surge (ha)
Bareland	416.29	49.348	19.461	284	119.58	159.38
Grass	65.509	-	-	77.26	-	-
Mixed Forest	1801.7	64.233	97.5	942.26	134.28	776.87
Shrub	321.24	-	-	304.04	-	37.63
Total	2604.8	113.58	116.96	1607.55	253.87	973.87

Areas affected in 2006 eruption were 230.54 ha, or only 8% of the total study area (Table 5.2, Figure 5.4). The size of areas affected by pyroclastic flows and surge were approximately the same size. Landcover types affected by pyroclastic flows and surges were bareland and mixed forest, while grass and shrub were not affected. Area of mixed forest that was affected by pyroclastic surge was larger than that was affected by flow.

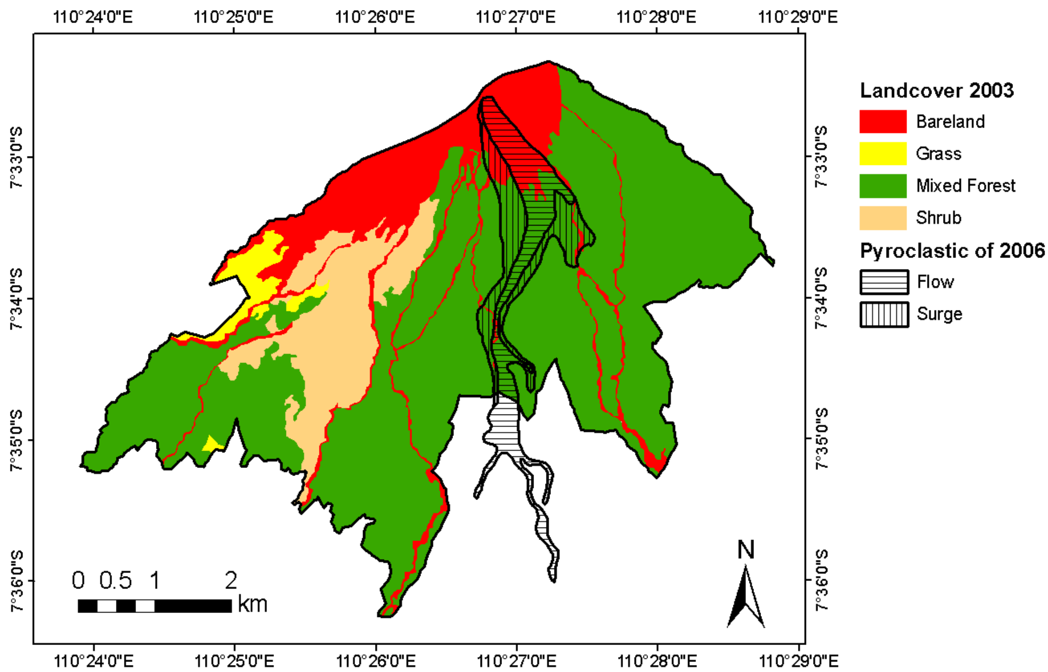


Figure 5.4 Landcover types affected in 2006 eruptions

Meanwhile the 2010 eruption affected much larger area than 2006 (Figure 5.5). About 43% of study area was affected in 2010 eruption. Areas affected by pyroclastic flows and surge were 253.87 ha and 973.87 ha respectively. The areas affected by pyroclastic surges were much larger than that affected by flows. The flow affected bareland and mixed forest, while the surges affected bareland, mixed forest and shrub.

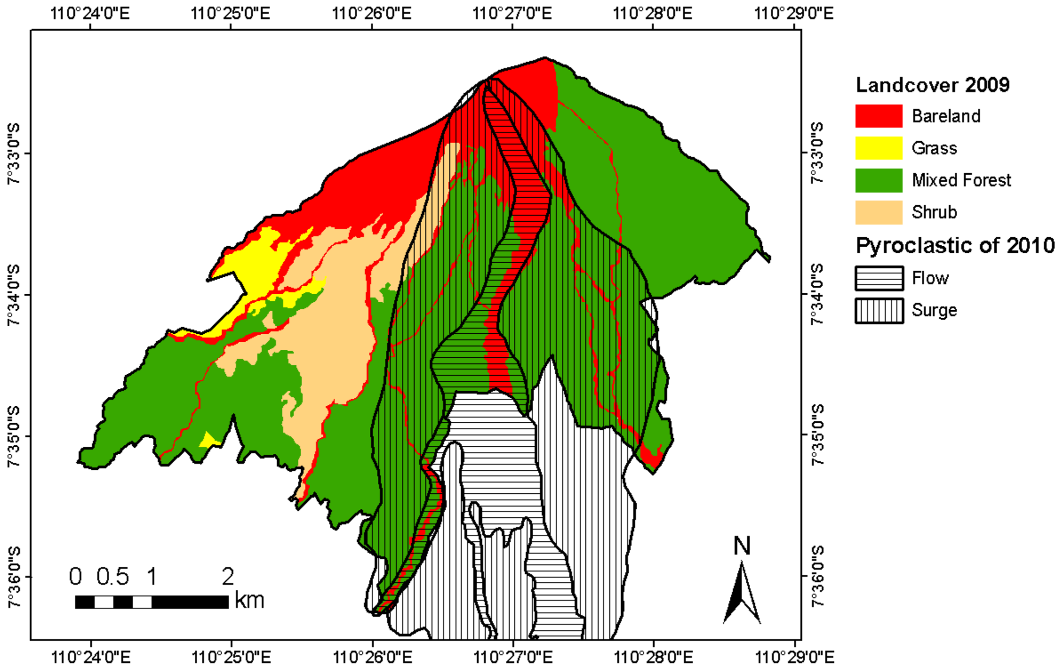


Figure 5.5 Landcover types affected in 2010 eruptions

5.1.3. Landcover Changes after the Eruptions

Further analysis was done to know the distribution of landcover changes in 2003-2009 and 2009-2012.

Table 5.3 Landcover change in 2003 - 2009

LC 2003	LC 2009				Sum
	Bareland	**Grass**	**Mixed Forest**	**Shrub**	
Bareland	476.21	9.63	0.01	0.01	485.86
Grass	0.00	65.75	0.00	0.00	65.75
Mixed Forest	86.85	0.00	1852.11	23.18	1962.14
Shrub	0.83	2.07	0.00	318.44	321.34
Sum	563.89	77.45	1852.12	341.63	2835.09

In period 2003-2009, the largest landcover decrease occurred in mixed forest, 86 ha and 23 ha of this class were changed into bareland and shrub respectively (Table 5.3). Meanwhile in the other landcover types there were only small changes. The distribution of these changes is given in Figure 5.6.

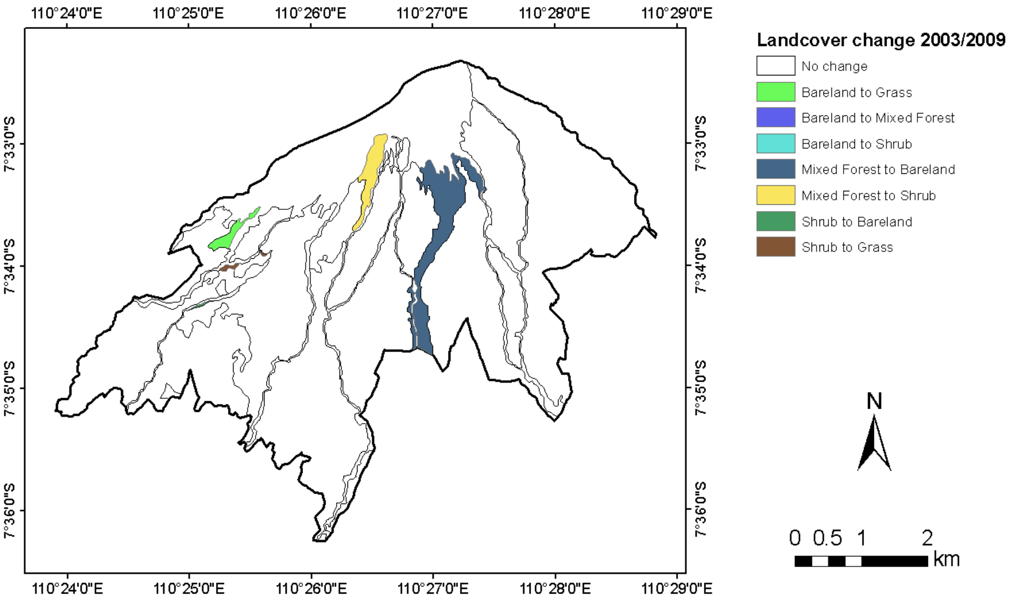


Figure 5.6 Landcover change in period 2003-2009

Largest landcover changes in period 2009-2012 were also occurred in mixed forest class (Table 5.4). About 765 ha of mixed forest were changed into bareland, grass and shrub. These changes also occurred in areas affected by pyroclastic flows and surges (Figure 5.7)

Table 5.4 Landcover change in 2009 - 2012

LC 2009	LC 2012				Sum
	Bareland	**Grass**	**Mixed Forest**	**Shrub**	
Bareland	563.06	0.00	0.06	0.77	563.89
Grass	0.00	77.45	0.00	0.00	77.45
Mixed Forest	105.41	99.02	1086.08	561.60	1852.11
Shrub	1.69	0.00	0.00	339.95	341.64
Sum	670.16	176.47	1086.14	902.32	2835.09

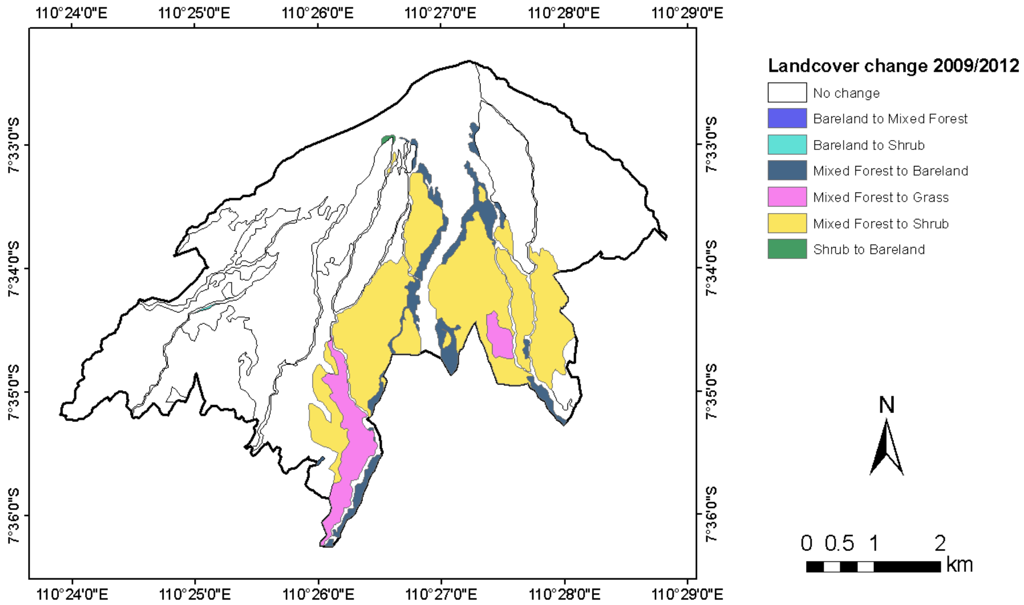


Figure 5.7 Landcover change in period 2009-2012

5.1.4. GMNP Zones Affected by Pyroclastic Flows and Surges

As presented in Table 5.5, GMNP zones affected in the 2006 and 2010 eruptions were different.

Table 5.5 GMNP zones affected in 2006 and 2010 eruptions

GMNP Zones	Pyroclastic 2006			Pyroclastic 2010		
	Not Affected	Flow	Surge	Not Affected	Flow	Surge
	area (ha)	(ha)	(ha)	(ha)	(ha)	(ha)
Sanctuary	483.40	89.28	55.50	339.94	98.38	189.85
Intensive Use	80.80	-	-	77.59		3.21
Mitigation	192.81	19.61	17.77	26.07	79.94	124.18
Rehabilitation	262.72	-	-	86.86	40.75	135.11
Religious and Cultural	8.02	-	-		7.99	0.02
Wilderness	1319.83	4.69	41.93	893.40	18.49	454.55
Traditional	254.82	-	1.76	181.33	8.31	66.95
Total	2602.38	113.57	116.96	1605.18	253.87	973.87

Merapi eruption in 2006 affected only four zones, namely sanctuary, mitigation, wilderness and traditional zone (Figure 5.8). The most affected zone in 2006 eruption was sanctuary. 144.78 ha or about 23% area of this zone were affected. It was also the most affected by pyroclastic flows and surges. This was because the areas surrounding the Merapi crater are designated as sanctuary zone. The areas of wilderness zone affected by pyroclastic surge and flows were 46.62 ha, but it was only 3% of its total area.

Meanwhile, the eruption in 2010 affected all zones (Figure 5.9). Sanctuary zone had the largest areas affected by pyroclastic flows, and wilderness zone had the largest areas affected by pyroclastic surges. Religious and cultural zone was 100% affected by pyroclastic flows and surges. However, this zone is the smallest zone in GMNP and it is intended to accommodate cultural and religious activity of the people living in the surrounding of Merapi.

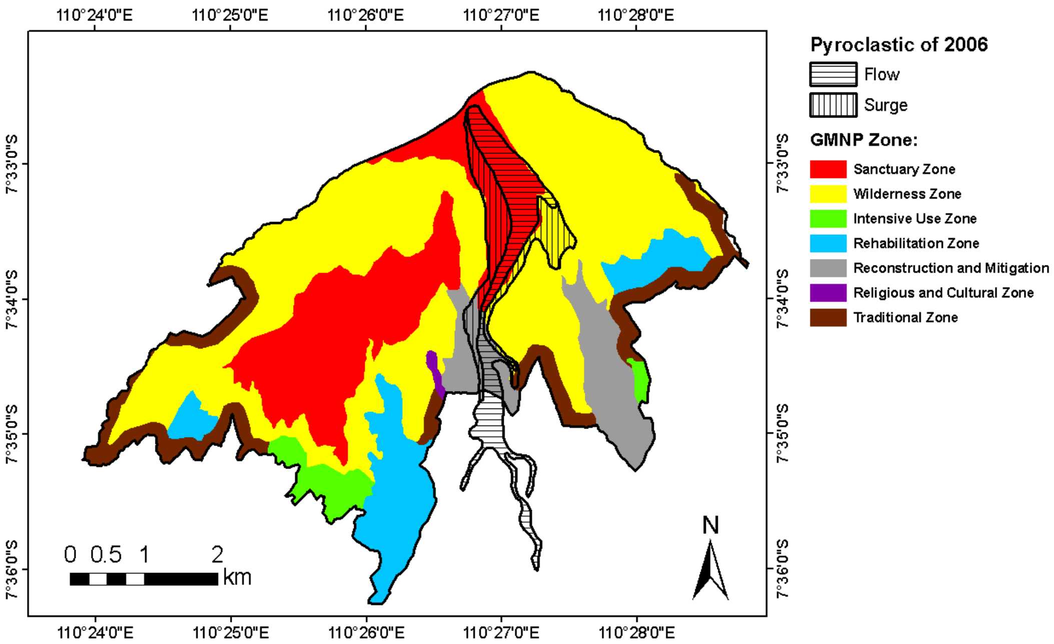


Figure 5.8 GMNP zones affected in 2006 eruption

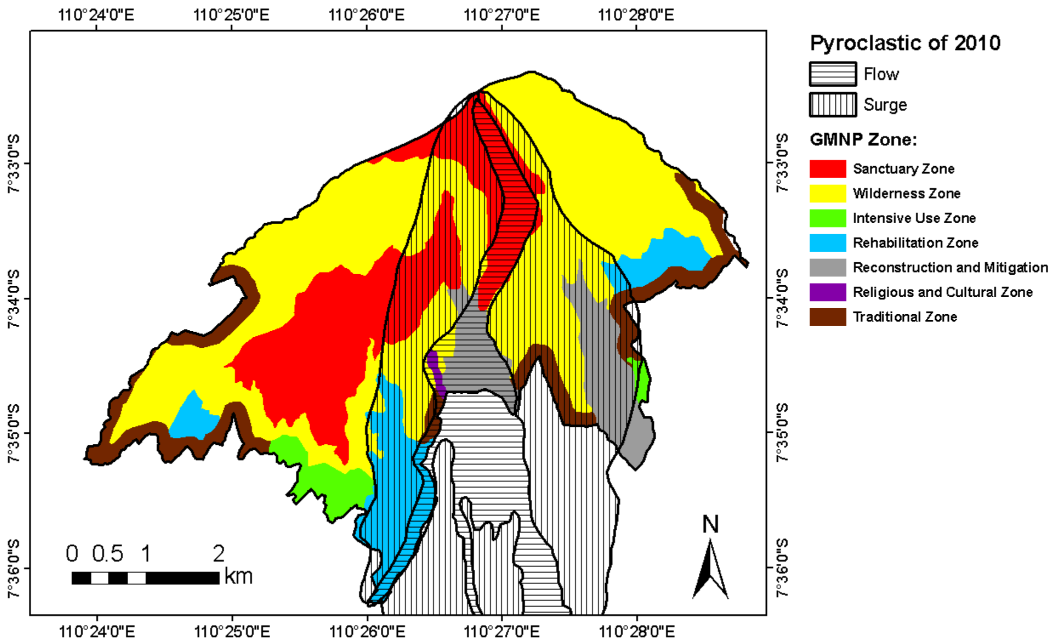


Figure 5.9 GMNP zones affected in 2010 eruption

5.2. Relationship between Vegetation Indices and Canopy Cover

5.2.1. Simple Regression Results

Results of the simple regression between selected vegetation indices and canopy cover is given in the Table 5.6 and Appendix 4. It shows the equation and the coefficient of determination (R^2) of selected vegetation indices. These results showed that there is positive relationship between vegetation indices and canopy cover.

In general ratio-based indices (NDVI, RVI) gave higher R^2 value than soil-adjusted indices (SAVI, $MSAVI_2$). The best fit model was NDVI with power regression model which have the highest R^2 value of 0.704. It means about 70% of the variance in canopy cover was explained by this model. Although the rationale of proposing soil-adjusted indices are to reduce the error of NDVI, but the results showed differently. NDVI showed higher R^2 value in all regression models than other indices.

Table 5.6 Regression model of selected vegetation indices

Vegetation Index	Regression Model	Equation	R^2
NDVI	Linear	$y = 109.0x - 27.66$	$R^2 = 0.302$
	Polynomial	$y = 158.8x^2 - 43.48x + 1.847$	$R^2 = 0.329$
	Exponential	$y = 0.000103e^{18.58x}$	$R^2 = 0.697$
	Power	$y = 548.4x^{7.309}$	$R^2 = 0.704$
RVI	Linear	$y = 9.601x - 6.808$	$R^2 = 0.311$
	Polynomial	$y = -1.035x^2 + 19.59x - 28.35$	$R^2 = 0.328$
	Exponential	$y = 0.020e^{1.294x}$	$R^2 = 0.449$
	Power	$y = 0.001x^{6.148}$	$R^2 = 0.632$
SAVI	Linear	$y = 123.3x - 2.768$	$R^2 = 0.266$
	Polynomial	$y = -210.7x^2 + 259.9x - 21.88$	$R^2 = 0.284$
	Exponential	$y = 0.020e^{18.1x}$	$R^2 = 0.455$
	Power	$y = 4649.x^{5.268}$	$R^2 = 0.615$
$MSAVI_2$	Linear	$y = 109.4x + 4.701$	$R^2 = 0.248$
	Polynomial	$y = -275.9x^2 + 286.1x - 19.36$	$R^2 = 0.286$
	Exponential	$y = 0.077e^{15.44x}$	$R^2 = 0.392$
	Power	$y = 3095.x^{4.541}$	$R^2 = 0.588$

y : canopy cover (in percent)
x: selected vegetation indices

The results showed in general non linear relationship, especially power regression models, performed better in explaining variance of canopy cover than linear and polynomial models. These results confirmed that vegetation indices have certain point of saturations in explaining ecological properties such as canopy cover (Kerr & Ostrovsky, 2003).

5.2.2. NDVI Transformation and Canopy Cover Maps

Based on regression results, NDVI was selected as vegetation index used in studying vegetation regeneration. Therefore all imageries were transformed into NDVI (Figure 5.10). The power regression equation of NDVI was applied to all NDVI images to produce canopy cover maps from all years (Figure 5.11).

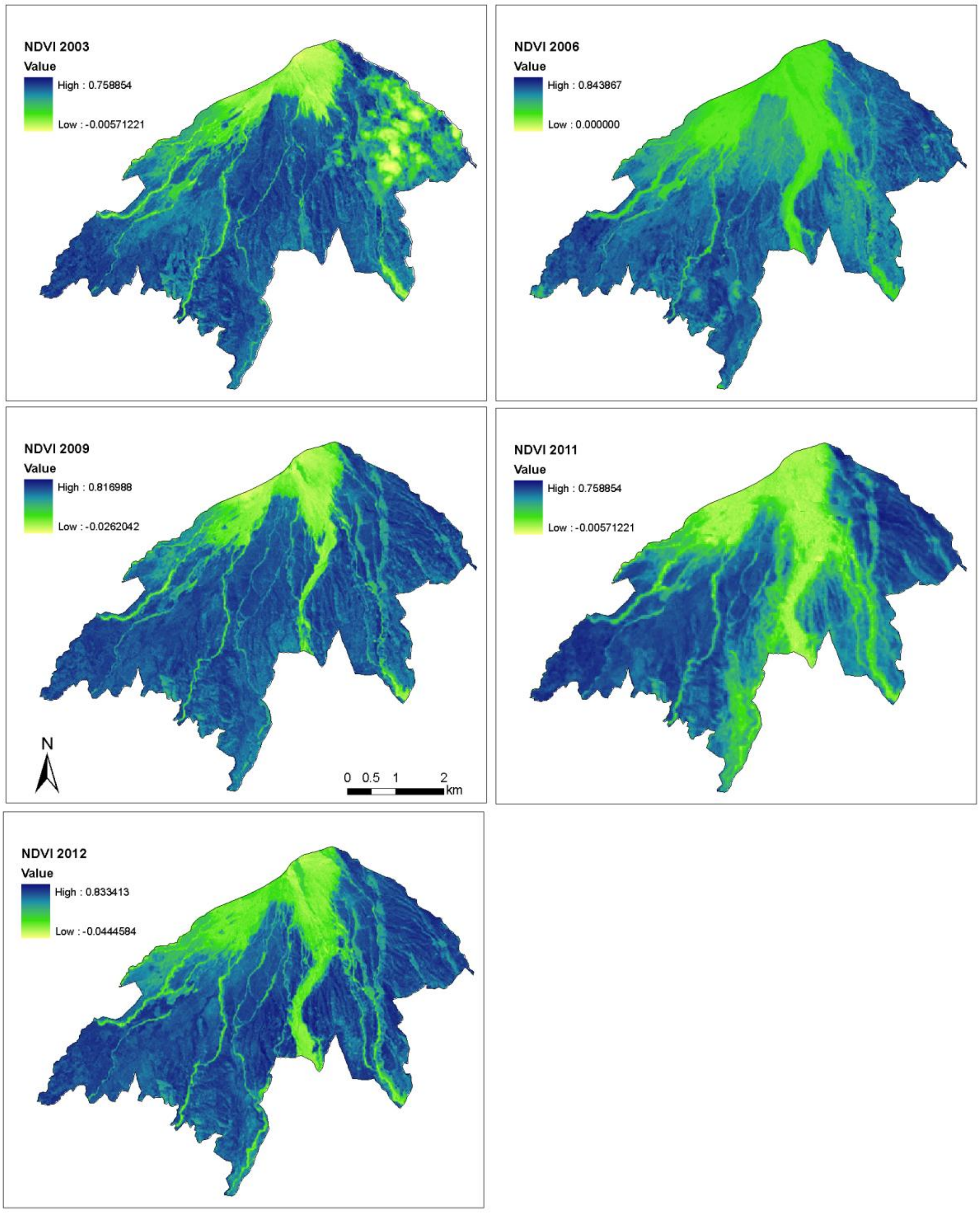


Figure 5.10 NDVI images of study area

From Figure 5.10 it can be seen that there were changes of NDVI in areas affected by 2006 and 2010 eruptions. NDVI images after eruptions (NDVI 2006 and 2011) showed decreases in NDVI value, in areas affected by pyroclastic flows and surges. However in the following images after eruptions (NDVI 2009 and 2012), those affected areas showed increases of NDVI values in the areas affected by pyroclastic surges. Although the NDVI values in areas affected by pyroclastic flows remained low. These findings suggested that there was more rapid vegetation regeneration in pyroclastic surges areas compared to the flows areas.

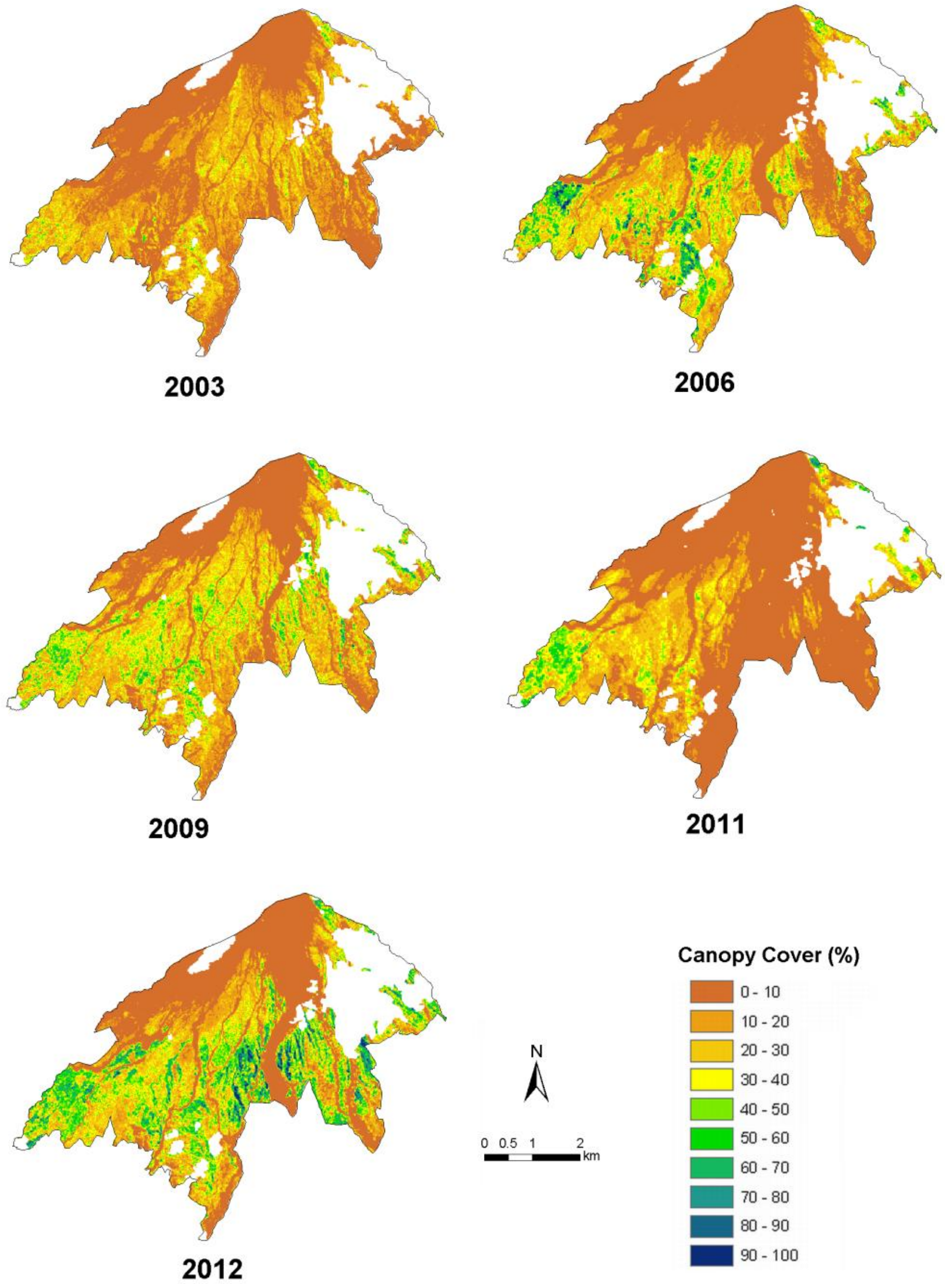


Figure 5.11 Canopy cover map of study area
(clouds are masked out)

The canopy cover maps from 2003 – 2012 also showed changes of canopy cover in the study area, especially in the areas affected in 2006 and 2010 eruptions. As presented in Figure 5.12 and Appendix 5, that area of canopy cover 0-10 % showed fluctuating trend. In 2006 and 2011 (after eruptions), areas of this class was relatively high, but in the following years (2009 and 2012), areas of this class decreased. Areas showing increases in canopy cover were located in affected areas (Figure 5.11).

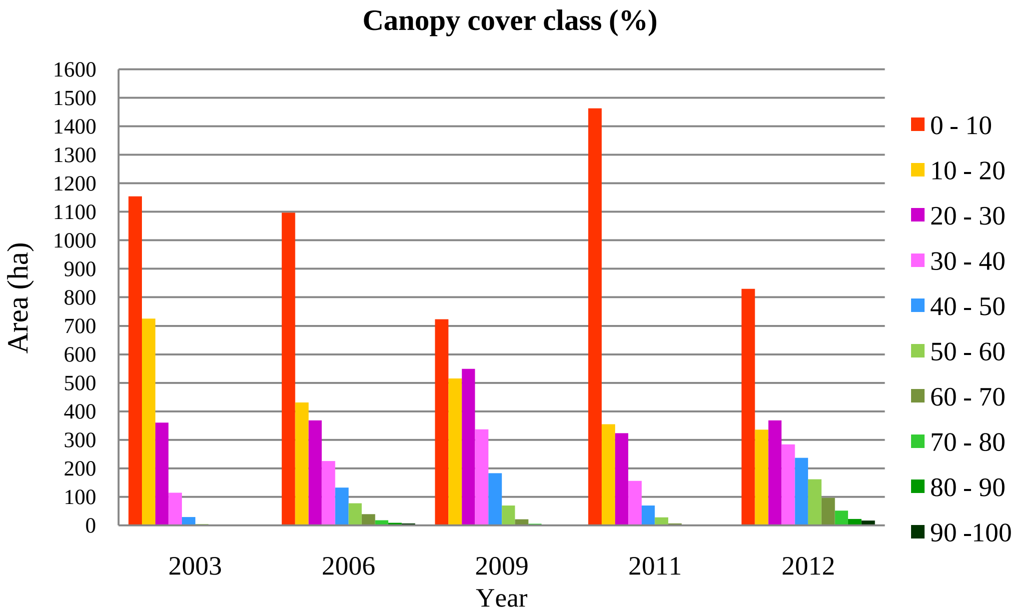


Figure 5.12 Canopy cover class of 2003 – 2012

5.3. Comparison of Vegetation Regeneration in Different Landcover Types and Zones

5.3.1. After 2006 Eruption

In Different Landcover Types

ANOVA analysis was done to compare mean of canopy cover change (CC) as indicator of vegetation regeneration. After 2006 eruption, there were differences of vegetation regeneration in different landcover types. As showed in Table 5.7 that the average value of regeneration were different across landcover types. It showed that the regeneration in mixed forest and shrubs were higher than regeneration in bareland and grass.

Table 5.7 Descriptive statistics of CC09-06 in different landcover types

Landcover	N	Mean	Std. Dev	Min	Max
Bareland	87	7.63	5.99	0.02	30.57
Grass	40	6.42	4.45	1.26	18.73
Mixed Forest	1307	15.10	10.86	0.01	68.06
Shrub	330	15.43	8.73	1.05	53.65

Results of the ANOVA analysis showed that there was significant difference between landcover types with $p<0.05$ (Table 5.8). Post-hoc test confirmed that there were significant differences between four pair of landcover types (Table 5.9). Meanwhile the differences between grass and bareland and mixed forest and shrub was not significantly different ($p>0.05$)

Table 5.8 ANOVA result of CC09-06 in different landcover types

Source	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	7462.242	3	2487.414	23.923	.000
Within Groups	182999.648	1760	103.977		
Total	190461.890	1763			

Table 5.9 Post-hoc test of regeneration in different landcover types

Landcover	Bareland	Grass	MixedForest
Grass	.924		
Mixed Forest	**.000**	**.000**	
Shrub	**.000**	**.000**	.954

In Different GMNP Zones

ANOVA analysis was done also to compare mean of canopy cover change in different GMNP zones. Results showed that the average value of regeneration within zones were statistically different (Table 5.10). After 2006 eruption, the regeneration in sanctuary zone and wilderness zone were higher than other zones. Because these zones were affected in 2006 eruption showing that vegetation regenerations in affected zones were similar and were higher than non affected zones.

Table 5.10 Descriptive statistics of CC09-06 in different GMNP zones

Zone	N	Mean	Std. Dev	Min	Max
Sanctuary	428	15.25	9.63	0.01	44.15
Utilization	22	6.64	4.94	1.05	21.15
Rehabilitation	83	13.15	11.31	1.16	45.81
Mitigation	174	12.87	10.09	0.01	53.44
Religious and Culture	10	6.81	5.29	1.41	15.73
Wilderness	929	15.41	10.74	1.06	68.06
Traditional	118	11.58	9.40	1.07	43.79

Results of the ANOVA analysis showed that there was significant difference between zones with $p < 0.05$ (Table 5.11). Post-hoc test confirmed that there were significant differences of vegetation regeneration between five pairs (Table 5.12)

Table 5.11 ANOVA result of CC09-06 in different zones

Source	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	4565.972	6	760.995	7.193	.000
Within Groups	185895.918	1757	105.803		
Total	190461.890	1763			

Table 5.12 Post-hoc test of regeneration in different zones

Zone	Sanctuary	Intensive use	Rehabilitation	Mitigation	Religious and cultural	Wilderness
Intensive use	**.003**					
Rehabilitation	.613	.116				
Mitigation	.135	.105	1.000			
Religious and Cultural	.138	1.000	.521	.541		
Wilderness	1.000	**.002**	.466	**.045**	.118	
Traditional	**.011**	.373	.938	.941	.798	**.003**

5.3.2. After 2010 Eruption

In Different Landcover Types

After 2010 eruption the average values of regeneration in different land cover types were also different. As presented in Table 5.13, the regeneration in mixed forest was much higher than other landcover types, and regeneration in bareland was the lowest.

Table 5.13 Descriptive statistics of CC12-11 in different landcover types

Landcover	N	Mean	Std. Dev	Min	Max
Bareland	120	3.358	4.474	0.000	23.160
Grass	51	4.955	3.508	1.039	16.361
Mixed Forest	1237	23.964	18.409	0.000	89.051
Shrub	356	12.479	10.588	1.006	55.341

Results of the ANOVA analysis showed that there was significant difference between landcover types with $p<0.05$ (Table 5.14). Post-hoc test confirmed that there were differences between five pair of landcover types (Table 5.15). The only not significant difference was between bareland and grass.

Table 5.14 ANOVA result of CC12-11 in different landcover types

Source	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	84185.506	3	28061.835	106.982	.000
Within Groups	461657.387	1760	262.305		
Total	545842.893	1763			

Table 5.15 Post-hoc test of regeneration in different landcover types

Landcover	Bareland	Grass	MixedForest
Grass	0.935		
MixedForest	**0.000**	**0.000**	
Shrub	**0.000**	**0.010**	**0.000**

In Different GMNP Zones

The average values of regeneration in different zones after 2010 eruption were also significantly different, where vegetation regeneration in religious and cultural zone was the highest, and the regeneration in sanctuary was the lowest (Table 5.16).

Table 5.16 Descriptive statistics of CC12-11 in different GMNP zones

Zone	N	Mean	Std. Dev	Min	Max
Sanctuary	428	14.00	11.69	0.00	58.99
Utilization	22	17.88	12.54	2.23	53.51
Rehabilitation	83	19.49	14.52	0.40	77.66
Mitigation	174	24.56	22.69	0.00	83.94
Religious and Cultural	10	47.34	15.69	28.12	68.03
Wilderness	929	20.24	17.91	1.04	89.05
Traditional	118	26.97	19.77	1.14	77.49

Results of the ANOVA analysis showed that there was significant difference between zones with $p < 0.05$ (Table 5.17), and post-hoc test confirmed that there are significant differences of vegetation regeneration between twelve pairs (Table 5.18)

Table 5.17 ANOVA result of CC12-11 in different zones

Source	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	32237.706	6	5372.951	18.380	.000
Within Groups	513605.187	1757	292.319		
Total	545842.893	1763			

Table 5.18 Post-hoc test of regeneration in different zones

Zone	Sanctuary	Intensive use	Rehabilitation	Mitigation	Religious and cultural	Wilderness
Intensive use	.945					
Rehabilitation	.105	1.000				
Mitigation	**.000**	.598	.283			
Religious and Cultural	**.000**	**.000**	**.000**	**.001**		
Wilderness	**.000**	.995	1.000	**.037**	**.000**	
Traditional	**.000**	.250	**.037**	.901	**.006**	**.001**

Results of ANOVA of vegetation regeneration after the 2006 and 2010 eruptions showed that there were differences of vegetation regeneration between different landcover types and different zones. From the descriptive statistics, it can be seen that the mean canopy cover changes after the 2010 eruption were higher than after 2006. Based on the fieldwork observation, the vegetation regeneration after 2010 eruption was dominated by the growth of *Acacia decurrens* species, mostly in areas affected by pyroclastic surges.

As reported by Yuniasih (2013) the domination of the *Acacia decurrens* after the eruption was caused by the simultaneous seed germination of this species which was stimulated by high temperatures from pyroclastic hazards. And also this species is intolerant of shade so it can grow quickly in barren areas.

The rapid growth rate of acacia has been under the serious concern of the GMNP bureau, because this species is considered as non native and invasive species that can endanger the biodiversity of the national park. The rapid growth of *Acacia decurrens* is considered as high class of threat due to its high vegetation density, and wide distribution across affected areas.

5.4. Determination of Influencing Environmental Factor to Vegetation Regeneration

5.4.1. After 2006 Eruption

Results of stepwise multiple linear regressions showed that distance to crater, aspect, elevation and rainfall were the influencing factors in vegetation regeneration after 2006 eruption (Table 5.19).

Table 5.19 Stepwise multiple linear regression output

Coefficients

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	20.542	.757		27.141	.000
	Dist	-.002	.000	-.194	-8.289	.000
2	(Constant)	25.553	1.015		25.167	.000
	Dist	-.001	.000	-.170	-7.303	.000
	Aspect	-1.134	.156	-.169	-7.275	.000
3	(Constant)	37.123	4.972		7.466	.000
	Dist	-.002	.000	-.305	-4.960	.000
	Aspect	-1.192	.158	-.178	-7.565	.000
	Elev	-.005	.002	-.148	-2.377	.018
4	(Constant)	16.911	11.061		1.529	.126
	Dist	-.002	.000	-.292	-4.719	.000
	Aspect	-1.332	.172	-.199	-7.761	.000
	Elev	-.005	.002	-.139	-2.236	.025
	Rainf	.009	.004	.052	2.045	.041

a. Dependent Variable: cc09_06

Distance to crater and elevation were negatively correlated with response variable, meaning that areas located further from the crater had higher regeneration, and the locations in the lower altitude also had higher vegetation regeneration. The model summary showed that the inclusion of these variables gave the R^2 value of 0.071 (Table 5.20). It means that the model can explain 7% of vegetation regeneration.

Table 5.20 Model summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.194[a]	.038	.037	10.19985284
2	.256[b]	.066	.065	10.05281016
3	.262[c]	.069	.067	10.03956782
4	.266[d]	.071	.069	10.03050284

a. Predictors: (Constant), distance to crater

b. Predictors: (Constant), distance to crater, aspect

c. Predictors: (Constant), distance to crater, aspect, elevation

d. Predictors: (Constant), distance to crater, aspect, elevation, rainfall

5.4.2. After 2010 Eruption

Results of stepwise multiple linear regression for determining influencing factor after the 2010 eruption showed that elevation and rainfall were the influencing factors in vegetation regeneration after 2010 eruption (Table 5.21).

Table 5.21 Stepwise multiple linear regression output

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	200.254	15.083		13.277	.000
	rainfall	-.077	.006	-.274	-11.975	.000
2	(Constant)	209.793	15.088		13.904	.000
	rainfall	-.077	.006	-.274	-12.059	.000
	elevation	-.007	.001	-.117	-5.159	.000

a. Dependent Variable: cc12_11

Rainfall and elevation were negatively correlated with response variable, meaning that areas with lower rainfall had higher vegetation regeneration, and locations in lower altitude also had higher vegetation regeneration. From the model summary it can be seen that the inclusion of the two variables give the R^2 value of 0.089 (Table 5.22), slightly higher than R^2 of regression model after 2006 eruption.

Table 5.22 Model summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.274[a]	.075	.075	16.925428425
2	.298[b]	.089	.088	16.803744936

a. Predictors: (Constant), rainfall

b. Predictors: (Constant), rainfall, elevation

5.5. Research Limitations

This research was limited on pyroclastic flows and surges hazard of 2006 and 2010 Merapi eruptions in GMNP. It did not consider other volcanic hazards such as ashfall and lahars. This was decided based on the fact that pyroclastic flows and surges are the primary volcanic hazards which have the most destructive effect on vegetation in GMNP areas. There were also some limitations with the data. Pyroclastic flows and surges maps were manually digitized from the previously published study. This process may have introduced errors in the accuracy of the pyroclastic hazard maps.

This research used vegetation index changes as surrogate variables to assess the overall vegetation regeneration rather than ecological measures such as changes in vegetation structure and composition. This surrogate measurement was made from satellite data with 15 m resolution. Patterns of vegetation can be different if observed with different scale and also depend on what vegetation characteristic measured (Lawrence, 2005). Therefore the conclusions and inferences drawn from this study are limited to the nature of these measurements.

6. Conclusions and Recommendations

6.1. Conclusions

The answers of research questions are:

1. What was the vegetation cover before the eruptions in 2006 and 2010?
   In 2003 (before the 2006 eruption), landcover in study area was mixed forest (1959.98 ha), bareland (485.87 ha), grass (67.91 ha) and shrub (321.35 ha). In 2009 (before the 2010 eruption) landcover in study area was: mixed forest (1852.11 ha), bareland (563.90 ha), grass (77.45 ha), and shrub (341.64 ha).

2. Which vegetation types were affected in the 2006 and 2010 eruptions?
   Vegetation types that were affected in 2006 eruption are mixed forest (161.73 ha). Vegetation types that were affected in 2006 eruption are mixed forest (911.15 ha), and shrub (37.63 ha).

3. Which GMNP zones were affected in the 2006 and 2010 eruptions?
   Zones that were affected in 2006 eruption are: sanctuary, mitigation, wilderness and traditional zones. While the 2010 eruption affected all zones: sanctuary, intensive use, mitigation, rehabilitation, religious and cultural, wilderness, and traditional.

4. What is the relationship between selected vegetation indices and canopy cover?
   There are four vegetation indices tested (RVI, NDVI, SAVI, $MSAVI_2$). Results from simple regression model concluded that NDVI with power regression model have the highest R^2 value (0.704). This model can explain 70% of variance in canopy cover.

5. Is there a difference in vegetation regeneration within the different landcover types and GMNP zones?
   From the ANOVA analysis of vegetation regeneration after 2006 and 2010 eruptions, there are differences of vegetation regeneration within different landcover types and different GMNP zones.

6. Which environmental factors influence vegetation regeneration?
   The vegetation after 2006 eruption was influenced by four factors: distance to crater, aspect, elevation, and rainfall. While the regeneration after 2010 eruption was influenced by two factors: rainfall and elevation

6.2. Recommendations

Based on the results of the study, the following recommendations were formulated:

1. This study employed visual interpretation in analysis of landcover changes after eruptions. It is recommended to use different method in landcover classification and also to develop more detailed landcover/vegetation classes based on the vegetation structure and composition.

2. Vegetation regeneration in all affected GMNP zones is dominated by *Acacia decurrens* which is invasive species and threatening the biodiversity of the national park. The GMNP bureau must take action to limit the invasion of acacia, possibly by rehabilitating and restoring the affected areas using native vegetation species. Since the regulation prohibits such activities in sanctuary zone, it is recommended to re-designate the affected sanctuary zones as rehabilitation zones.

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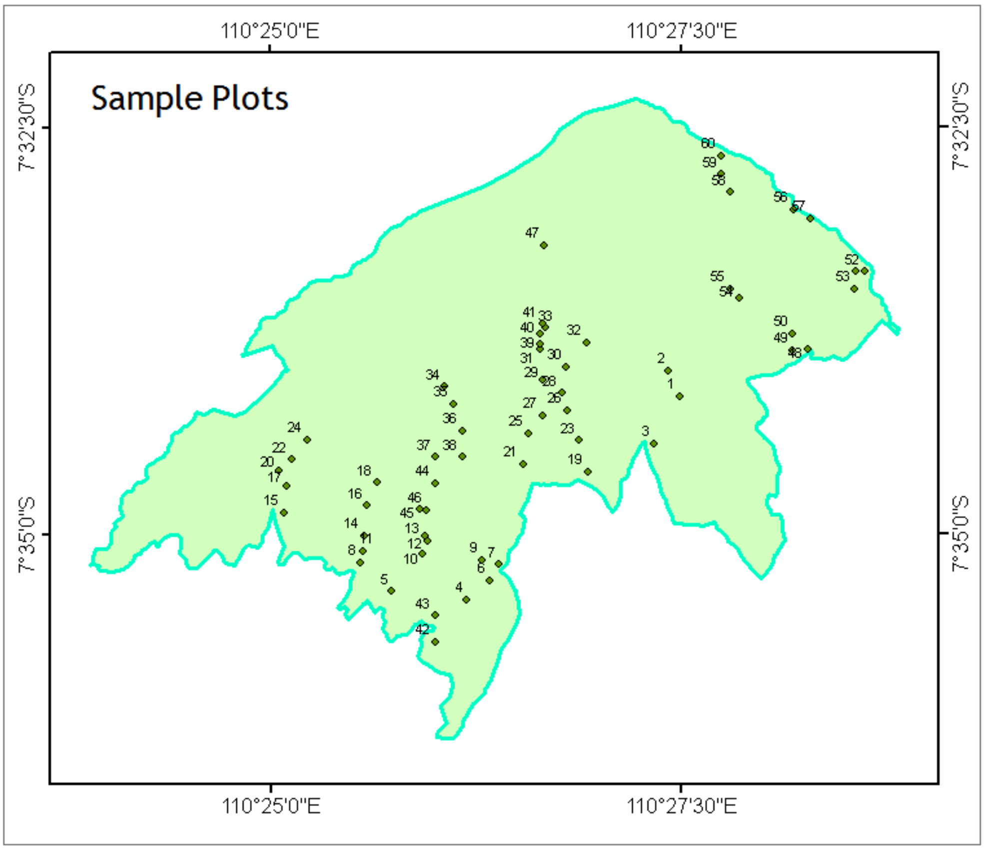
Appendix 1. Sample plots data

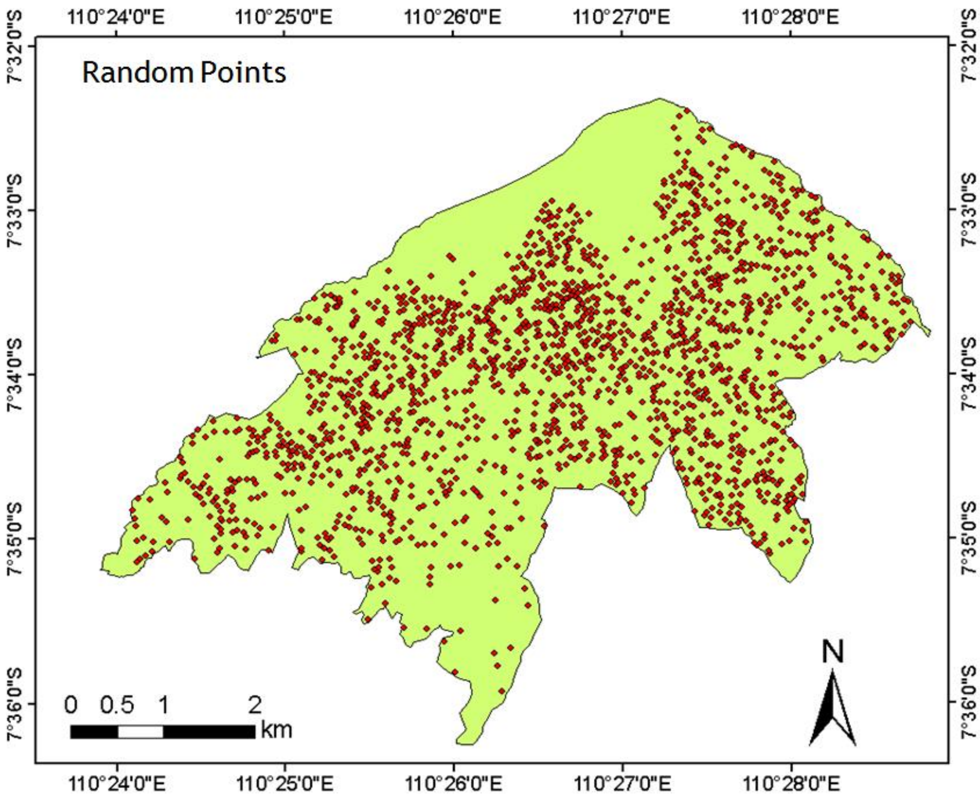
Nr	X (m)	Y (m)	Canopy Density (%)	NDVI	RVI	SAVI	MSAVI2
1	440231	9163288	87.001	0.748	6.942	0.419	0.397
2	440109	9163572	56.001	0.698	5.627	0.480	0.475
3	439947	9162748	88.001	0.770	7.704	0.457	0.444
4	437852	9160984	41.001	0.687	5.391	0.492	0.490
5	437009	9161076	90.001	0.590	3.880	0.270	0.232
6	438103	9161198	40.001	0.645	4.631	0.405	0.384
7	438212	9161381	28.001	0.549	3.431	0.319	0.289
8	436653	9161397	34.001	0.618	4.233	0.242	0.201
9	438016	9161434	14.001	0.565	3.598	0.346	0.320
10	437360	9161507	62.001	0.681	5.275	0.388	0.362
11	436680	9161536	25.001	0.667	5.014	0.370	0.341
12	437408	9161646	43.001	0.711	5.926	0.450	0.436
13	437383	9161698	33.001	0.731	6.447	0.462	0.451
14	436697	9161705	21.001	0.623	4.304	0.302	0.265
15	435800	9161965	48.001	0.623	4.310	0.285	0.246
16	436733	9162046	33.001	0.643	4.609	0.265	0.224
17	435836	9162272	69.001	0.637	4.515	0.317	0.281
18	436843	9162306	28.001	0.727	6.317	0.454	0.442
19	439207	9162428	0.001	0.145	1.340	0.065	0.052
20	435750	9162436	50.001	0.678	5.210	0.384	0.357
21	438477	9162517	36.001	0.671	5.080	0.356	0.324
22	435886	9162570	52.001	0.671	5.080	0.409	0.388
23	439110	9162783	0.001	0.158	1.376	0.071	0.057
24	436057	9162795	66.001	0.740	6.702	0.455	0.442
25	438534	9162862	65.001	0.728	6.349	0.435	0.417
26	438972	9163124	0.001	0.151	1.355	0.069	0.056
27	438702	9163068	70.001	0.781	8.140	0.553	0.568
28	438916	9163320	0.001	0.450	2.639	0.214	0.181
29	438703	9163478	63.001	0.766	7.549	0.500	0.500
30	438968	9163621	75.001	0.723	6.208	0.486	0.482
31	438664	9163822	73.001	0.705	5.785	0.401	0.377
32	439186	9163891	0.001	0.498	2.988	0.252	0.218
33	438726	9164060	35.001	0.517	3.137	0.268	0.234
34	437604	9163396	31.001	0.735	6.561	0.447	0.432
35	437696	9163199	47.001	0.756	7.196	0.482	0.476
36	437801	9162896	37.001	0.514	3.119	0.286	0.254
37	437502	9162598	22.001	0.674	5.140	0.397	0.373
38	437800	9162597	22.001	0.644	4.618	0.306	0.269
39	438672	9163877	59.001	0.671	5.080	0.356	0.324
40	438670	9163998	16.001	0.671	5.080	0.336	0.301
41	438697	9164102	83.001	0.671	5.080	0.356	0.324
42	437497	9160501	93.001	0.671	5.080	0.356	0.324
43	437498	9160801	93.001	0.682	5.291	0.370	0.340
44	437499	9162297	72.001	0.758	7.257	0.528	0.536
45	437317	9162002	58.001	0.683	5.310	0.351	0.318
46	437401	9161997	83.001	0.722	6.187	0.446	0.432
47	438717	9164999	21.001	0.570	3.647	0.267	0.229
48	441666	9163818	57.001	0.686	5.378	0.462	0.453
49	441503	9163803	32.001	0.660	4.884	0.361	0.331
50	441499	9163999	81.001	0.753	7.098	0.499	0.498
51	442199	9164701	28.001	0.679	5.233	0.346	0.312
52	442303	9164699	42.001	0.701	5.695	0.375	0.344
53	442197	9164500	35.001	0.743	6.773	0.501	0.501
54	440902	9164398	4.001	0.667	5.003	0.332	0.296
55	440800	9164505	11.001	0.598	3.979	0.244	0.204
56	441503	9165399	25.001	0.721	6.168	0.465	0.455
57	441701	9165297	28.001	0.780	8.075	0.549	0.564
58	440803	9165597	16.001	0.732	6.470	0.483	0.479
59	440701	9165799	14.001	0.544	3.386	0.170	0.134
60	440696	9166004	18.001	0.640	4.559	0.338	0.305

Note : X Y coordinates in UTM 49 South

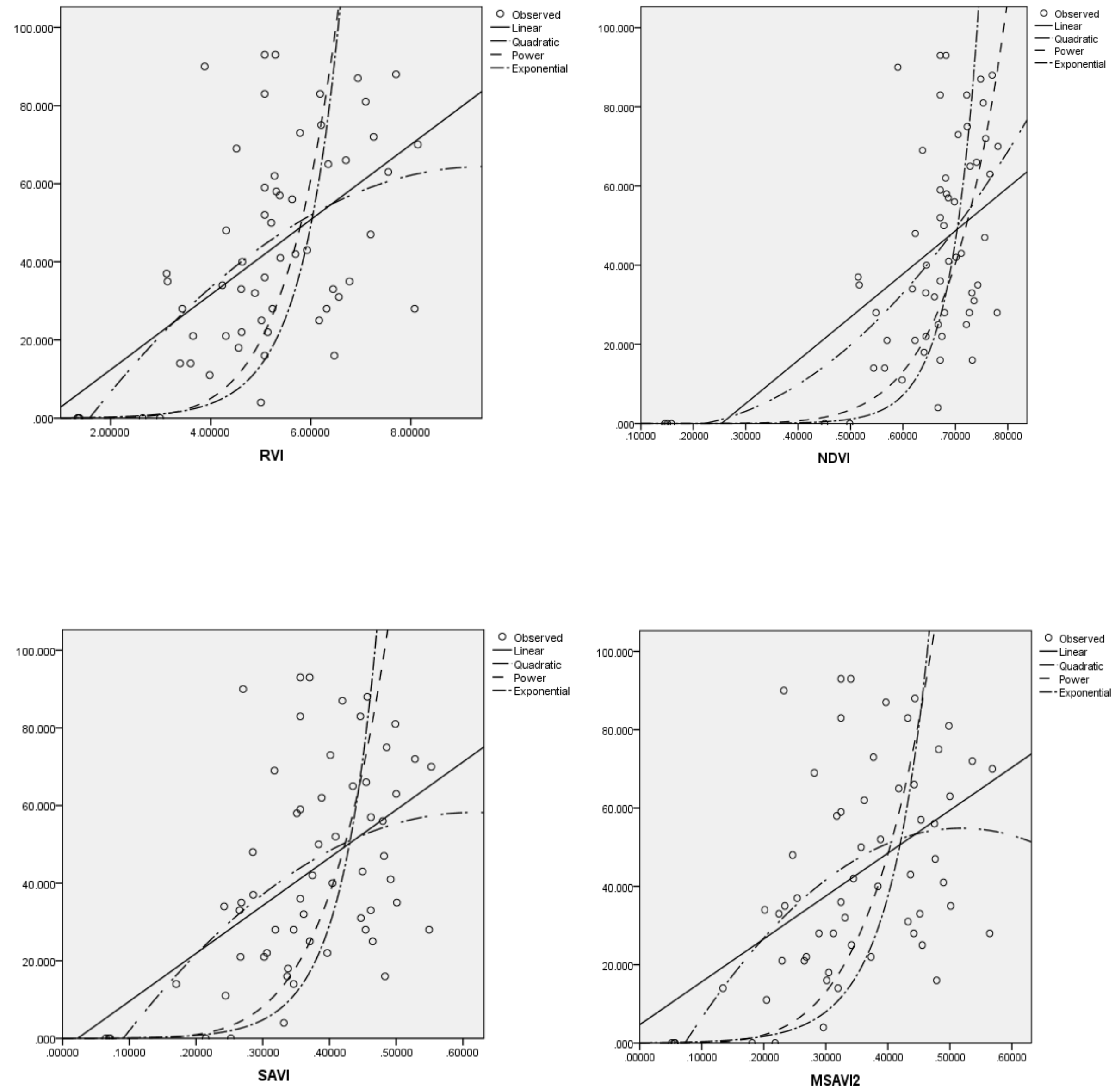
Appendix 2. Sample plot locations



Appendix 3. Generated random points



Appendix 4. Scatter diagrams of regression models between vegetation indices and canopy cover



Appendix 5. Canopy cover change maps in 2006-2009 (CC 09-06) and 2011-2012 (CC 12-11)