Mapping Forest Vulnerability to Fire and Landslides in the Cordillera Region, Philippines

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ABSTRACT

Forest fires and landslides pose significant threats to the Cordillera's forests. Despite their detrimental impact, the vulnerability of forests in this region has received limited attention in previous studies. To address this research gap, this study employs satellite imagery and remotely sensed datasets to identify forest areas in the region that are susceptible to fires and landslides. In 2021, the forest cover in the region spans approximately 1.35 million hectares, accounting for over 73% of its total land area. However, approximately 116 thousand hectares, or 8.5% of the forest in the region, are prone to fires. The study notes an increasing trend of fire incidents and burned areas observed in both natural and plantation forests in the region. This trend could be linked to the region's rising temperatures and extended drought. In the next four decades, a projected rise in temperature of 1.1 to 1.3°C and a decrease in precipitation (-8.8 mm) during the dry season could result in more severe forest fires, larger burned areas, and longer fire durations. Furthermore, nearly 73% of the region's forests are vulnerable to landslides at a high to extremely high level. This vulnerability is reflected in the 182 landslides that occurred in the region between 2007 and 2018. The output of this study could be used in the adaptation and mitigation plans, and risk reduction activities in the region. The findings of this study highlight the need for urgent action to prevent further forest degradation due to anthropogenic and natural hazards.

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INTRODUCTION

The regulation of Earth's climate is significantly dependent on tropical forests (Artaxo et al. 2022). They contribute to sustainable development by regulating ecosystems, protecting biodiversity, playing an important role in the global carbon cycle, and supporting livelihoods (IUCN 2021). However, climate change has been adversely affecting these forests at the local and regional levels (Graham et al. 1990; Joshi et al. 2012). In particular, wildfire, drought, invasive species, insect and pathogen infestations, typhoons, windstorms, ice storms, and landslides can all have an impact on forests as a consequence of these global climatic changes (Dale et al. 2001). Based on the report from the Intergovernmental Panel on Climate Change (IPCC) (2021), a warmer climate, as a result of changes in temperature and precipitation, can intensify very dry and very wet seasons, which can influence the duration, extent, frequency, occurrence, timing, and intensity of disturbances (Baker 1995), such as forest fires and landslides. That is, climate change and forest ecosystems are inextricably connected (Carvalho et al. 2004). Deforestation and forest degradation result in the release of carbon dioxide (CO_2) into the atmosphere, which aggravates climate change. This is the second greatest source of human-induced CO_2 in the atmosphere, after fossil fuel combustion (Van der Werf et al. 2009). In return, climate change is impacting the forests and their effectiveness to provide ecosystem services (Lasco et al. 2008).

The Philippines has very little contribution to global Greenhouse Gas (GHG) emissions, with only 0.39% (Buendia et al. 2018). Unfortunately, it is one of the most vulnerable countries to the climate crisis, and it suffers most from extreme weather events (Eckstein, et al. 2020). The country's forest ecosystems are one of the most sensitive to climate change-induced variability of precipitation and temperature (Cruz et al. 2017). However, very few studies analyzing the consequences of climate change on the Philippines' forests have been done. At present, the forest cover in the country is around seven (7) million hectares (ha), or 23% of the country's total land area, based on the latest Philippine Forestry Statistics (PFS) report published by the Forest Management Bureau (2020). Most of the forests in the country are found in three (3) regions: Region 2 (Sierra Madre Mountain Range), Region IVB (or the MIMAROPA), and the Cordillera Administrative Region (CAR). On a negative note, these forest areas are among the world's hottest hotspots due to the continuous biodiversity loss caused by land use conversion, deforestation from agricultural encroachment and logging activities, mining, and pollution (Carandang, et al. 2013). It has been determined that climate change will aggravate the degraded situation of the country's forests and biodiversity (Cruz et al. 2017) if there is no transformational change in the country's approach to reducing deforestation (Atmadja et al. 2021). Thus, empirical studies on the vulnerability of forests to changing climates are essential, particularly in these regions that house the country's last forest frontiers.

This paper determined the forest areas in the Cordillera region that are vulnerable to fires and landslides using publicly available satellite imagery and remotely sensed datasets. Also, a high-resolution forest cover map of the region was generated. The output of this paper could serve as an important input in climate change adaptation and mitigation plans, forest conservation plans, risk reduction activities, project implementation, and land use planning, and may provide relevant information to policymakers in the region as well.

MATERIALS AND METHODS

Study Area

The study area is located in the six (6) provinces of the CAR namely, Abra, Apayao, Benguet, Ifugao, Kalinga, and Mountain Province, located on the northern island of Luzon in the Philippines (Figure 1). It is a landlocked region characterized by mountainous terrain with moderate to very steep slopes. These provinces are home to various Indigenous People (IP) groups. The region is renowned as one of the last forest frontiers in the country and harbors diverse flora and fauna, including the endangered Philippine Eagle found in Apayao province (Araza et al. 2021; Daipan and Franco 2022).

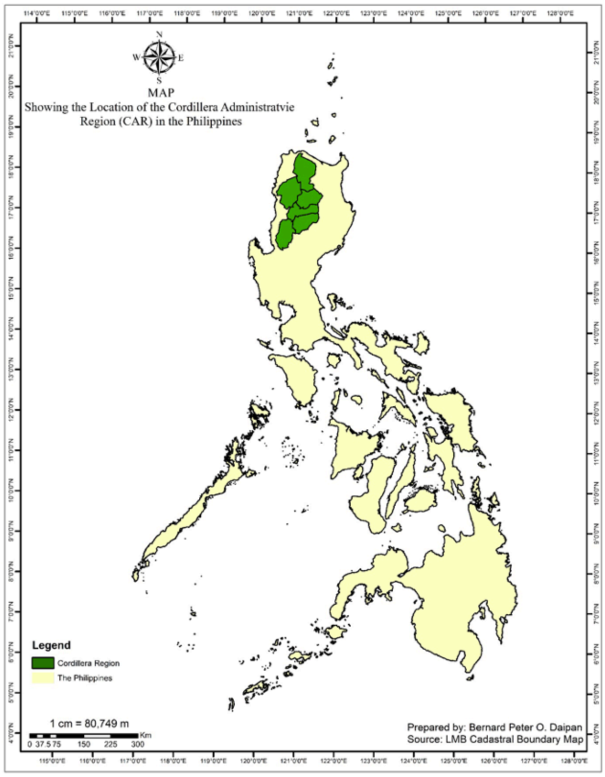

Figure 1: Map showing the study area.

Dataset

Land Use Land Cover (LULC)

The LULC data used in this paper was derived from the European Space Agency's (ESA's) Sentinel-2 imagery with a 10-m spatial resolution jointly developed and produced by Esri, Impact Observatory (IO), and the Microsoft organization. The data displays a global LULC time series from 2017-2021, however, only the 2021 LULC was used in the analysis of this study. The annual LULC data were generated using Artificial Intelligence (AI) and deep learning land classification models (Karra et al. 2021). The models produced 10 classes of LULC, these are water, trees, flooded vegetation, crops, built areas, bare ground, snow or ice, clouds, and rangeland. Here, trees (forest), built areas (settlement), and crops (agricultural) variables were used. The tree class is defined as a considerable collection of tall trees, at least 15 feet or higher, in dense vegetation. The built areas class includes manmade structures such as houses, buildings, and roads, among others. On the other hand, the crop class depicts agricultural areas. The full description of these classes can be found on Esri's website. This 10-m LULC data is open source and can be accessed from the Living Atlas ArcGIS website or through Microsoft's Planetary Computer website.

Road Network

The road network dataset was extracted from the Open Street Map (OSM) data downloaded using the OSMdownloader

Plugins in QGIS. The Philippine roads were a subset of the CAR boundary layer. This served as one of the factors in forest fire vulnerability assessment.

Landslide Vulnerability

The global landslide vulnerability map used in the study area was obtained from the Landslide Hazard Assessment for Situational Awareness (LHASA) developed at Goddard Space Flight Center (GSFC) for detecting real-time rainfall-induced landslides worldwide. This global landslide vulnerability map (raster format) was generated using a heuristic fuzzy approach combining various variables such as elevation, fault lines, deforestation, geologic data, road network, and slope classification (Stanley and Kirschbaum 2017) and the precipitation data from the Global Precipitation Measurement Mission (GPM). The accuracy of this map was assessed using NASA's Global Landslide Catalog (GLC). The landslide vulnerability is presented and classified from Very Low to Very High. This dataset can be downloaded from the GPM NASA website.

Geospatial Analysis

Forest Cover Determination

The downloaded 2021 LULC raster data were subset to the region of interest (ROI), in this case, the Cordillera Administrative Boundary Map, using the extract by mask layer algorithm in raster analysis functions. The extracted data was then converted to a vector layer using the polygonize (raster to vector) algorithm. This was done to easily compute the areas of each LULC type. After converting the dataset into a vector layer, the forest cover was extracted by exporting the selected forest data into a new shapefile layer. The forest cover was intersected with the ROI to determine the forest cover per province in 2021. Areas were computed using the field calculator option found in the attribute table of the map layer.

Forest Fire Vulnerability

In determining the forest fire vulnerability in the ROI, three (3) anthropogenic factors were utilized. These were the road networks downloaded from the OSM, the built-up areas or settlements, and the crops or agricultural areas. Both of these datasets were extracted from the 2021 LULC data in the ROI. Following the methods applied in the study of Sivrikaya et al. (2014), these three variables were buffered to a 100-meter distance to signify a very high risk of forest fire. The buffered datasets were merged and dissolved to show the possible areas where forest fires may take place. The combined layers were clipped using the forest as the input variable to identify forest areas that are highly vulnerable to fire. The areas (in ha) of forest vulnerable to fires were computed for each of the provinces.

Landslide Vulnerability in Forest Areas

The global landslide vulnerability (LV) map was subset to the ROI using the extracted data using mask layer functions in the GIS environment. The subset data was converted to a vector layer and intersected with the boundary of the ROI. The polygonized LV map was then clipped with the extracted forest data from the LULC to identify forest areas vulnerable to landslides in the region. The areas (ha) of each vulnerability class, from very low to very high, were computed per province.

Software Used and Flowchart of Methodology

All the datasets were processed using Quantum Geographic Information System (QGIS) software version 3.16. It is open-source software that can perform various geospatial analyses. All the map layers were projected to the World Geodetic System 1984 (WGS 84) with the Universal Transverse Mercator (UTM) Zone 51 North as its coordinate system. The flowchart of all the geospatial analyses performed in this paper is presented in Figure 2.

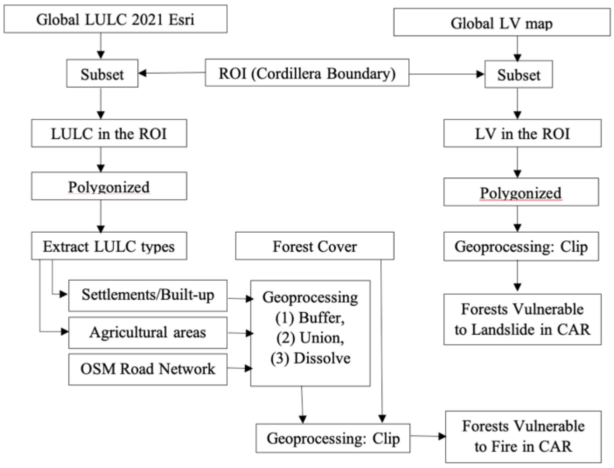

Figure 2: Flowchart of the geospatial analysis in the GIS environment.

RESULTS AND DISCUSSION

Forest Cover

The forest area in the region (Figure 3) is equivalent to around 1.35 million ha, or almost 73% of its total land area. The province of Apayao remains the most forested area in CAR, with an area of around 700 thousand ha. This is followed by Abra and Benguet, with forest areas of around 260 thousand ha and 224 thousand ha, respectively (Table 1). The region is dubbed the watershed cradle of the north since it supplies its neighboring lowland regions with irrigation, domestic water supply, and electricity through its four major dams. The role of these forests in these watersheds cannot be overemphasized. Forests help to keep watersheds stable by protecting the soil surface from the direct effects of torrential rains (Pereira 1989). However, it was observed that the forest areas in the region, particularly in the provinces of Benguet, the northern portion of Abra, and the eastern portions of Ifugao, Kalinga, and Mountain Province, are already fragmented. Only the province of Apayao has contiguous forests that extend to the central part of the region. This may infer that the region's forests are slowly being depleted. In the paper of Daipan and Franco (2022), they mentioned that from 2001 to 2019, there has been a forest loss in the region of almost 71 thousand hectares (ha), with an annual deforestation rate of around 3.7 thousand ha/year. They concluded that these forest losses caused the deterioration of the region's watersheds, which are driven primarily by illegal logging and agricultural expansion. Furthermore, it is a known fact that climate change has a significant impact on forests. But the forests in the region are likely to be more affected by LULC changes compared with climate change as long as the high deforestation rate in the region continues (Kirschbaum and Fischlln 1996). The impact of forest loss in the region, caused by either LULC change or climate change, will always lead to a biodiversity crisis in the study area. Thus, there is an urgent need to protect and conserve the remaining forests in the region.

The forest data generated in this paper is an important input in many conservation plans, project implementation, land use planning, and even to policymakers in the region, if not the country. This data could also serve as a basis for evaluating the reforestation efforts of the government. Finally, the spatially explicit forest map could be used in many different scientific types of research, such as habitat modeling, climate change impact, species distribution, vulnerability assessment, watershed modeling, and hydrologic modeling, among others.

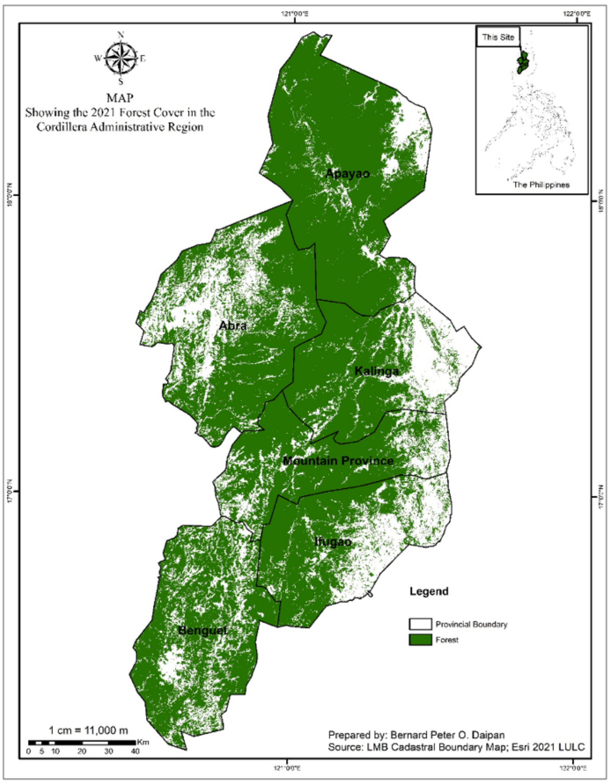

Figure 3: The forest cover of the Cordillera Administrative Region in 2021.

Table 1: The computed forests per province based on the 2021 Land Cover

Province	Area (ha)	Forest Area (ha)	% Forest Cover/ Province
Abra	385,691.69	260,740.27	67.60
Apayao	423,613.41	369,818.85	87.30
Benguet	305,116.74	224,056.61	73.43
Ifugao	258,281.60	158,520.07	61.37
Kalinga	264,892.41	174,265.73	65.79
Mountain Province	228,064.03	170,930.61	74.95
(Region) TOTAL	1,865,659.86	1,358,332.14	72.81

Source: ESA-Global Land Use Land Cover

Forest Fire Vulnerability

The forest fire vulnerability assessment conducted in this paper using anthropogenic factors, such as proximity to roads, settlements, and agricultural areas, found that roughly 116 thousand ha of forest areas in CAR are vulnerable to fires. This vulnerable area makes up approximately 8.5% of the region's total forest area. Benguet province had the highest forest area vulnerable to fire compared with the other provinces in the region, with an estimated area of around 37 thousand ha. The computed forest areas vulnerable to fires per province are presented in Table 2.

Table 2: The forest areas vulnerable to fires in the Cordillera

Provinces	Forest (ha)	Vulnerable to Forest Fire (ha)	%
Abra	260,740.2721	13,438.253	5.15
Apayao	369,818.8484	17,279.545	4.67
Benguet	224,056.6099	37,237.993	16.62
Ifugao	158,520.066	20,158.605	12.72
Kalinga	174,265.734	12,784.002	7.34
Mountain Province	170,930.6099	15,145.495	8.86
Grand Total	1,358,332.14	116,043.893	8.54

The anthropogenic hazard variables were selected since several reports suggested that humans were the primary cause of forest fires in the region, whether intentionally or not (PNA 2019; Torres 2020). Furthermore, according to the authorities, cattle grazing, slash-and-burn or kaingin, and negligence were the origins of the forest fires, particularly in the province of Benguet, which were exacerbated by the dry weather, lack of rain, and northeast monsoon wind (Rappler 2020). This may infer that the presence of human settlements near forest areas increases the chances of fires. Authorities have also claimed that the major cause of forest fires in the region is slash-and-burn farming practices. As traditionally practiced in the region, kaingin farming involves the clearing or cutting down of forests and subsequently burning them to give way to crops (Suarez and Sajise 2010), such as sweet potatoes, cassava, and corn, among others.

Several studies suggest that forest areas with a 100-meter distance from road networks, settlements, and agricultural areas are extremely or highly vulnerable to forest fires (Cáceres 2011; Sivrikaya et al. 2014; Erten et al. 2002). Thus, a 100-m buffer was used in determining the highly vulnerable forest areas to fire incidence in the region. The limitation of this paper is that it did not take into account physical factors like elevation, slope, aspect, and forest type or LULC, which could affect forest fire vulnerabilities in the study area. It was observed on the generated forest fire vulnerability map (Figure 4) that the more fragmented the forest is, the more vulnerable it is to fires.

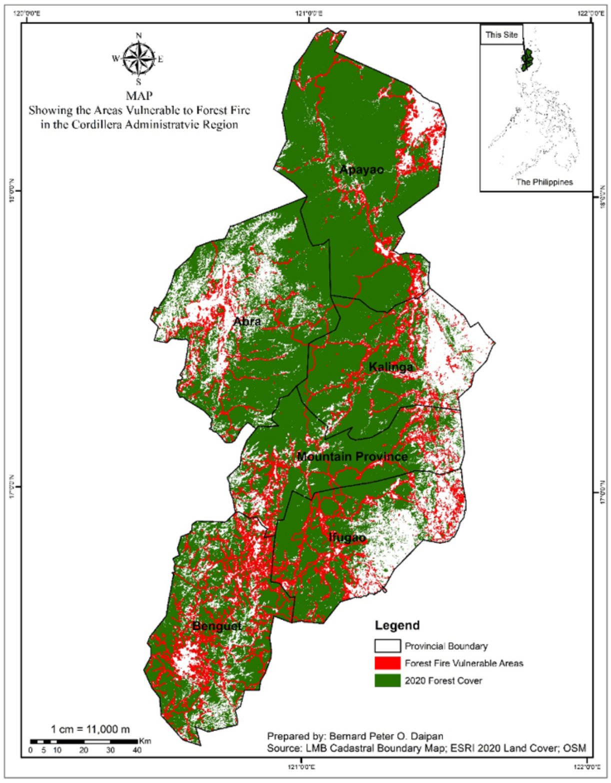

Figure 4: The forest fire-vulnerable areas in the Cordillera Administrative Region.

Forest Fire Incidents

The forest fire incident report in the region was obtained at the Regional Office of the Department of Environment and Natural Resources (DENR). The report contains burned natural forests, plantation forests, and grassland from 2013 to 2020. Also, it contains the estimated damage cost in Philippine pesos (Php). Based on the report presented in Table 3, around 8 thousand ha of natural forest and 11.5 thousand ha of plantation forests were burned during the said period. According to Pogeyed (2001), due to the rugged hilly topography, a lack of proper equipment, and a lack of qualified staff, large forest fires in the region, specifically in the pine forest ecosystems, can burn for weeks and are difficult to suppress. The total reported damage cost of forest fires, including the grassland area, amounts to almost Php. 122 million. The graph in Figure 5 shows that there is an increasing trend of fire incidents and burned areas both in natural forests and plantation forests in the region. This trend could be evidence of the impact of increasing temperatures and a longer drought in the region. When there are more droughts, there will be more fires as a result of the accumulation of more combustible dry organic substances (Kirschbaum and Fischlln 1996).

Table 3: Forest fire incidents in the Cordillera from 2013 to 2020 with their corresponding damage costs.

YEAR	Natural Forest (ha)	Plantation Forest (ha)	Grassland (ha)	Total (ha)	Damaged Cost (Php)
2013	20	317.42	3.95	341.37	3,419,451.99
2014	688.05	265.05	275	1228.1	9,807,066.23
2015	1557.42	1167.49	83.28	2808.19	9,458,400.91
2016	1121.57	3773.62	468.76	5363.95	39,839,839.66
2017	55.03	939.6	0	994.63	9,140,346.08
2018	289.64	2498.48	26.92	2815.04	33,005,836.83
2019	2442.46	1207.83	82.17	3732.46	10,080,168.88
2020	1897.882	1397.27	128.61	3423.762	6,951,091.64
Total	8,072.05	11,566.76	1,068.69	20,707.50	121,702,202.22
Average	1,009.01	1,445.85	133.59	2,588.44	15,212,775.28

Source: DENR Regional Office, Cordillera Region

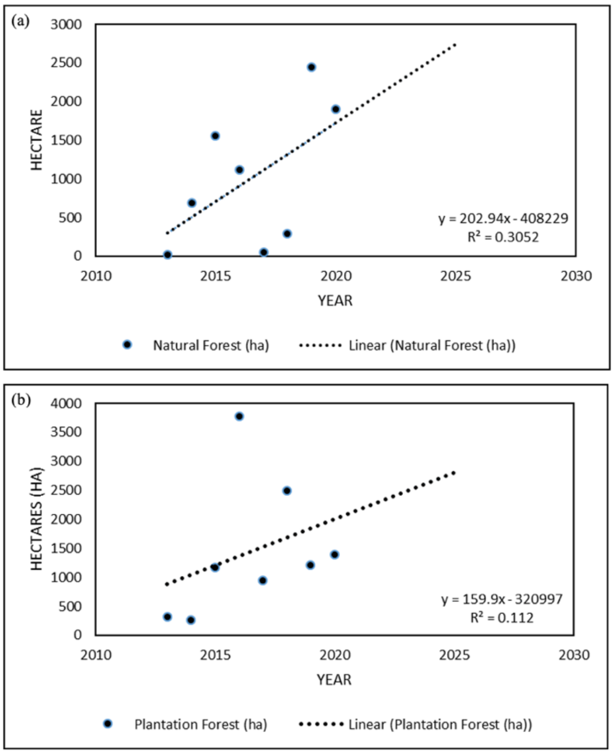

Figure 5: The trend of forest fire incidence and burned areas in the CAR from 2013 to 2020. (a). Natural forest; (b) Plantation forest.

Based on the report (Figure 6), Benguet province had the highest incidence of forest fire, with 11 thousand ha burned from 2013 to 2020, or 54% of the total burned forest area in the region. This was followed by Kalinga, Mountain Province, Ifugao, and Abra. The province of Apayao recorded the lowest burned area in the same period, with only 43 ha of forest. One plausible reason for the high incidence of forest fires in the province of Benguet is that its major vegetative cover is the pine forest, which is more vulnerable to fires compared to other forest ecosystems in the country (Pogeyed 2001). Although pine forests can also be found in the provinces of Ifugao, Mountain provinces, and a small portion of Abra, the province of Benguet seems to be more affected by forest fires. This could be attributed to various factors such as fragmented forests, proximity to settlements, upland farming practices, topography, and even a shortage of rainfall during the dry season in the province.

Landslide-Vulnerable Forest Areas

The total area of forests in the region that are very highly vulnerable to landslides, based on the overlay analysis using the data from LHASA, is almost 250 thousand ha, or 18% of the total forest area in the region. Benguet Province had the largest forest area that was very highly vulnerable to landslides, with 164 thousand ha. The provinces of Abra, Mountain Province, and Kalinga also had forest areas with more than 10 thousand ha that are very highly vulnerable to landslides (Table 4).

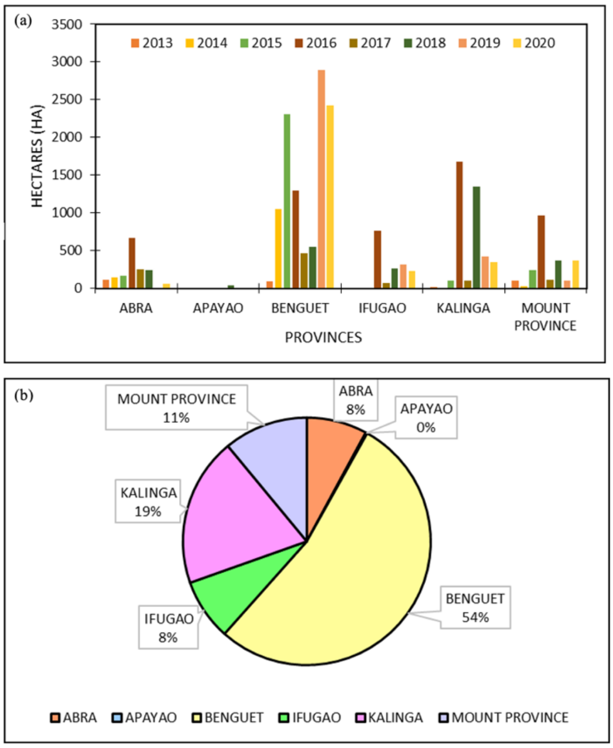

Figure 6: The (a) provincial data on the burned forest areas from 2013 to 2020 and the (b) percent distribution of burned forests region-wide.

It is interesting to note that almost 73% of the forests in the region have high to very high vulnerability to landslides. This only suggests that the region's topography has a rough and steep terrain that could be aggravated by anthropogenic factors such as the data used in generating the landslide vulnerability map. It was observed in Figure 7 that almost 80% of the forests in Benguet are very highly vulnerable to landslides (represented by the red color on the map). The forests in the eastern portion of Abra are also very highly vulnerable. The red linear patterns observed in the provinces of Apayao, Kalinga, Mountain Province, and Ifugao could be forest areas with slope modifications such as road construction, agricultural and/or settlement area expansion, which are very highly vulnerable to landslides. These areas should be prioritized in terms of risk reduction planning and implementation not only to minimize the loss of forests but, more importantly, to minimize or prevent their effect on humans.

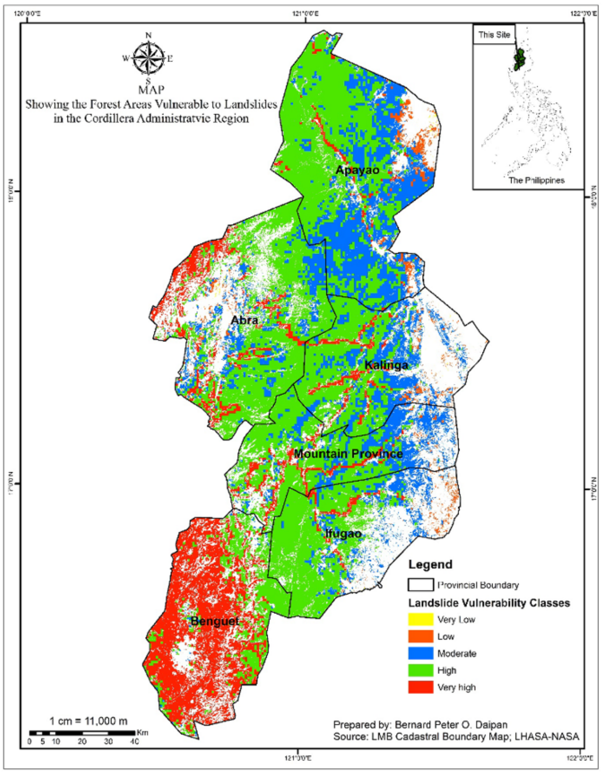

Figure 7: Forest areas vulnerable to landslides in the Cordillera Administrative Region.

Table 4: Forest areas vulnerable to landslides at different classes in the Cordillera.

Province	Very Low	Low	Moderate	High	Very High	Total
Abra	246.43	3,778.78	48,881.86	165,279.95	41,139.15	259,326.16
Apayao	270.62	13,118.14	141,263.95	205,436.76	7,933.58	368,023.04
Benguet		0.76	2,042.34	56,433.75	164,098.22	222,575.07
Ifugao	34.63	3,988.65	33,797.58	114,130.86	6,258.36	158,210.08
Kalinga	85.58	5,169.99	59,838.64	96,281.84	12,870.27	174,246.33
Mountain Province	5.44	1,832.05	53,570.04	98,473.13	16,885.58	170,766.24
Total	642.69	27,888.36	339,394.40	736,036.29	249,185.17	1,353,146.91

Table 5: Number of landslide occurrences in the Cordillera from 2007 to 2018.

Province	Year												Total
	07	08	09	10	11	12	13	14	15	16	17	18	
Abra		1		2		1	1						5
Apayao	1		2	7									10
Benguet	4	9	21	12	8	4	13		13	14	3	4	105
Ifugao	1	1	1	5	4			1		4	1	3	21
Kalinga		1	4	9	1	2				3		1	21
Mountain Province	1		4	2	1	1			3	6		2	20
Total	7	12	32	37	14	8	14	1	16	27	4	10	182

Source: NASA's Global Landslide Catalog

Though this paper focuses only on the forest areas vulnerable to landslides in the region, the spatial data generated in this study could be used in planning and risk mitigation activities in the provinces of the region. It could be incorporated into the different forest conservation and development plans, such as the Forest Land Use Plans (FLUP) and/or Comprehensive Land Use Plans (CLUP), of the different LGUs from the provincial to municipal levels. It could also be an important input to the Local Climate Change Action Plan (LCCAP). It is the LGUs' action plan to address climate change problems. According to the Local Government Academy (LGA) (2017), it focuses on both climate change adaptation and mitigation, and it explains how LGUs aim to respond to the effects of climate change and include them in their development plans. Thus, identifying the forests at risk of landslides using data tested by NASA's disaster program and stakeholders in real-world scenarios is extremely beneficial. LHASA version 2 is a powerful landslide vulnerability assessment tool that is freely accessible to the general public. However, appropriate geospatial techniques should be executed to generate the data at the local or provincial level.

Landslide Occurrences

At present, an online database or comprehensive list of historical landslide occurrences in the region from government agencies is nonexistent. However, a landslide occurrence compilation from NASA's Global Landslide Catalog (GLC) was used in quantifying and evaluating the landslide occurrences in the region. The data is from the Cooperative Open Online Landslide Repository (COOLR), which is a worldwide database of landslide occurrences from scientists, citizen scientists, and NASA. The recorded landslide incidents from the GLC were compiled through internet news media, newspaper links to reported landslides, hazard databases, scientific reports, blog entries, and other sources. The landslide catalog's major source of information is online news items, which can be obtained through Google Alerts and other search engine sources (Kirschbaum et al. 2010; Kirschbaum et al. 2015).

Based on this data, a total of 182 occurrences of landslides in the region from 2007 to 2018 were recorded. As expected, Benguet Province had the highest number of landslides in the region, with a total of 105 incidents. The lowest was recorded in the province of Abra, with only 5 incidents in 12 years (Table 5). As discussed earlier, the rugged, mountainous nature of the province of Benguet contributes to its vulnerability to landslides. According to the Cordillera Disaster Response and Development Services (CDRDS) (2021), other contributory factors that trigger the landslide in the region include the forest cover reduction due to anthropogenic activities such as small and large-scale mining activities, slash-and-burn agricultural practices or "kaingin", particularly in the upland communities of Abra, Benguet, Kalinga, and Mountain Province, which is still persistent at present.

The limitation of this data is that the landslide occurrences in the region were only represented by geographic points in the map layer (Figure 8). It has no spatial data as to the extent of the landslide, so the affected area cannot be computed or even overlaid on the forest map. Based on the landslide information from NASA-GLC, planning decisions, such as project location, design, and construction methods must consider the possibility of landslide occurrence. To effectively evaluate the degree of landslide vulnerability in the region, more comprehensive information, such as the meets and bounds of landslide occurrence, should be obtained.

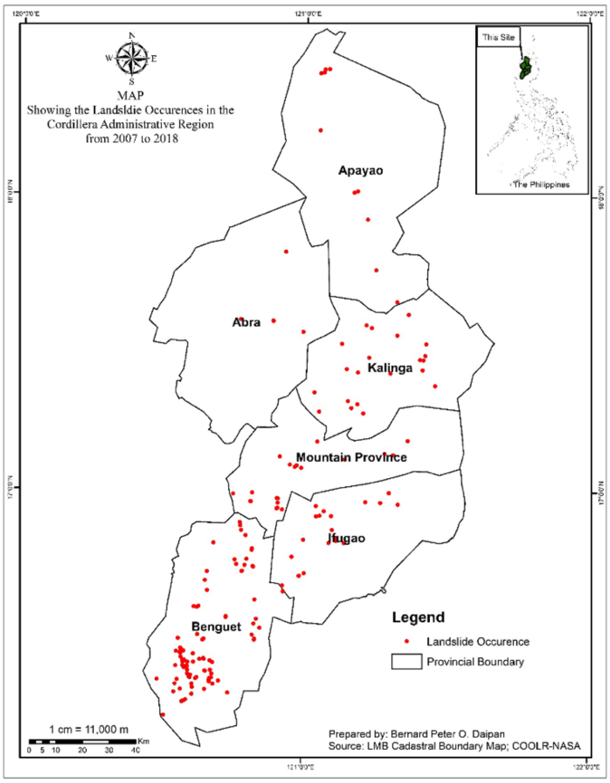

Figure 8: Landslide Occurrences in the Cordillera Administrative Region.

Projected Temperature and Precipitation Changes and Their Implications for Forest Vulnerability in the Cordillera Region

The projected changes in temperature and precipitation at the provincial level were based on the Representative Concentration Pathway (RCP) scenarios obtained from the Development of high-resolution observation-based gridded sub-daily climate data for the Philippines (ClimGridPh) project of the Department of Science and Technology – Philippine Atmospheric, Geophysical, and Astronomical Services Administration (DOST-PAGASA) (2020). Table 6 presents the projected quarterly changes in temperature for the Cordillera region in the Philippines. It provides information on the observed baseline temperatures and the projected changes for two future periods: 2036-2065 and 2070-2099. The analysis reveals a consistent warming trend across the Cordillera region. On average, the temperatures are projected to increase by approximately 1°C from 2036 to 2065 compared to the observed baseline. This increase is expected to continue in the subsequent period of 2070-2099, with average temperature changes ranging from 1.1°C to 1.4°C. These temperature increases are not limited to a specific season but are anticipated throughout the year. The provinces within the Cordillera region are likely to experience similar patterns of change. While the specific values may differ slightly between provinces, the overall trend remains consistent across the region. These projected changes in temperature can have significant implications for the Cordillera's forest ecosystem. The rising temperatures may impact forest fires, requiring appropriate measures to mitigate potential risks.

Considering the average changes in precipitation for the Cordillera region, it is estimated that between 2036 and 2065, there will be an average increase of 4.27 mm in DJF, while the other seasons are projected to experience a decrease ranging from 8.88 mm to 29.93 mm. Between 2070 and 2099, the average changes indicate a slight decrease in precipitation, with values ranging from -0.58 mm to -24.3 mm across the seasons. The projected increase in temperature and decrease in precipitation during the dry season in the region may increase the occurrence of forest fires soon, especially in the pine forest ecosystems (Jaranilla-Sanchez, et al. 2007). Under this warmer climate, it is expected that more severe forest fires, more burned areas, and a longer fire duration (Flannigan et al., 2006) may take place in the coming decades, which will in turn affect more people and livelihoods in the region.

Approaches for Strengthening Disaster Preparedness

Strengthening disaster preparedness and recovery at the barangay level is still the best adaptation strategy. To enhance disaster preparedness and recovery at the barangay level, a comprehensive approach is needed. Firstly, it is important to identify the community's vulnerability to forest fires and landslides. This can be achieved through risk assessments and community mapping with the help of technical experts who can model the areas in the barangay prone to such disasters, and this paper, including all the generated data, can be used. Once these vulnerabilities are identified, action planning can be initiated. The plan should include escape routes in case of forest fires, first aid, disaster preparedness kits, and evacuation places. It is also crucial to have a recovery action plan in place to ensure continuous operation during and after a disaster. In addition, the formation and strengthening of Barangay forest fire brigades or volunteers should be conducted. Each barangay with a high risk of forest fires should form a group or team of volunteers to respond to forest fires. Proper training in forest fire suppression and rescue operations should be provided to the forest fire brigade members.

Rehabilitation of degraded forest ecosystems and watersheds should also be prioritized to minimize the occurrence of landslides. The identification of degraded forest areas in the community is highly recommended, and a forest rehabilitation action plan should be created at the barangay level with a definite time frame. The plan should include seedling production, out-planting of fire-resistant forest tree species, maintenance, and protection until the degraded areas or fragmented forests in the community are restored.

Another important strategy is to increase forest resistance and resilience by establishing adapted (forest fire-resistant) and acceptable species and planting mixed species in an uneven-age forest structure. This includes fire hazard reduction through the construction of forest fire buffer zones, particularly along roads and human settlements. The reduction of fragmented forest landscapes by incorporating corridors or vegetation strips in agricultural areas should also be implemented.

Table 6: The projected quarterly changes in temperature per province in the Cordillera.

Provinces	Temperature Change	DJF	MAM	JJA	SON
Abra	Observed Baseline	24.5	27.4	27.2	26.4
	Projected Change (2036-2065)	25.5	28.4	28.2	27.4
	Change in C°	1	1	1	1
	Projected Change (2070-2099)	25.6	28.8	28.6	27.7
	Change in C°	1.1	1.4	1.4	1.3
Apayao	Observed Baseline	24.8	28	28.4	27.1
	Projected Change (2036-2065)	25.7	28.8	29.4	28
	Change in C°	0.9	0.8	1	0.9
	Projected Change (2070-2099)	25.8	29.2	29.7	28.3
	Change in C°	1	1.2	1.3	1.2
Benguet	Observed Baseline	19.4	21.9	22	21.2
	Projected Change (2036-2065)	20.5	23	23.1	22.3
	Change in C°	1.1	1.1	1.1	1.1
	Projected Change (2070-2099)	20.7	23.4	23.4	22.5
	Change in C°	1.3	1.5	1.4	1.3
Ifugao	Observed Baseline	22.2	25.6	25.8	24.5
	Projected Change (2036-2065)	23.2	26.5	26.8	25.5
	Change in C°	1	0.9	1	1
	Projected Change (2070-2099)	23.3	26.9	27.2	25.8
	Change in C°	1.1	1.3	1.4	1.3
Kalinga	Observed Baseline	23.8	27.5	27.7	26.1
	Projected Change (2036-2065)	24.8	28.4	28.7	27.1
	Change in C°	1	0.9	1	1
	Projected Change (2070-2099)	24.9	28.8	29.1	27.4
	Change in C°	1.1	1.3	1.4	1.3
Mountain Province	Observed Baseline	22.7	26	26.1	24.9
	Projected Change (2036-2065)	23.7	27	27.1	25.9
	Change in C°	1	1	1	1
	Projected Change (2070-2099)	23.8	27.3	27.5	26.2
	Change in C°	1.1	1.3	1.4	1.3
Cordillera Region	Average Change in C° (2036-2065)	1	0.95	1.02	1
	Average Change in C° (2070-2099)	1.1	1.3	1.4	1.3

Source: DOST-PAGASA, 2020

Table 7: The projected changes in precipitation per province in the Cordillera.

Provinces	Precipitation (mm)	DJF	MAM	JJA	SON
Abra	Observed Baseline	43.5	221	1219	634
	Projected Change (2036-2065)	47.4	204.7	1190.4	610.6
	Change in mm	3.9	-16.3	-28.6	-23.4
	Projected Change (2070-2099)	41.2	208.4	1197.1	616.4
	Change in mm	-2.3	-12.6	-21.9	-17.6
Apayao	Observed Baseline	144.6	184	822.7	720.1
	Projected Change (2036-2065)	146.3	176.8	789.6	707.8
	Change in mm	1.7	-7.2	-33.1	-12.3
	Projected Change (2070-2099)	146.1	177.3	794	712.1
	Change in mm	1.5	-6.7	-28.7	-8
Benguet	Observed Baseline	47.7	422	1735	932
	Projected Change (2036-2065)	54.2	411	1710.4	907.2
	Change in mm	6.5	-11	-24.6	-24.8
	Projected Change (2070-2099)	46.1	408.4	1718.2	919.8
	Change in mm	-1.6	-13.6	-16.8	-12.2
Ifugao	Observed Baseline	102.6	321	1071	724.9
	Projected Change (2036-2065)	107.4	313.8	1035.2	710.3
	Change in mm	4.8	-7.2	-35.8	-14.6
	Projected Change (2070-2099)	102.8	310.7	1039.4	709.4
	Change in mm	0.2	-10.3	-31.6	-15.5
Kalinga	Observed Baseline	92.3	228	892.3	691.9
	Projected Change (2036-2065)	97.1	224.3	855.8	678.1
	Change in mm	4.8	-3.7	-36.5	-13.8
	Projected Change (2070-2099)	93	217.7	864	678.5
	Change in mm	0.7	-10.3	-28.3	-13.4
Mountain Province	Observed Baseline	74.8	286.8	1121.1	699.2
	Projected Change (2036-2065)	78.7	278.9	1100.1	681.2
	Change in mm	3.9	-7.9	-21	-18
	Projected Change (2070-2099)	72.8	276.7	1102.6	690.1
	Change in mm	-2	-10.1	-18.5	-9.1
Cordillera Region	Average Change (2036-2065)	4.27	-8.88	-29.93	-17.82
	Average Change (2070-2099)	-0.58	-10.60	-24.30	-12.63

Source: DOST-PAGASA, 2020

Finally, multi-stakeholder partnership and participation should be considered. The adaptation of forest communities requires the participation of different forest stakeholders, such as researchers, financial institutions (both local and international), government agencies like DENR, DA, BFP, PNP, DOST, MDRRM, NCIP, Academe, LGUs, among others, and the community as the primary actors. Improved decision-making and shared understanding of future worst-case scenarios brought about by climate change should be prioritized to ensure the success of disaster preparedness and recovery efforts at the barangay level.

CONCLUSION

The region's forest cover was around 1.35 million ha in 2021, accounting for over 73% of its total land area. It is, however, already fragmented and rapidly depleting, as shown in the remotely sensed land cover map. Also, these forests are vulnerable to fire on an estimated 116 thousand ha, or 8.5% of the forest in the region. It was observed that the more fragmented the forest, the more vulnerable it is to fires. From 2013 to 2020, eight (8) thousand ha of natural forest and 11.5 thousand ha of plantation forests were burned, with kaingin practices being the most likely cause. There has been an increasing trend of fire incidents and burned areas observed in both natural and plantation forests in the region. This trend could be linked to the region's rising temperatures and extended drought. The expected increase in temperature and decrease in precipitation in the region during the dry season could lead to an increase in forest fires soon, particularly in pine forest ecosystems. More severe forest fires, larger burned areas, and longer fire durations are projected as a result of the warming climate in the decades ahead, affecting more people and livelihoods in the region. Furthermore, nearly 73% of the region's forests are vulnerable to landslides at a high to extremely high level. This is reflected in the 182 landslides that occurred in the region between 2007 and 2018. The contributory factors to these landslides include the region's rough topography, forest cover decline owing to anthropogenic activities such as local and large-scale mining, and slash-and-burn agriculture practices or "kaingin" particularly in upland communities.

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CONFLICT OF INTEREST

The authors declare no conflicts of interest, whether actual or perceived, that could potentially influence the impartiality or objectivity of the research findings presented in this manuscript.

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