Space Technology for Policy-Making and Management of Protected Mountain Range in Southern Philippines

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Abstract
This paper was aimed to assist the management of a protected densely forested mountain range in the perspective of forest and land degradation brought about by natural and human-induced fire occurrences. Historical fire events in the area over the last 15 years were acquired from two space-borne sensors. From 2003 to 2013, the number of fire occurrence was low and much of these were in the buffer zone (average of 1.1 per year). However, an increasing trend was found starting in 2014 then peaked at 2016 when El Niño phenomenon happened. Two forest fires were identified between March and April 2016 that largely occurred inside the protected area. High resolution Sentinel-2A images before and after the forest fires were also processed to accurately delineate and calculate the actual area destroyed. These findings are expected to help policy-makers to review the existing rules and regulations in improving the protection and conservation of the area.

1. Introduction

Protected areas (PA) are created for various purposes such as, among others, to conserve important geological features and ecological processes, maintain cultural values and to protect and enhance biodiversity and ecosystem services (Dudley, 2008 and Brenes et al., 2018). Global initiatives such as the Convention on Biological Diversity and the declarations of ASEAN Heritage Parks have been mobilized for conservation cause, maintain ecological processes and ensure sustainable ecosystems of protected areas (UN-CBD, 1992 and ASEAN, 2015). In spite of these efforts, deforestation and continued forest and habitat degradation are still prevalent at high rates due to poor management, illegal cutting of trees, slash-and-burn farming and forest fires (Chokkalingam et al., 2006 and Brenes et al., 2018). The latter may be rare in tropical forest under normal conditions (Laurance and Williamson, 2001 and Lasco et al., 2001) which can be attributed to climate (e.g. high humidity or frequent rainfall). However, Cochrane (2003) observed that fires in rainforests become more frequent as a consequence of land-use practices. The slash-and-burn cultivation, locally known as *kaingin*, is usually applied by farmers as a means to opening new lands (Lawrence, 1997). Others characterize it as an act of prescribed burning for land preparation (Cairns and Garrity, 1999). In the tropics, this kind of practice has been seen as the primary source of deforestation and forest degradation for many years (Lawrence et al., 2010, Fox et al., 2009 and Mukul et al, 2016). In the Philippines, the selection and administration of PA, whether as terrestrial, wetland or marine, is under the umbrella of the National Integrated Protected Areas System (NIPAS) institutionalized in the year 1992 (RA 7586). The system is spearheaded by the Department of Environment and Natural Resources (DENR) and, together with other stakeholders, constitutes the Protected Area Management Board (PAMB) which is the policy-making and highest governing body of the PA. In order for the Board to be effective, comprehensive documentation, timely monitoring and scientific-based analysis are all critical. The technology of remote sensing (RS) is an extremely powerful tool for the task as it enables coverage of large, remote and non-sampled areas over different time periods, thus providing a continuous source of environmental information (He et al., 2015 as cited by Regos et al., 2017).

In the year 2000, the Philippine Republic Act 8978 was signed into a law declaring the Mt. Kitanglad Range as a protected area and its peripheral areas as buffer zones. Nine years later, it was also declared as an ASEAN Heritage Park. Mt. Kitanglad Range provides various ecosystem services (e.g. water for domestic, agricultural, industrial, and commercial use, source for power generation) to over 100,000 households in various towns and is also prominently known as the ancestral domain of three major indigenous tribes

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(DENR-USAID, 2015). Given its astounding ecological, economic and cultural importance, it is therefore essential that this landscape must be one of the top priority in terms of proper management and conservation equipped with efficient and appropriate technological tools. This study is aimed to perform multi-temporal and spatial analyses on the occurrence of fires, both natural and human-induced in a mountainous range with mixed tropical forest using different remote sensing datasets. The results of the analysis is expected to serve as the basis for future planning and crafting of policies that should be beneficial to the protection and conservation of the area.

2. Methodology

2.1 Study Area

The Mt. Kitanglad Range is in the Province of Bukidnon, southern Philippines (8°08′N 124°55′E) (Figure 1). Having been classified under the natural park category, it now bears the official name of Mt. Kitanglad Range Natural Park (MKRNP). Situated in the north-central region of Mindanao island, MKRNP occupies a total area of 47,270 ha (with 66% as protected area) encompassing seven municipalities and one city (PENRO-DENR, 2016). The protected range is the country's one of the few remaining rainforest and has the second highest peak in the country named Mt. Duland-dulang at 2,938 m (asl) (ASEAN, 2010). The rainy season in the province lasts from March to October with average monthly rainfall of 241.68 mm (data from 2006-2011) (PAGASA-DOST, 2014).

During its last survey in 2010, the total forest cover was 43,900 ha or 93% of its total land area. At least 58 families and 185 species of trees and other woody vegetation species have been recorded in the area (Canoy and Suminguit, 2010). MKRNP has the highest tree density ever reported in a tropical forest with six major habitat types, ranging from lowland evergreen forest, lower montane forest, mossy forest, grasslands, freshwater wetlands and caves (ASEAN, 2010). In terms of faunal resources, the park is endowed with a variety of rare and endemic species and has one of the most diverse mammal faunas including the endangered Philippine Eagle (*Pithecophaga jefferyi*) (Lawrence et al., 2006, Townsend Peterson et al., 2008 and Canoy and Suminguit, 2010).

2.2 Remote Sensing Data

2.2.1 Monitoring satellites

Historical fire occurrences over the study area were obtained from the Moderate Resolution Imaging Spectroradiometer (MODIS) (Collection 6 NRT) and the Visible Infrared Imaging Radiometer Suite (VIIRS) (Active Fire Product NRT) which are both available for downloading at the Fire Information for Resource Management System (FIRMS) website. The MODIS instrument, onboard the Terra and Aqua satellites, performs fire detection using a contextual algorithm that exploits the strong emission of mid-infrared radiation from fires (Giglio et al., 2003). Each hotspot/active fire detection represents the center of approximately 1 km pixel flagged by the algorithm as containing one or more fires or other thermal anomalies (NASA, 2018). Since 2000, MODIS instrument has been acquiring data continuously providing global coverage every 1-2 days.

On the other hand, VIIRS instrument on board the Suomi National Polar-orbiting Partnership (S-NPP) satellite also acquires data continuously since 2012. Its algorithm is a hybrid thresholding and contextual algorithm using radiometric signals from 4 micron and 11 micron bands and suite of tests for internal cloud mask and rejection of false alarms (Schroeder et al., 2014). Based on the product description, VIIRS provides greater response over fires of relatively small areas due to its higher spatial resolution of 375 m and has improved night time performance. The minimum detectable size of the fire could range between 100 m^2 to 1,000 m^2.

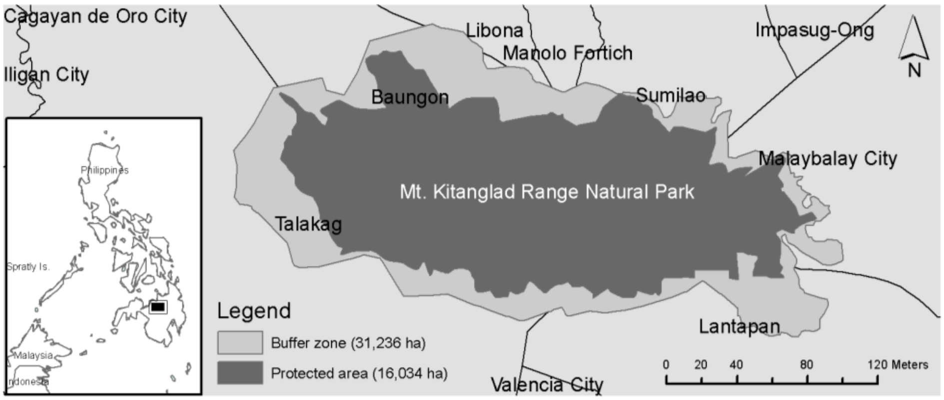

Figure 1: Geographical location of the study site

2.2.2 Optical images

Two high-resolution Sentinel-2A Multi Spectral Instrument (MSI) imageries taken at different dates were used for the analysis. The first one, dated 04 December 2015, corresponded prior to the forest fire while the second image was acquired on 02 April 2016. Both datasets were downloaded as Level 1C products (Top-of-atmosphere reflectance) which went through radiometric and geometric corrections at sub-pixel accuracy (ESA, 2015). A semi-automatic atmospheric correction called dark object subtraction (DOS) (Chavez, 1996) was used for calibrating to bottom-of-atmosphere surface reflectance implemented in QGIS (ver 2.18.11). The pre-fire image had brighter illumination condition causing too much shadows on the rugged terrain. Both images are contaminated with 10-20% clouds so masking was necessary. Delineation of clouds including its shadows was performed by unsupervised classification with 90% overall accuracy. Sentinel-2A has 12 spectral bands ranging from coastal blue to shortwave infrared (SWIR). Specifically useful in this study are the red edge band 6 (740 cm), near infrared band 8a (865 nm), SWIR bands 11 (1,610 nm) and 12 (2,190 nm). These 4 bands have a spatial resolution of 20 m.

2.3 Vector Datasets

Land classification used was based on the 2010 nationwide land cover map by the National Mapping and Resource Information Authority (NAMRIA). Such map was a product of object-based classification with ground validation (overall accuracy = 89%) (Manuel, 2014 and DENR, 2015). The images used were mostly taken from the Advanced Visible and Near Infrared Radiometer type 2 (AVNIR-2) in combination with SPOT-5 and Landsat 7. On the other hand, administrative boundaries were obtained from the Philippine Statistics Authority (PSA) during the 2015 country-wide population census.

2.4 Data Processing and Analysis

Multi-temporal analysis from MODIS and VIIRS data was conducted to reveal any patterns. Detected fires were summarized on a yearly basis on both PA and buffer zone (BZ) overlaid with the different land cover types. Meanwhile, delineating burnt areas was done by calculating the normalized burn ratio index (NBRI) (Key and Benson, 2006) from the Sentinel-2A MSI images with the formula:

$$\frac{NIR - SWIR}{NIR + SWIR}$$

Equation 1

NBRI takes advantage of reflectance increase in the shortwave infrared (SWIR) spectral domain in combination with the near infrared (NIR) reflectance drop associated with the vegetation removal (Veraverbeke et al., 2011). As red edge bands found to be more effective for similar analysis (e.g. Fernandez-Manso et al., 2016, Navarro et al., 2017 and Olpenda, 2017), band 6 together with band 12 were chosen for equation 1. NBRI has typical values close to zero where negative and positive values denote burnt and non-burnt areas, respectively. In order to assess the severity of the fire, the difference between the NBRI of pre-fire and post-fire were calculated (dNBRI). As pre-fire NBRI should normally have higher values for healthy vegetation, dNBRI values of above zero were assessed on the level of severity where the range (e.g. zero to maximum value) was equally divided into three classes to represent slightly, moderately and severely damaged.

2.5 Flowchart of the Method

As a graphical summary of the procedures and data processes performed by the author, a diagram is shown in Figure 2 below.

3. Results

3.1 Analysis of MODIS and VIIRS Products

A time series graph of detected fires in MKRNP over the last 15 years is illustrated in Figure 3. There were 98 detections from both MODIS and VIIRS from which 37% occurred inside the PA. Since 2003 up to 2013, the number of fire occurrence was generally low from both PA and BZ with annual average of 1.1. However, an increasing trend was found starting in 2014 then peaked at 2016 that reached up to more than 60 detections from the combined PA and BZ. The locations of these fires are displayed in Figure 4 represented by triangle symbol.

Majority of these fires are found within the BZ where the land is relatively flat and can be interpreted as controlled burning considering the closeness to each other and yet they mostly happened at different years. The sudden increase of observations in 2016 (refer to Figure 3) pertains to those patches of fires on the northern side transcending the common borders of PA and BZ. These were actually forest fires that were properly documented during the first quarter of 2016 (Gallardo and Balane, 2016).In addition, fires detected were also grouped based on which month they occurred. Findings showed that close to 60% of these happened in the month of March followed by April at 27%.

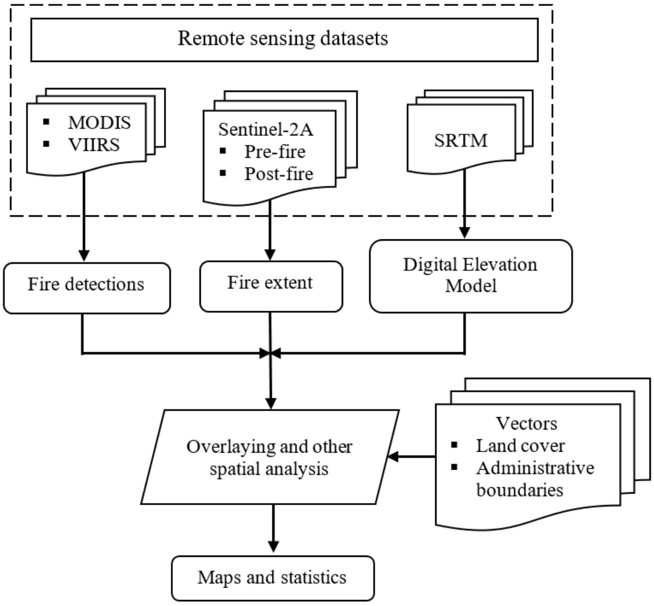

Figure 2: Flowchart, data processes and datasets used in this study

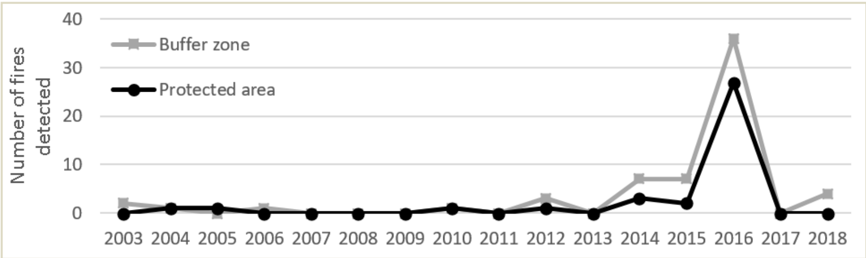

Figure 3: Number of fires detected by MODIS and VIIRS in MKRNP per year (2003 – 2018)

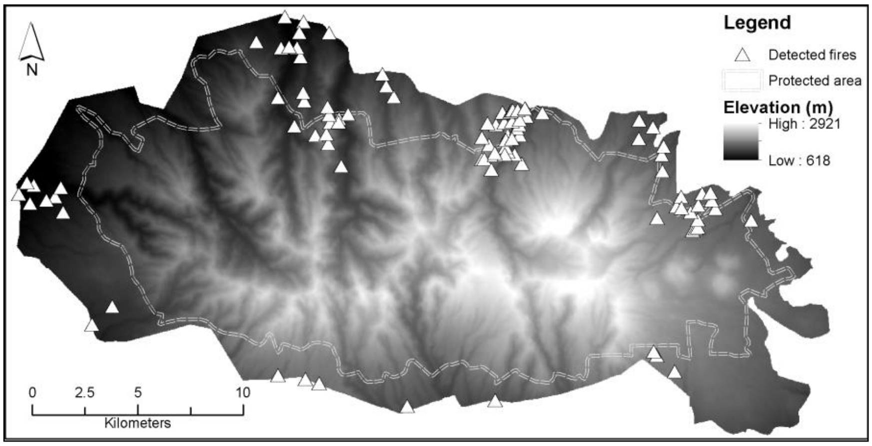

Figure 4: Fires detected by MODIS and VIIRS products in both buffer zone and protected area of MKRNP from 2003 to 2018. Elevation data is a 30-m resolution raster from Shuttle Radar Topography Mission (SRTM)

Offsetting the effects of forest fires that led to a higher number of detections on the same month, the combined observations for March and April are still high (73%) which were mostly inside the BZ. This finding strengthens my claim that fires in BZ are agriculture-related practices that are done on a yearly basis such as harvesting and sowing. Burning of agricultural waste is done to dispose it or to prepare the land in time with the rainy season (Brandt, 1996 and Walpole, 2010).

3.2 Spatial Analysis Based on Land Cover

Figure 5 displays the distributions of fires detected per land cover types. Formations where trees form a discontinuous layer covering 10% to 40% of ground pertains to open forest while closed forest are natural forest where trees in the various storeys and undergrowth cover at least 40% of the ground (FAO, 2015). Within the PA, half of the detected fires (18 of 36) happened inside the closed forest. From the combined observations in BZ and PA, 68% occurred in both open and closed forest.

3.3 Forest Fires in 2016

Figure 6a shows the first forest fire in MKRNP that happened in March 2016. The image is Sentinel-2A acquired on 02 April 2016 utilizing the two SWIR and NIR bands for red, green and blue (RGB) color composites, respectively. With this band combination, dark brown pertains to burnt areas while dark blue is vegetation. It is apparent that the forest fire just at the inner border of PA lasted for two days (22-23 March). As far as the sensors are concerned, that fire originated also inside the PA. Based on the land cover map, the fire destroyed some parts of closed forest (at least two red pixels of 23 March). Prior to this event, there were already similar detections, or at least burning, as early as 2004 and 2010. There might have been an instance that the fire started from the BZ, most likely an intentional burning that uncontrollably spread out and reached the PA (as in the case of 28 March 2014 detection). A week after the abovementioned forest fire, another one broke out about 8 km to the west on April 1, 2016 (Figure 6b). Based on MODIS and VIIRS monitoring, it also went on for two successive days (1-2 April 2016). That observation matched well with the Sentine-2A where on-going flames and active fires were clearly distinguished by the SWIR bands. The fire started at the BZ-PA boundary. A personal communication with a forester from the DENR who surveyed the affected areas confirmed that the damage included large trees. Similarly, there was already fire detected in higher elevation above the burnt areas as early 2014.

3.4 Fire Severity Delineation

The results of computing NBRI to delineate burnt areas and the severity are illustrated in Figure 7. The effect of shadows from the terrain is apparent in pre-fire NBRI having negative values (red pixels) scattered all over the mountain range. Nevertheless, these negative values were offset by the post-fire NBRI having more positive values. It also remarkably shows the identified forest fires as well as the results of burning agricultural lands on the lower elevations around the periphery of BZ. The difference between the two indices (dNBRI) (bottom index map) reveals the level of severity while eliminating the shadow effects in the pre-fire image.

Table 1 below summarizes the level of fire severity generated from dNBRI per municipality. The total damaged area (low to high) in BZ and PA, respectively are 1,346.15 ha and 287.31 ha for a grand total of 1,633.46 ha.

Figure 5: Percentage distribution of detected fires based on land cover

Table 1: Distribution of fire severity per municipality/city in hectares

Municipality/city	**Low**		**Moderate**		**High**	
	BZ	PA	BZ	PA	BZ	PA
Baungon	399.38	64.95	51.61	19.21	2.44	4.29
Malaybalay City	65.57	19.60	10.39	3.05	0.03	-
Impasugong	155.06	2.36	18.41	-	0.28	-
Lantapan	219.15	44.85	29.26	13.72	0.35	-
Libona	5.13	-	0.25	-	-	-
Manolo Fortich	62.50	38.07	65.18	53.28	-	0.4
Sumilao	2.92	-	2.83	-	-	-
Talakag	204.36	21.13	50.93	2.41	0.12	-

Total	1,114.07	190.97	228.87	91.66	3.22	4.69

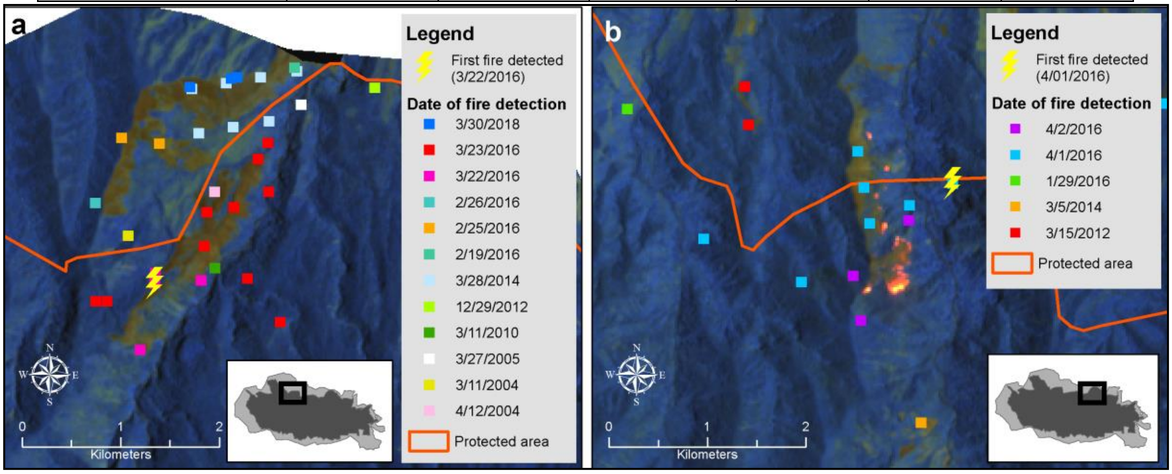

Figure 6: Forest fire in MKRNP on (a) March and (b) April 2016 with spatio-temporal display of fire detection by MODIS and VIIRS product. The basemap used is Sentinel-2A image in bands 12-11-8a RGB composite acquired on April 2, 2016

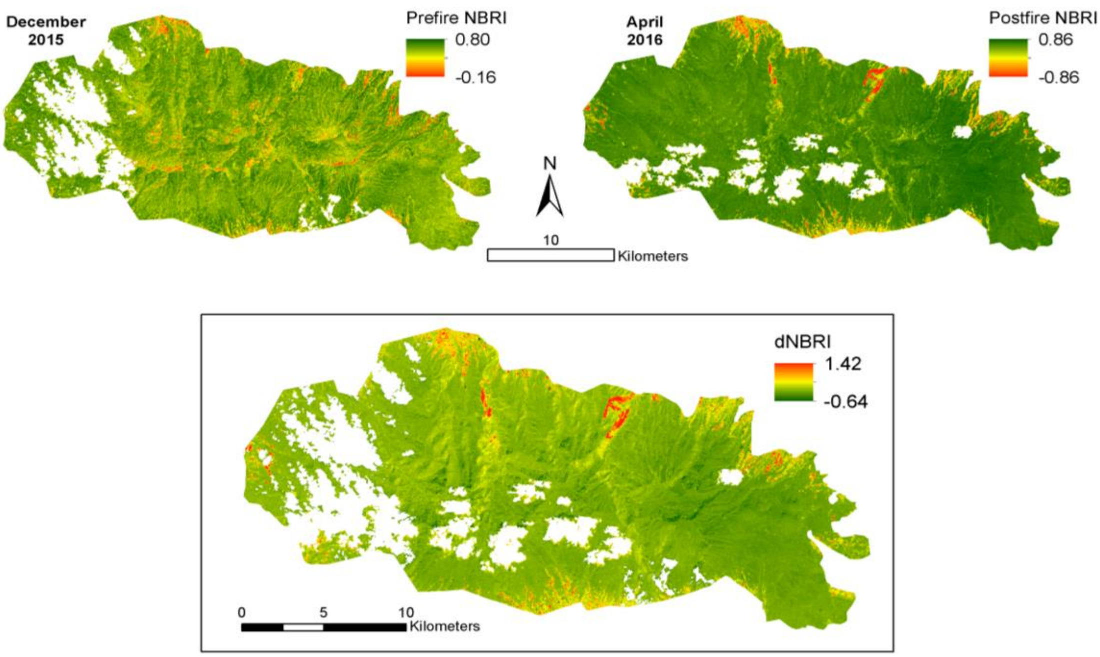

Figure 7: Pre-fire NBRI maps of MKRNP (top-left) and post-fire (top-right). Difference between pre-fire and post-fire (dNBRI) (bottom)

The burnt area in PA is 2.6x larger than the one in Mt. Apo caused also by fire in March 2016 (Olpenda, 2017). All municipalities experienced low to moderate level of fire severity in BZ. From the damaged done in PA, both Baungon and Manolo Fortich share almost the same percentage (~32% each), followed by Lantapan (20%). Amongst them, only Libona and Sumilao did not have any burning incidence within PA.

4. Discussions and Conclusions

4.1 The El Niño Phenomenon

Between 2015 and 2016, the strongest El Niño event ever recorded was formed, affecting several countries in Asia including the Philippines (UN-WFP, 2016). The El Niño phenomenon, recurring a cycle of 2 to 7 years, is caused by the warming of sea surface temperature in the Pacific that resulted to reduced rainfall and consequently leading to dry spells and droughts (UN-FAO, 2017).

During the first quarter of 2016, over 85% of the country was considered to be affected by the dry conditions with Mindanao being the most affected (UN-WFP, 2016 and UN-FAO, 2017). Aside from Mt. Kitanglad, several grassfires and forest fires also broke out to at least four other mountains, mostly protected areas too, between March to April on the same year (Bartolome, 2016, PNA, 2016 and Espina, 2016). The simultaneous outbreaks of fires in the mountains of the Philippines are very rare as far as the knowledge of this author is concern. Large forest fires were also recorded in Congo, Africa during the first months of 2016 (Verhegghen et al., 2016) and in Madeira Island, Portugal on August 2016 (Navarro et al., 2017). Judging by these local and global events, it can be surmised that tropical forest fires are often more severe during El Niño events as what Cochrane (2003) concluded.

4.2 Basis for Law Enforcements and Policy-Making

The Philippine Atmospheric, Geophysical, and Astronomical Services Administration (PAGASA) were able to forecast that the recent El Niño have been forming since April 2015 and will likely continue until the first half of 2016 (UN-WFP, 2016). However, this study showed that as early as 2014, the number of fire events already started to increase. As this phenomenon is periodic in the region, the management of the protected area may need to regulate controlled burning at least one year earlier and intensify the monitoring mechanism. Future strict monitoring must specifically focus during the months of February to April when agricultural waste burning is prevalent based on the 15-year data of MODIS and VIIRS.

Whether the fires in MKRNP were caused by nature (e.g. lightning) or anthropogenic (e.g. slash-and-burn), there are indications that there were already fires previously detected on the heavily burnt areas inside the PA. Burning of vegetation, waste products or any materials inside the PA harmful to inhabitants or animals is prohibited by law (RA 8978). Further, it might not be conclusive that the source of the forest fire originated inside the PA as there are technical reasons for non-detection of fires but it is also possible that the first fire lit was too small to be detected (NASA, 2018). Nevertheless, the revelations from this study is a good basis to start an investigation by looking at those sites with historical fire background and areas with crops that are close to the common boarder of BZ and PA.

As introduced earlier, the PAMB acts as the governing body that oversees the management and operation of MKRNP. Members of this Board include the mayors or their authorized representatives of the towns and cities with territory inside the PA. Since quantified damaged areas (PA and BZ) were found to be distributed among the municipalities, it is thus justifiable that responsibilities must be delegated to these respective local government units to make appropriate actions in order to avoid another catastrophe.

5. Conclusion

This study has demonstrated how effectively useful the space technology can be, particularly satellite remote sensing, when it comes to monitoring and assessment of land degradation brought about by forest fire or agricultural burning. Detections of fires could be detected from space-born sensors even on areas with difficult accessibility. Due to the high temporal and spatial resolutions of the sensors, long-term analysis of historical events of either burning or fires can be done at an acceptable accuracy. Such process can reveal patterns that can be beneficial for management purposes in reducing the effects of the said catastrophe. Post-fire evaluation can easily be executed by computing an index (e.g. dNBRI) using a computer algorithm for recovery and rehabilitation planning.

It is recommended though that field validation must be done for similar studies in the future. Integration with other satellite imageries as well as the usage of drone is another potential undertaking to improve the study.

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