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Soil Erosion and Composite Land Degradation Using USLE Model and Geomatics Approaches for Soil Conservation of Mount Data National Park

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Abstract

Mount Data National Park (MDNP) situated across the municipalities of Sabangan, Tadian, and Bauko in Mountain Province, Philippines (16°52′41′′ N, 120°50′18′′ E), encompasses approximately 3,502.10 hectares of ecologically critical, high-elevation land. This study assessed historical and projected soil erosion dynamics on the plateau, evaluated associated soil degradation risks, and identified key anthropogenic drivers to inform sustainable management strategies. Utilizing Remote Sensing and Geographic Information System (GIS) techniques alongside the Drivers, Pressures, State, Impacts, and Responses (DPSIR) framework adapted from regional literature, the study revealed significant spatio-temporal dynamics characterized by agricultural expansion and forest contraction. Between 1992 and 2022, agricultural land expanded from 1,267.99 ha to 1,774.73 ha, while shrub and grasslands increased from 549.37 ha to 600.08 ha. Conversely, forest cover declined markedly from 1,374.61 ha in 1990 to 941.91 ha in 2022, and built-up areas decreased from 307.10 ha to 181.42 ha. Predictive modeling through 2030 projects a further reduction in forest cover (by 73.68 ha or 2.13%) and built-up areas (by 61.99 ha or 1.78%), driven by continued gains in agricultural land (87.82 ha or 2.47%) and shrub/grassland (50.71 ha or 1.44%). DPSIR analysis indicates that these conversions trigger severe environmental and socio-economic degradation, including the loss of natural vegetation, terrestrial biodiversity decline, accelerated soil erosion and fertility loss, deteriorated water quality and yield, microclimate alteration, and escalating farm input costs that diminish crop quality. Anthropogenic pressures remain the primary driver of forest conversion to agriculture on the Mount Data National Park (MDNP). To achieve land degradation neutrality, the immediate, wide-scale adoption of sustainable land management (SLM) practices is imperative. It is strongly recommended that the *Sangguniang Panlalawigan* and congressional representatives of the affected areas enact legislative resolutions establishing an inter-agency committee led by the DENR–Protected Area Management Bureau (PAMB) to review, revise, and enforce sustainable land-use policies for MDNP.

Keywords: National Park, soil erosion, degree and extent of soil erosion, composite land degradation, geomatics approaches, and universal soil loss erosion.

1. Introduction

Land is one of the precious limited natural resources, but its inherent production potential is under pressure due to various land use activities, primarily for agricultural expansion and economic growth.

These activities have transformed one-third to one-half of our planet's land surface in the form of forest clearance, agricultural practice, and urban expansion, which made profound impacts on ecosystem service, food production, and the environment [1]. While land and soil degradation is a natural process, human land use activities degrade and pollute the quality of soils and land utility. Soil loss has detrimental impacts on agricultural productivity and overall ecological functions that ultimately affect rural livelihoods and living standards [3] [4] [5] [6]. Soil loss is a global problem that affects both developing and high-income countries. However, its impact is more significant in poorer countries, where agricultural activity is crucial to the development and livelihoods of the majority of the population [7] [8].

Based on a Global Assessment of the Status of Human-induced soil degradation classification, 1990 (GLASOD), about 70% of the country's land has been degraded, with soil erosion as the dominant form of land degradation in the Philippines. This severe environmental degradation has had a magnifying effect on the local livelihoods that requires urgent intervention measures [9].

Mount Data National Park is one of the typical highland areas in the northern Philippines, where land degradation has been a challenge to the region. It could be recognized that historically unsustainable land use, high population pressure, the uneven spatial and temporal distribution of rainfall, rugged terrain (which allows for easy soil runoff), low vegetation cover, and inadequate investment in soil and water conservation (SWC) measures, progressive expansion of cultivation onto steeper slopes, lack of following periods, limited or lack of access to credit and inputs, and use of crop residue and manure for soil fertility management, intensify environmental degradation [10].

These issues are all closely interrelated and interwoven in a complex and mutually reinforcing cycle of environmental trap, which has led to enduring food deficiency, persistent poverty, and associated household food insecurity. This is evident from many productive safety net program beneficiaries and highland-farming aid-dependent populations in the study area. Besides the local socio-economic and bio-physical challenges mentioned above, the impact of global climate change and sporadic drought exert extra strain on the community's livelihood pattern and soil conservation strategies.

There have been rare studies carried out to quantify erosion rates in MDNP. In addition, the soil loss estimated by different researchers varied for the plateau. This implies that there is a need to have specific information on soil erosion to support timely information for decision-makers and land managers that plan the correct soil conservation planning. As different portions of the landscape vary in sensitivity to erosion through differences in their slope, soil, and land use and cover attributes, it was necessary to estimate rates of soil erosion and develop a soil loss intensity map of the study plateau using USLE within a GIS environment, identify severity areas and prioritize areas for specific soil conservation plans.

2. Objectives of the study

This study zeroes in on the search for sustainable land use practices and effective conservation and utilization efforts for MDNP, using the Universal Soil Loss Equation (USLE) model and Geographic Information System (GIS). The results of this analysis are critical factors that should be considered before anyone can prepare an intervention on soil conservation appropriate for the MDNP, Mountain Province, Northern Luzon highlands of the Philippines. In particular, the study tries to address the following specific objectives:

1. Estimate the degree and extent of soil erosion using the Universal Soil Loss Equation (USLE) model through geo-informatical approaches of the Mount Data National Park.
2. Analyze the Composite Land Degradation Index (CLDI); and
3. Simulate the USLE model parameters and come up with predictive soil erosion and,
4. To offer recommendations design to assist policymakers, such as the MDNP-PAMB, and government agencies in balancing conservation with developmental pressures.

3. Literature review

Global efforts to combat land degradation

There is a growing conviction that countries' struggle for poverty eradication and sustainable development is unlikely successful without effectively addressing land degradation challenges [11] [12]. Countries' research reports indicate, however, that there is promising future to avert land degradation trends and reverse degraded lands with appropriate interventions and efforts. This is supported by evidence that a significant proportion (2.7%) of world's land area have showed improvement during the previous three decades [13].

Despite there have been persistent efforts by the global community to combat land degradation since the United Nations Conference on Environment and Development (held in Rio de Janeiro in June 1992), the success is still smaller as compared to the extent of the problem [5] [14]. Cognizant of the need for a more concerted management of land resources than ever before, heads of states and governments of world adopted the Rio+20 declaration, the Future We Want' at the UN General Assembly held in 2012 and stressed on the issue of land degradation as an urgent and a top priority. They agreed to strive for the realization of land-degradation neutral world in the context of sustainable development [15].

Furthermore, land degradation neutrality and the need for SLM were established as one of the targets in the sustainable development goals as adopted by the UN summit in New York in September 2015. Accordingly, goal number 15 of the sustainable Development Goals were adopted by the United Nations to care for, restore and enhance sustainable use land resources, combat land degradation and reverse degraded lands [3] [13] [16]. It was in this line that the Addis Accord promoted the need for mobilization of financial resources for the achievement of SLM, protecting our ecosystems for all by combating desertification and restoring degraded land [13].

Land degradation in Philippine context

The Philippines covers an estimated area of 29.9 million hectares of land much of which are undulating with at least three-fifths classified as "uplands with sloping terrain." There are 419 river basins with steep and short topography. The country is one of the most seriously environmentally threatened nations because of widespread soil erosion that affect the sustainability of its agriculture and forestry production. Almost half (45%) of the arable lands in the Philippines have been moderately to severely eroded. Moreover, significant watershed integrity has been lost due to inappropriate upland agriculture, deforestation, road construction and mining, leading to water shortages, sedimentation and devastating effects of natural disasters, such as typhoons, increasing population and rural poverty, poor land and watershed management and increasing incidence of El Nino and La Nina [3] [17] [13] [18].

Further, about half of the total population of the country, which stands at around 93 million, the *Philippines* had a total *population* of 109,035,343) are dependent on natural resources as their source of livelihood and income. Most of these people (28%) are living below the poverty line. The declining productivity of their farm plots due mainly to soil erosion, nutrient depletion and water deficiency further sinks them into poverty [17] [19].

Continuous degradation of land resources and reduction in their productivity would affect about 35% of the labor force which is dependent on agriculture. It would also most likely lower the agriculture sector's contribution to the economy which was quite significant in 2010 posting an average of 18% of Gross Domestic Product (GDP). Moreover, the income generated from the export of agricultural products would not be sustained and would decline over the long term [17] [3].

The saturation of lowlands (0-18% slope classified as alienable and disposable (A&D) lands for agriculture development) pushes landless fanners to move up into forest lands where appropriate agriculture support cannot be provided by Department of Agriculture (DA) because these areas are classified as public forest lands which are under Department of Environment and Natural Resources' (DENR) jurisdiction. Even if some upland areas beyond 18% in slope (boundary for forest lands) are found suitable for agriculture cultivation, they cannot be developed for such by virtue of existing laws [5] [13] [20]. In many such areas, DA and DENR are having difficulties in introducing Sustainable Land Management (SLM) technology packages (DA espouses the use of soil conservation fanning methods while DENR requires the practice of community-based agroforestry methods) because of the large number of distantly and spatially scattered and hardly accessible upland farmers and the lack of coordination between the two departments in maximizing their extension services [21].

Land degradation in the Philippine highlands

The forests, which used to blanket the uplands, have now been largely cleared. According to the Department of Environment and Natural Resources, the country's forests cover in 1900 was 21 million ha (70% of land area); by 2005, this was down to 7 million ha (23%). However, removal of primary forests should not be largely attributed to intensification; rather, logging was initially responsible for the degradation of primary to secondary forests and grasslands. This opened forest land to shifting cultivation and much later, to intensive agriculture [22].

The Cordillera Administrative Region's (CAR) total land area is 1,865,660 hectares or 6.2 percent of the total land area of the country. It has a mountainous topography characterized by towering peaks, plateaus and intermittent patches of valley. About 71 percent of the region's land area has slopes of 30 degrees and above. CAR has six provinces these are: Abra, Apayao, Benguet, Ifugao, Kalinga and Mountain Province, and two cities – the chartered city of Baguio and the component city of Tabuk in Kalinga. Soil erosion was the most common type of soil degradation. The majority of the land area of the region were susceptible in slight erosion (36%). There were also areas susceptible to moderate (32%) to severe erosion (22%).

Human activities such as, land use conversion, deforestation and illegal logging, kaingin and other unsustainable farming practices, and poor land and water management have caused the quality of soil to decline contributing to soil degradation. UN Food and Agriculture Organization (FAO) defined soil degradation as the change in soil health status resulting in a diminished capacity to provide goods and services [19].

Land management sustainability indicators and assessment method

Assessing SLM is not an easy task. This is due to the fact that the determination of spatial and temporal boundaries for assessment is difficult. Moreover, selection of indicators to evaluate is not simple and sustainability evaluation requirement long term data which are practically scarce especially for developing countries [23]. Despite these challenges, most literatures have suggested some ideal indicator for the assessment of sustainable land management.

Indicators are pointers which show the condition, quality or state of the environment. Such indicators are used to monitor the sustainability status of land use and management systems and to determine whether the quality of land remains stable or is declining or improving over time [24]. The literature suggests that the following components are key indicators for the appraisal and monitoring of SLM practices: LULC dynamics; status of biodiversity; water availability and quality; biomass productivity; socio-economic conditions; land productivity trends (annual and perennial crops, pastures, trees etc.); soil fertility status; rate of runoff, condition of soil erosion and sedimentation [25].

Problems of land degradation can be documented in many parts of the world to various degrees with various impacts [26]. However, there is no single best method for assessing land degradation or rehabilitations. The most common approach is the integration of different sources of information. In these methodological approaches, the status and trends of land degradation or rehabilitation dynamics are evaluated based on site-based indicators (e.g. laboratory measurements of samples taken from the field and field measurements), use of geo-spatial data analysis derived from remote sensing (e.g. the use of GIS tools like LULC and NDVI) and stakeholder perspectives including experts judgment, land users opinion, in-depth interviews and observations on changes in land productivity [12] [27] [28].

Role of Remote Sensing and GIS in Sustainable Land Management

Land resource and environmental decision makers require quantitative information on the spatial distribution of land use types and their conditions as well as temporal changes. Undoubtedly Remote Sensing and GIS technology has enabled ecologist and natural resource managers to acquire timely data and observed periodical change [28]. Remote sensing and GIS are, therefore, powerful tools to obtain precise and timely information on the status of the natural resource before and after the implementation of SLM program, indicating the changed scenario. Remote Sensing technology integrated with GIS has emerged has an efficient, time saving, cost effective and indispensable tool for watershed resources management and monitoring activities [21].

Multi-temporal remotely sensed data conjunction with socio-economic not only provide input for better sustainable land management implementations but also help in monitoring its success and progress. It is also important in delineation, characterization, prioritization of erosion prone areas and generation of variety of derived maps of the area of interest [11]. The nature and extent of the change, and the spatial distribution and relationship of the change need attention when examining the state of natural environment including LULC dynamics using GIS and remote sensing [29].

Soil Erosion Models

To estimate soil erosion and to develop optimal soil erosion management plans, many erosion models, such as Universal Soil Loss Equation (USLE), Water Erosion Prediction Project (WEPP), Soil and Water Assessment Tool (SWAT), and European Soil Erosion Model (EUROSEM), have been developed [30] [31] [32] [33]. Among these models, the USLE has remained the most practical method of estimating soil erosion potential in fields and to estimate the effects of different control management practices on soil erosion for nearly 40 years while other process-based erosion models have intensive data and computation requirements [34]. Although originally developed as an empirical model, revisions of the USLE could lead to a conceptual model that provides a capacity to extend well beyond the conditions experienced in the associated data set [30].

Many refinements and revisions have been made to produce the Revised Universal Soil Loss Equation (RUSLE), but it overestimates soil erosion if the surface of soil has a high capacity to infiltrate rainfall; this is due to the lack o f a runoff factor in the RUSLE [3]. The degree of overestimation falls as the ability of the soil to produce surface runoff increases. A number of models have been developed to attempt to overcome inaccuracy in estimation of soil erosion by considering short time periods rather than over a year, such as the Modified Universal Soil Loss Equation MUSLE (Williams 1976) which performed better than the Universal Soil Loss Equation (USLE) in estimation and prediction of soil loss [34] [35]. However, MUSLE estimates the overall loss of soil during a single rainfall event and so would require rainfall intensities from a number of gauges spread over the study area, which are not available here and so MUSLE is not appropriate for this study. Land degradation can also be evaluated through prediction of the amount of soil erosion using USLE methodology [21] [34]. Appropriate and consistent quantitative techniques for soil erosion estimation and prediction can be provided by USLE [34] [36].

USLE is particularly appropriate because it may enable a linkage to be established between land cover, topography, soil characteristics and farming practice and soil loss, particularly through water erosion [34]. USLE has been widely used to provide a quantitative and consistent approach for estimating soil loss in hilly areas [30]. USLE has had an extremely profound influence on how research on the conservation of soil is conducted over the whole world. It is able to forecast the distribution of soil erosion spatial patterns and evaluate its causes [34]. The USLE holds many benefits because of a perceived ease of parameterization use and leads to a more conceptual approach that gives a flexible capacity beyond the experienced conditions in the related data set. Although USLE has met with practical success as support for the reduction of soil erosion, it cannot simulate soil erosion as this is a dynamic process scattered through watersheds and time changing [37].

4. Materials and methods

Profile of the Study Area

Location and Size

Geographically, the study area entirely lies within the Municipalities of Sabangan, Tadian, and Bauko, in Mountain Province, Cordillera Administrative Region (CAR). It is situated between 16°52'41" north latitude and 120°50'18" East longitude (Figure 1). The MDNP, Mountain Province section covers a portion of the MDNP and 100 meters on both sides of the length of the Halsema National Road from Barangay Sinto, Bauko, down to Barangay Napua, Sabangan. It has an approximate area of 3,502.10 hectares based on the generated area from the DENR, CENRO Sabangan report (2019). The location of the study sites are in Barangays Sinto, Mount Data, Sadsadan, Monamon Sur, Mabaay all of Bauko municipality, and barangays of Lenga and Dacudac, Tadian all of Mountain Province [10] [38].

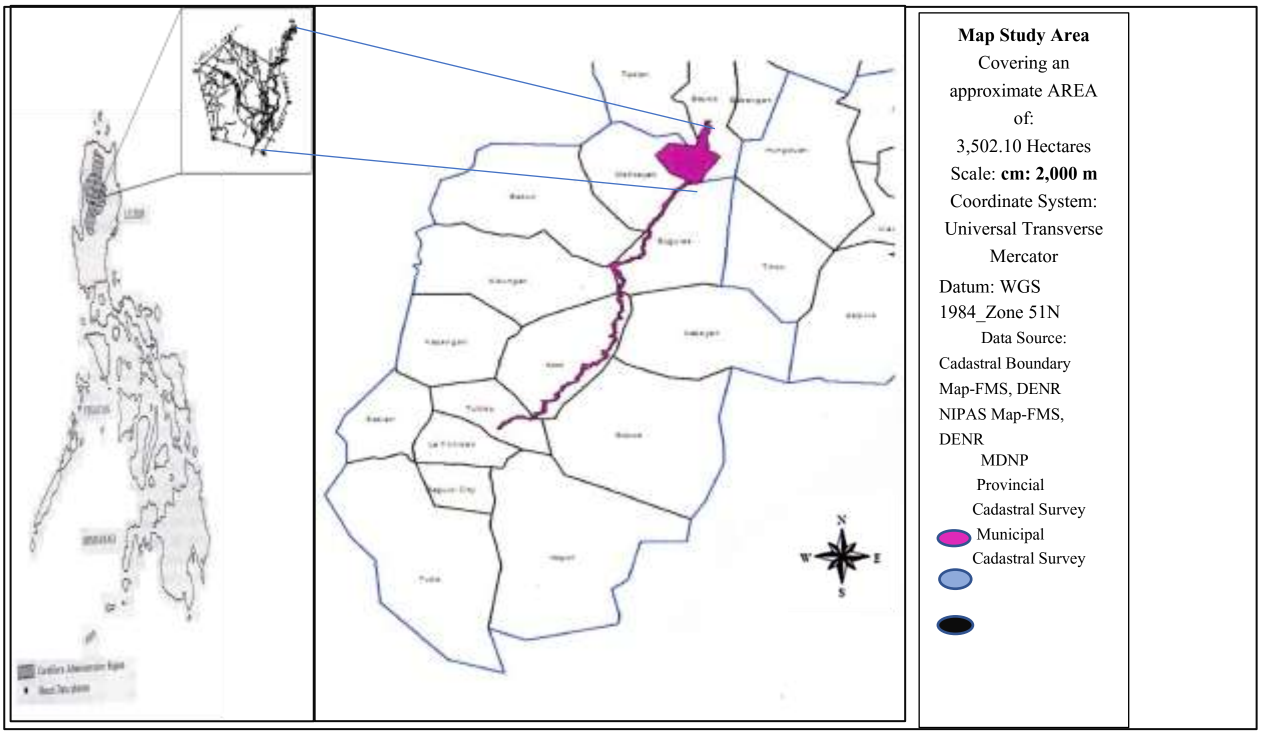


Figure 1. Location map of the Mount Data National Park

Geographic Features

The study area is generally mountainous with rolling and very rugged terrain on steep slopes. Barangays within the MDNP have elevations ranging from 1,650 meters above sea level to 2,365 meters above sea level. The MDNP is the widest part of the park. It has a rolling terrain from moderately flat to moderately steep slopes. Steep slopes can be found within the perimeter boundary of the plateau. MDNP slopes range from 0% to 84%. The Halsema National Road portion of the MDNP has several interesting rock formations and deep ravines. Mount Data Cliff section of the Halsema Highway is carved on limestone rock formation. Description of rock formations, springs, volcanic craters, Rock formations as described in the Ecological Profile of the Municipality of Bauko in 2014 based on a land geological survey of the Mines and Geosciences Bureau (MGB) characterizes the land as "thick, extensive, and transgressed mixed marine deposits. The deposits which are underlain by conglomerates and associated with Polaris coal measures include wackes, shells, reefs, and limestone. It also contains undifferentiated rocks characterized by large gray wackes, splotched metamorphosed shales, and pyroclastic rocks in Barangays Sadsadan and Monamon Sur. Rocks like Oligocene-Miocene can be found in Mabaay, Monamon Norte, Mount Data, Sinto and some parts of Sadsadan and Monamon Sur."

Six (6) soil types are found in the study area these are sabangan loam; balili gravelly loam; cervantes loam; rough mountainous land; guinaoang loam; and mountain soil undifferentiated [2] [10].

Climatic Conditions

The MDNP-Mountain Province section is characterized by Climate Type 3, where seasons are not pronounced but are relatively dry from November to April and wet for the rest of the year [19]. January to April is usually dry season with observable droughts pushed by El Nino. The months of July to September are rainy with observable stronger (category 4 and 5) but fewer typhoons from October to December. Rainfall in the MDNP in 2017 was 72.7 millimeters during the dry season and a high of 616.5 millimeters during the rainy season. Temperatures peak at 26 degrees Celsius during the dry season and may reach a low of 4 degrees Celsius from October to February. Humidity is 82% during the dry season; the wet season is 88% to 92% [10] [19].

Land-uses of the MDNP

The area, with a total of 3,502 hectares is characterized by different land uses such as agricultural land with an estimated total land area of 1,501.70 hectares; brush or shrub land with 501.91 hectares; open forest with a total of 267.17 hectares; and the remainder were build-up areas and grassland and eroded rocks. The main agricultural areas are located largely at the MDNP in the barangays of Monamon Sur (553.12 hectares), Sadsadan (405.80 hectares), Mount Data (100.85 hectares), Sinto (85.99 hectares) and in areas with boundary disputes namely at Bauko and Mankayan (114.89 hectares) and Tadian and Bauko (192.82 hectares).

The most common crops planted on the agricultural land are potatoes (*Solanum tuberusum*), Broccoli *(Brassica oleracea var. italica)* and cabbage (*Brassica oleracea*). Other crops are carrots (*Daucus carota*), Chinese cabbage (*Brassica rapa subsp. chinensis*), and pechay (*Brassica rapa)*. The average produced in 0.4-0.7 ha is approximately 4 to 7 tons. For cabbage, the average production in the same area is 6-8 tons [10] [38].

The settlement pattern of the reservation is influenced by the presence of the national road network, availability of water, and livelihood. The settlement is clustered frequently over 5 kilometers apart. Local communities in the reservation are centered on vegetable farming activities as its favor large-scale production of highland vegetable crops. Additional vegetable crops are also grown in small gardens adjacent to the houses. These vegetable gardens were usually burnt prior to their creation, and they were fertilized with chicken manure. Majority of the population gain income from vegetable farming. Other livelihood engagements are business enterprises such as general merchandise, agricultural supplies and sari-sari stores, daily or contractual farm and business labor and the employment from the public and private institutions found in the area.

Patches of open pine forest are in the following barangays: Mount Data (55.46 hectares), Sabangan and Bauko (55.68 hectares combined), Mabaay (47.77 hectares), Sinto (29.41 hectares), Monamon Sur (21.89 hectares), and Sadsadan (13.35 hectares). Other sporadic open forests are situated in the tri-boundary area of the municipalities of Tadian, Bauko, and Mankayan. Additionally, the Wane watershed which covers 87 hectares across the barangays of Monamon Sur, Mount Data, and Sinto contains the only mossy forest in the study area.

Under the current classification system, alienable and disposable lands have been declared rocky, eroded, or otherwise unneeded for forest purposes [2] [10] [38].

Hydrology

The area is drained by four major channels: Abra river, Chico river, Amburayan river and Agno river basin. Water resources are abundant from the river systems and perennial creeks that are abound all over the park. These water resources supply the domestic, commercial, industrial and agricultural needs of the communities found within the National Park, though water supply becomes a problem during the dry seasons. There are two watershed components of the MDNP; these are the Bellang and Wane Watersheds [2] [10] [38].

Eco-tourism

The park has no recreation facilities and no specific areas where visitors and tourists concentrate, thus depriving the Office of the DENR or the LGUs of maintaining records of visitors who frequented the park. However, the LGU of Mountain Province is maintaining an economy class hotel and restaurant in the MDNP located at barangay Mount Data, Bauko, Mountain Province. Having been operational since 1962, it serves as mid-point stop-over for the tourists and travelers on their way from Baguio City to the Sagada Cave and the famous rice terraces of Banaue, Ifugao.

The tourist spots of the Parks are Mount Bandilaan, about 30 minutes ride by private vehicle from Mount Data hotel; the 200-step hill leads to the shrine of the Blessed Virgin Mary. The area, which is surrounded by vegetable gardens gives a bird's-eye view of the different barangays of Bauko, Mountain Province, and the town of Quirino, Ilocos Sur. Moreover, about 30 minutes' drive from the Hotel is the Inodey Falls Viewpoint. It is one of the main attractions of Bauko. However, during the dry season, one can hardly see the falls' full view due to insufficient water [38].

Soil Erosion Estimation Based on USLE Model

Model Structure and Parameters Description

The study area is subdivided into four land uses depending on slope category (0 - 18%, 18 - 30%, 30 - 50%, 50 - 84%, and above 84%). Four (4) dominant land use types are: forest cover (broadleaved and Pine), shrub, and grassland; agricultural land and Built-up areas are purposively selected.

In implementing the erosion vulnerability model, the Universal Soil Erosion Equation (USLE) will be used. The USLE is essentially a sediment 'production' function from fields and slope elements; it does not simulate the transport and deposition of sediment, only sheet and rill erosion. Therefore, it is not suitable as an indicator of downstream siltation effects and river sediment loads [36]. In this study, soil erosion assessment and mapping are based on the Geomatics approach. Thus, it employs the spatial database management features of the GIS computer software, which facilitates the analysis of the spatiotemporal dimensions of land and soil degradation [3].

The elements involved in the determination of soil erosion and hence erosion of land quality. The model is applied within GIS on a 200 x 200m cell basis and incorporates the diverse factors that have an impact (equation 1):

E = R*K*C*P*LS (Equation 1)

where E is the average annual soil erosion rate (t $ha^{-1}yr^{-1}$), R is a rainfall erosivity factor, K is a soil erodibility factor, LS is a topographic factor, C is the land cover management factor and P is a factor that defines soil conservation practice (Po et al., 2018). Each factor can be defined in a number of ways. Here the equations most applicable to the climate of the study area are selected.

Rainfall erosivity (R), Wischmeier & Smith (1978), that R, the rainfall factor, is calculated from expressions that describe the energy of a rainstorm and observed maximum rainfall intensities [7]. In the absence of such detailed information, an alternative equation in terms of the mean annual precipitation could be used. This procedure has also been used by a number of investigators (e.g., Htun et al., 2008 as cited by Abdalrahman, 2017). There is a relationship between rainfall and soil erosion which is directly proportional. The rainfall factor R can be calculated from two equations based on rainfall data [7]. The first equation (2) is derive from the study at Misamis Oriental, Philippines for erosivity and [3] [39]. Rainfall data from PAGASA meteorological stations can be used in calculating R factor using the equation:

$$R = 38.5 + 0.35\,P \qquad \text{(Equation 2)}$$

where P = mean annual precipitation
The second equation (3) has been tested in a number of countries, for example the study of Schmitt (2007) in Negros Island, Philippines.

$$R = 0.264\,MFI^{1.50} \qquad \text{(Equation 3)}$$

where:

$$MFI = \frac{\sum_{1990}^{2020} \frac{\sum Monthly\ rain\ fall^2}{Annual\ rain\ fall}}{30}$$

In this study, R-value calculated by the two equations is based on precipitation data for about thirty years (1990-2020).

Slope length factor (LS) is calculated following the method suggested by Bureau of Soils and Water Management (2020). Slope length (L) is a distance from the point of origin of overland flow to the point where the slope decreases sufficiently for deposition to occur or to the point where runoff enters a defined channel (wet or dry). Slope steepness (S) is the side slope of the land, usually expressed as percentage. Soil erosion increases more rapidly with slope steepness than it does with slope length [11] [30].
The LS factor can be calculated using the formula below:

$$LS = (L/22.1) * (0.065 + 0.045S + 0.0065S^2) \qquad \text{(Equation 4)}$$

Where: m = 0.5 for S>5%
0.4 for S 3-5%
0.3 for S 1-3%
0.2 for S<1%

S = slope (%), L = slope length (**m**).
A digital elevation model (DEM) determined the slope percentage, while a 200 m x 200m grid is use to establish the slope length.

The soil erodibility factor (K) represents the long-term average response of the soil to the erosive power related to precipitation and runoff. The soil erodibility factor (K) is a measure of the susceptibility of soil particles to detachment and transport by wind, rainfall and runoff. Texture is the principal factor affecting K, but structure, organic matter and permeability also contribute [34]. The K value can be calculated from two different ways. The first equation (5) is derived from Marino (2020):

$$K = (0.03H + 0.62/OM + 0.0082S - 0.0062C)\, S^{i} \qquad \text{(Equation 5)}$$

Where: H = the soil pH;
OM = the organic matter content, in percent;
S = percent sand;
C = the clay ratio = %clay / (%sand+%silt);
Si = percent silt/100
The second is, the K value is to be determined based on the BSWM (2020) soil erodibility values for various soil texture Appendix A.

The cover management factor (C) expresses the influence of land cover upon soil erosion. Many studies have determined values of the C factor based on land cover type, but according to [21] nil research on the cropping factor has been conducted in the Philippines itself. Other authors have modified the C factor that is based on cover type by additionally considering the quality of the vegetation [40]. The values for the USLE 'C' factor that will be used in this study were taken from the literature on crop systems since the Author is unsuccessful in searching for C factors appropriate for highland vegetable crops e.g. cabbage and potato. Measured C factor values from Misamis Oriental, Philippines is 0.5 for corn, 0.01, and 0.2 were used for grassland, and coconut palm, respectively; a C-factor of 0.28 from India was used for rice paddies (Maurya & Tanwar, 2010), and a C-factor of 0.06 from Thailand for forest cover [21]. Sugarcane land was given the same erodibility factor as maize land. C factor ranges from 1 to approximately 0, where higher values indicate no cover effect and soil erosion comparable to that from a tilled bare fallow, while lower C means a very strong cover effect resulting in no erosion.

The C factor use for the study area is determine using the procedure adopted from Abdalrahman (2017) and Schmitt (2007), and depends on the land cover and land use classes identified from the Landsat image data imported into GIS (table 1) [21] [40] [53];

Table 1. C values for different landuses of the MDNP

Dominant Land use	C value	Adopted from
Forest (Broadleaved and Pine)	0.007	*BSWM (2020)*
Shrub land, grass land, logging land and pasture land	0.05	*Tsai, F. et al. (2021) and*
Agricultural land Built-up Area or Settlement area	0.337 0.01	*Schmitt (2007)* *Abdalrahman (2017) and Tsai, F. et al. (2021)*

Erosion management practice (P factor)
The P factor reflects the impact of specific erosion management practices on the corresponding erosion rate with values between 0 and 1. Since the study method relies on satellite imagery for its surface land use information, the entire National Park is set to the *C* factor value this means that there are no soil or water conservation measures are applied to the study area. Thus, all *P* factor areas were given the same value of *C* factor as the traditional LULC land management practices. This is done as a means of equalizing the management parameters for all pixels since in most cases the visible effects of land management practices are far too small to be detected with civilian satellite imagery. This is also to avoid the effect of overestimating potential soil loss, which is considered to be the best approach to the problem. This method is also applied by BSWM, 2020 (Composite land degradation index mapping guidebook).

The extent of land degradation is calculated as the percentage of the area with severe land degradation, with respect to the total area under assessment. The extent of land degradation is classified according to the table below.

Table 2. Extent classes for soil erosion

Extent Class	Extent Rating	Limits of Extent Classes for erosion in the study area (Percent of total area of Polygon)
1	Very low	< 5 %
2	Low	5 - 25 %
3	Medium	25-50 %
4	High	50 - 75 %
5	Very High	> 75 %

Source: DA-BSWM. 2020. Composite Land Degradation Index Mapping Guidebook
The table hereunder presents the adopted degree of erosion class from BSWM.

Table 3. Degree of erosion class adapted from ERDB (2011)

Degree class	Descriptive rating	Limits of degree classes for a degradation in the concerned area (t/ha/yr.)
1	Very low	0-7
2	Low	7-12
3	Moderate	12-25
4	High	25-37
5	Very high	> 37

The Composite Land Degradation Index (CLDI)

The Composite Land Degradation Index (CLDI) is defined as a measure which describes land degradation based on the degree and spatial extent of soil erosion occurrences. CLDI (Table 5) is based on the method of land degradation assessment proposed by Brabant (2010) as stated by BSWM (2020).

The extent and degree of soil erosion are divided into classes that are given a value ranging from 1 to 5. The subtype has no numerical value and is represented by its symbol. The extent value (1–5) and the degree value (1–5) are thus totaled, while weighting the degree value according to the soil thickness of the study area which is <50 cm. This gives a composite numerical index that is identified by a degradation value ranging from 1 to 5 and by color, as indicated in the table below.

By convention, a different color is given to each index value. The redder the color the more the land is degraded, and the greener the color the less it is degraded. Neutral shades (grey or white) indicate land that is not affected by degradation [11] [41].

Approach for Validation of Model Results

Due to limited previous case studies specific to the study area, the validity of the model outputs are compared with numerical data outputs of similar studies in the Philippine highlands. Qualitative approach such as use of perception of local communities on soil erosion status will be sourced. To help farmers better explain the severity and onsite soil erosion occurrence. In addition, conducting selective field observations to identify most erosion prone areas. In supporting these processes, the color printed model output soil erosion severity map is taken in the field to check it on the ground and compare the model result with community perception.

Table 4. The composite numerical index for land degradation

Number of combinations of extent (bold) and *degree* (italic) indicators	Total value of the extent-degree combination	Degradation status index rating	Value of the composite degradation status index
1 + *7*	2	Very low*	1
1+*2* / **2**+*1*	3	Low	2
1+*3* / **2**+2/ **3**+1	4		
1+4 / **2**+3/ **3**+*2*/ **4**+*1*	5	Medium	3
1+*5* / **2**+*4* / **3**+*3*/ **4**+*2* / **5**+*1*	6		
2+*5* / **3**+*4* / **4**+*3* / **5**+*2*	7	High	4
3+*5* / **4**+*4* / **5**+*3*	8		
4+*5* / **5**+*4*	9	Very high	5
5+*5*	10		

Data Analysis Techniques

To identify the contribution of each parameter in USLE model, calculation of each factor as a specific thematic layer on the cell-by-cell bases [41]. Since both the Landsat images and the DEM use in this study had 30 m spatial resolution, all the required data layers were co-registered to a common pixel resolution and datum. After completing data input procedures and arranging each information layer, the mean annual soil erosion is calculated by multiplying each factor layers together according to the USLE formula (Equation 1) using the raster calculator of map algebra functions and associated packages in a GIS framework.

Then, the estimated annual mean soil erosion rates will be displayed in map showing spatial distributions of erosion risk for the MDNP and details of statistical soil erosion intensity classes and ranges of soil erosion rates are identified and categorized following the FAO soil description guidelines [42]. Finally, the spatial differences in rate of soil erosion in relation to corresponding landuse categories and slope classes are evaluated by using the zonal statistics function of the spatial analyst tools in ArcGIS software and the results will be supplemented by local community perceptions.

Other Important Aspects of Information to be Gathered

Site related information such as name of the soils in the local language and specific location name; the local name of SWC measures. Global Positioning System (GPS) will be used for geo-referencing different landuses. Georeferenced areas will give a better opportunity to compare landuses or land cover trends over time by returning to near the same point in future years. This can be beneficial to tracking SWC recommendation program effects on soil over time.

Participatory assessment and transects walks

The participatory transect walks and participant onsite observations will be conducted to triangulate information obtained through household surveys, Key-informant interviews, and focus group discussions to get acquainted with the actual situation on the ground. In each respondent-barangay, at least a one-day transect walk is deliberately carried out with residents and development agents. During the walk, on-farm observation and discussions with farmers working on their vegetable farms to get further clarification on the farm or land history; vegetation density and species diversity; perceived impacts of SWC technologies; local soil types and fertility status; use of farm inputs such as organic and inorganic fertilizers; pesticides; the general farming system; the cropping pattern and erosion risk; overall trends of environmental changes and livelihood constraints of the area will be noted. Along with this, dominant woody vegetation types, species composition, and the extent of vegetation degradation will be observed, documented, and acquiring photographs for further analysis and interpretation.

Secondary data

Additional data to supplement the primary information through a review of relevant literatures, archival data, policy documents, guidelines, and legislation from various government sources. Moreover, referring to census reports, statistical abstracts, earlier research results, conference proceedings, funding documents, project proposals and implementation reports, and journal articles. Both website and hard copy literature sources will be used to collect relevant literature and other documents. Landholding size, demographic aspects, cropping pattern, LCLU, and watershed activity reports will be collected from DA, LGUs, NGOs, and DENR offices. Several keywords such as land degradation, SLM, SWC, LULC, livelihood, etc., will also be used to search electronic literature.

Methods of Data Analysis

Both qualitative and quantitative approaches will be used to analyze the collected primary and secondary data. Quantitative approach like the inferential analysis or statistical techniques, such as regression and correlation will be employed to evaluate and describe the socio-economic attributes of the respondents. The frequencies for all the relevant variables are computed and presented in tables and percentages using cross tabulations to test differences between different variables and among categories of respondents. Moreover, using qualitative data for quantitative analyses, for example, a survey requesting Likert scale response alternatives will be analyzed by calculating a composite score. Average weightings approaches will accommodate variations in farmers' perceptions of each evaluating criterion's relative potentials and limitations (by giving scores to each criterion) on various land management strategies or practices. Selected graphs and shorter tables are displayed in the main text, whereas denser statistical tables and some supplementary data are presented in the annexes.

Qualitative approach is a comfortable method to describe the situation as it exists at present. Specifically, descriptive statistics (mean, median, standard deviation and pie charts, bar graphs). The results will be interpreted based on theoretical ideas underpinning the research and research objectives. Where appropriate, actual statements of the respondents obtained during the group and individual interviews will be included to illustrate

and support points of view expressed by the informants. Sustainability analysis compares the parameters set by the sustainable land management principles with the findings of actual field conditions. And consulting literature from similar studies to assess the reliability of results.
Statistical package for Social Science (SPSS) version 20 will be employed to analyze the data.

Model evaluations
Performing Model evaluation to test goodness-of-fit and validity of predicted possibilities [43]. Goodness-of-fit statistics assesses to test the fit of a logistic model against the data. It assesses using Hosmer–Lemeshow test as it allows for continuous and dichotomous variables. The classification table method will be employed to assess the predicted and observed scores observations [44]. The higher the percentages the better fit the model.

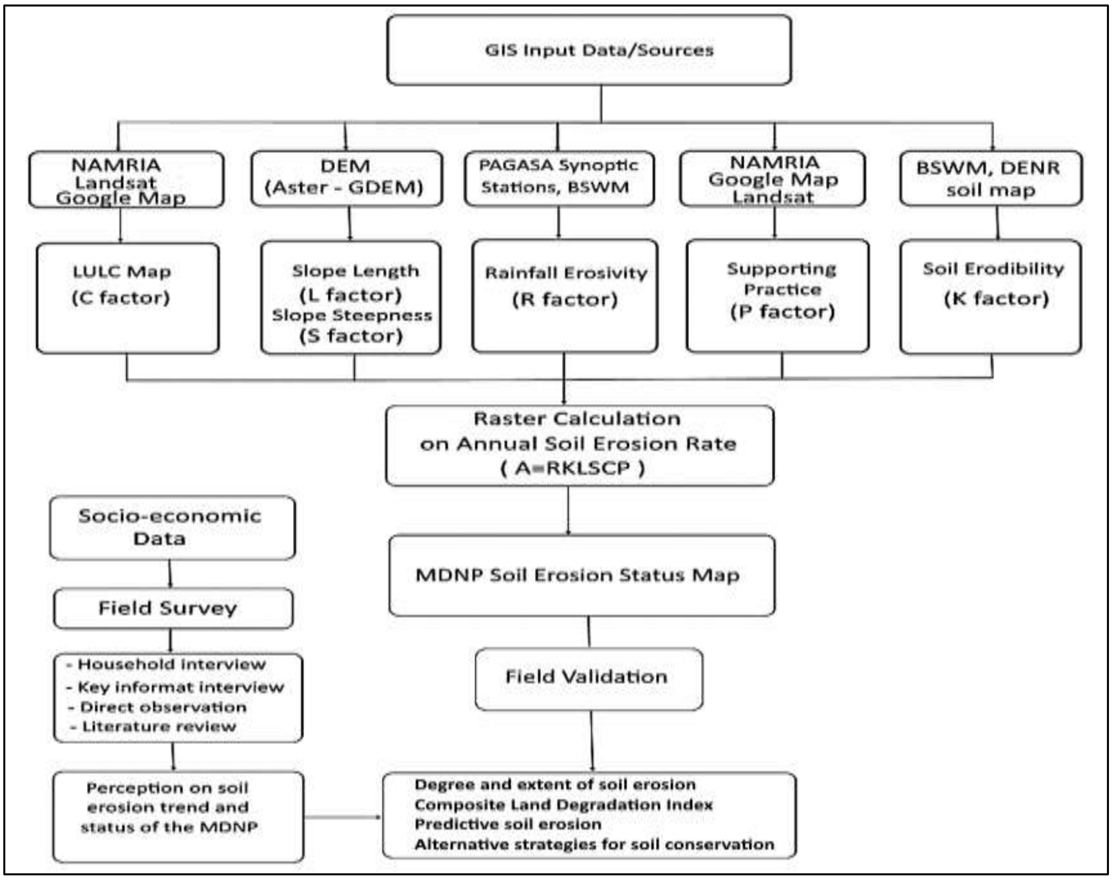


Figure 2. Sequential steps employed to estimate soil erosion by USLE Model (Modified from ARC, 1999 and BWSM, 2020)

5. Results and discussion

Soil loss rate and composite land degradation index using the universal soil loss equation (usle) model
GIS and geomatics were used which helped considerably in organizing the spatial data representing the effects of each factor affecting soil erosion. The factors that most influence soil erosion is linked to topography, vegetation type, soil properties, and land use or land cover. Average annual soil losses were calculated by multiplying five factors: R; the erosivity factor, *K*; the soil erodibility factor; *LS,* the topographic factor; *C,* the crop management factor and *P*; the conservation support practice. This chapter also assessed the Composite Land Degradation Index (CLDI) proposed by Brabant (2010) as spelled out in the Composite land degradation index mapping guidebook by the Bureau of Soil and Water Management (2020). The assessment involved identifying the stated five factors, quantifying the degree, and extent of soil erosion/degradation, and calculating the composite land degradation index (CLDI) for the MDNP.

Rainfall Erosivity (R factor)
The thirty-years average monthly and annual Rainfall data from Baguio City Monitoring station taken from Department of Science and Technology, Philippine Atmospheric Geophysical and Astronomical Services (DOST-PAGASA) and PSA-CAR (http://rssocar.psa.gov.ph/) were used for estimating the average annual precipitation (AAP), over the entire area of Mount Data National Park (MDNP). The determined mean R values (average

erosivity) of 225.02 $MJmmh^{-1}\ ha^{-1}\ yr^{-1}$ for the study was validated from National Oceanic and atmospheric Administration-National Centers for Environmental Information (NOAA-NCEI) that already interpolates data over large areas including the MDNP.

The long-term annual rainfall varies from 246.76 to 663mm, while the long-term mean annual rainfall varies between 509 and 545mm at the study area (Figure 31). The South-west areas (Benguet Province side) of the MDNP get relatively high rainfall while the north-west areas (Mountain Province side) received relatively low rainfall. The rainfall distribution has been influenced by topographic characteristics of the Park.

The R factor value ranges between 216.35 and 224.19 $MJmmh^{-1}\ ha^{-1}\ yr^{-1}$. The effect of rainfall on soil erosion is high at the upper elevation areas of the Park (Benguet Province side), with a mean erosivity value of 224.19 $MJmmh^{-1}\ ha^{-1}\ yr^{-1}$. On the other hand, the erosion potential of rainfall gradually decreases from the upper elevation to the lower elevation areas (Mountain Province side) of the MDNP with a mean erosivity value of 216.35 $MJmmh^{-1}\ ha^{-1}\ yr^{-1}$.

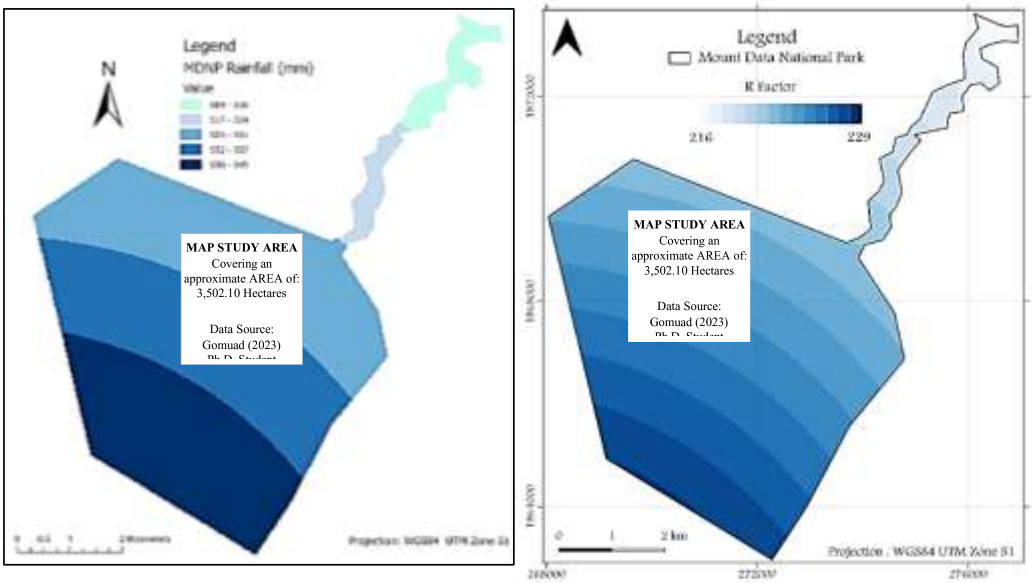


Figure 31. Map of mean annual rainfall (left) and rainfall erosivity (right) distribution of the study site

Soil Erodibility (*K* factor)

The soil type map and boundary shapefile of the study area were obtained from PhilGIS and the previous study of Bayagen (1996) and report from DENR-CENRO (2018) [2]. To ensure uniformity, all the raster layers were ensured to have pixel sizes of 30 m by 30 m and were aligned with each other, clipped and projected in ArcGIS or QGIS applications.

The *K* factor reflects the combined effect of soil properties, showing the general proneness of a particular soil type to erosion. In general, six types of soil classes were identified for the study area (Table 21). The dominant soil type, guinaoang loam, covers 2,050.84 ha of the National Park. The soil types constituting 59% of the area, mostly in the southeastern part, are characterized by poor to moderate drainage and shallow soil type (<50 cm), having moderate infiltration rates; altogether this results in a high erodibility if cultivated continuously.

Since the soil type in the study area was generally clay loam a *K* value of 0.30 was assumed for Balili gravely loam, sabangan loam, cervantes loam, guinaoang loam and Mountain soil undifferentiated while a *K* value of 0.50 was assumed for rough mountainous land in the calculations, based on Bureau of Soils and Water Management as shown in table 21 [3].

The erodibility map shows that Rough mountainous land is highly susceptible to soil erosion, with *K* value of 0.50. The rest of soil categories of the national park have moderate *K* values (Figure 32).

Table 9. Representative *K* values of soil erodibility of study area adapted from BSWM (2020) for various Philippine soils, and soil types in the slope categories and area coverage in hectare

SOIL TYPE Total area 3,500.60ha	Area Coverage Based SLOPE (%) Class				
	0 - 18	18 - 30	30 - 50	50 - 84	> 84

1. Cervantes loam	354.04	191.64	125.65	106.72	49.00
2. Mountain soil undifferentiated	31.65	36.94	34.71	14.94	0.28
3. Sabangan loam	46.31	77.77	122.68	85.01	16.98
4. Rough mountainous land	14.85	24.41	28.77	11.51	0.28
5. Guinaoang loam	680.24	607.48	456.31	246.11	60.69
6. Balili gravelly loam	20.88	22.18	24.96	6.87	0.74
Total	1,147.97	960.42	793.08	471.16	127.97

Description: 0 - 18% Flat to rolling, 18 - 30% moderately steep, 30 - 50% steep, 50 - 84% Very steep, above 84% Extremely steep

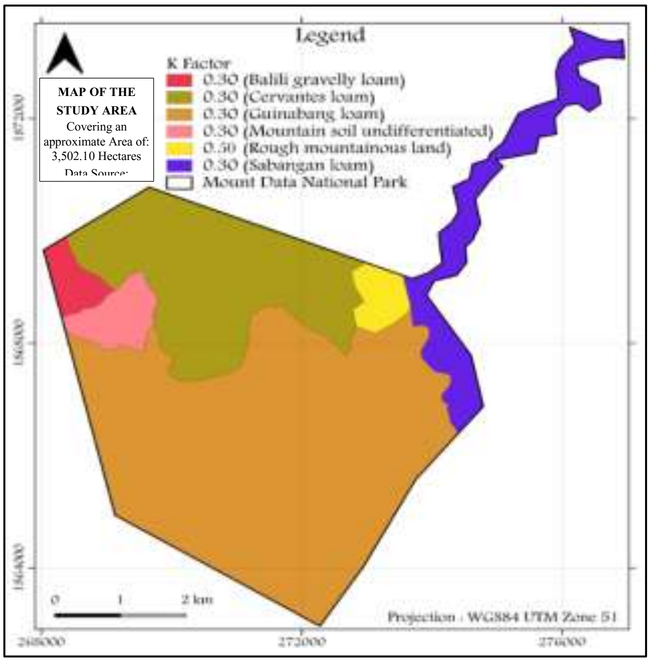


Figure 32. Soil *K* values map of the study site

Slope length and Steepness (*LS*) Factor

The 30 m spatial resolution digital elevation model (DEM) was used to generate slope by using "Spatial Analyst Tool Surface Slope" in GIS environment. The flow accumulation and slope steepness were computed from the DEM using GIS. Flow accumulation and slope maps were multiplied by using "Spatial Analyst Tool Map Algebra Raster Calculator" in GIS environment to calculate and map the slope length (*LS* factor). Slope length (*L*) is a distance from the point of origin of overland flow to the point where the slope decreases sufficiently for deposition to occur or to the point where runoff enters a defined channel. Slope steepness (*S*) is the side slope of the land, usually expressed as percentage. The combined *LS* factor indicates the effect of slope length and slope steepness on soil loss on the study area varies from 0 to >20 with green to red color gradient representing 0 to > 20 *LS* factor (Figure 33).

Soil loss increases more rapidly with slope steepness than it does with slope length. The figure 32 and tables 10 and 11 reveal that the plateau or plains of the National Park have relatively low *LS* values (0–10). While high *LS* values of 20 to >20 were mostly determined from the undulating upper plateau (red color) and along the sides of the National highway (Baguio-Bontoc Road).

Table 10. The *LS* values of the LULC categories and slope class

	Slope (%) Class					Total (ha)
LS value	**0 - 18**	**18 - 30**	**30 - 50**	**50 - 84**	**> 84**	
0	600.99	634.86	586.05	375.11	105.52	2,302.52
5	546.98	201.20	-	-	-	748.17
10	-	124.45	84.54	-	-	208.99
20	-	-	122.50	11.04	-	133.54
> 20	-	-	-	85.10	22.37	107.46

Total	1,147.96	960.50	793.09	471.25	127.88	3,500.69

Table 11. The *LS* values of the slope class

	LULC class (ha)				Total (ha)
LS value	Forest cover	Build-up areas	shrub and grassland	Agricultural land	
0	650.53	108.57	433.97	1,055.16	2,248.23
5	103.78	59.28	71.36	511.74	746.16
10	61.39	10.59	34.64	118.17	224.79
20	63.81	2.67	30.32	54.90	151.70
> 20	62.38	0.33	29.78	34.74	127.23
Total	941.89	181.42	600.08	1,774.71	3,498.10

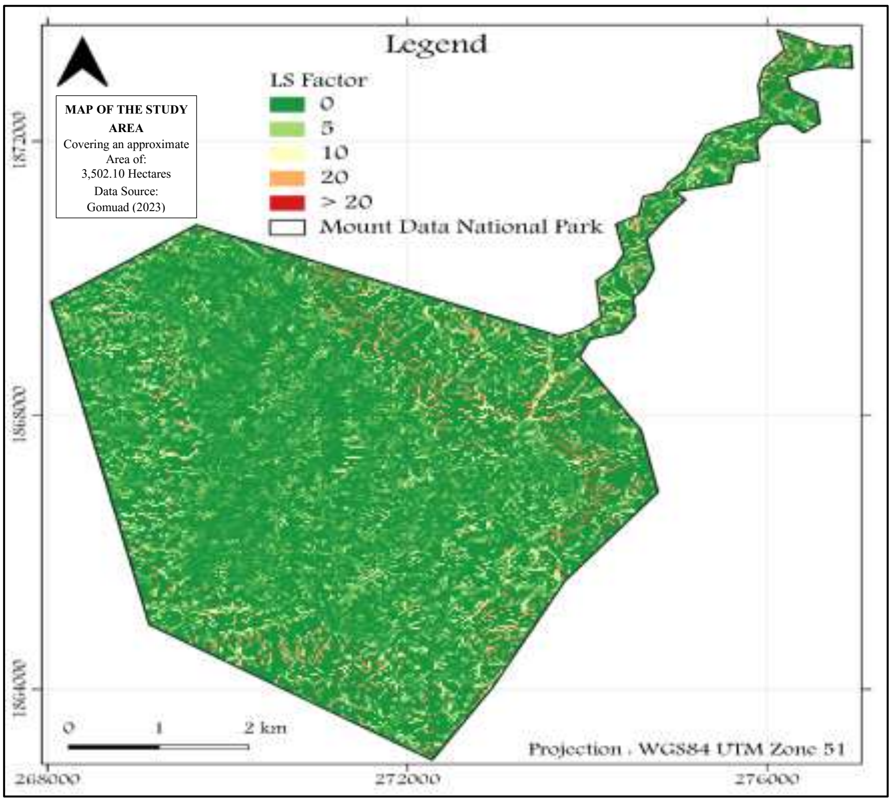


Figure 33. Map of slope length and steepness (LS) factor generated from the DEM and topographic map of the study site

Crop cover and management (*C* factor)

The land use and land cover map of the study area was prepared from the 2020 LULC map. The LANDSAT satellite image was used to classify the current land use and land cover map. A field checking effort was made to collect ground truth information from the 2020 land use and land cover map. Based on the 2020 land use classification map, a corresponding *C* value assigned in a GIS.

The **C factor** represents the effect of plants, crop sequences, and other surface covers on soil erosion. It is a dimensionless parameter with values ranging from 0 to 1. As shown in Figure 33, four representative land cover classes were identified in the study area: agricultural land, forest cover, shrubs/grassland, and built-up areas. The C-factor values for these classes were adapted from existing literature: **0.337** for agricultural land (Abdalrahman, 2017), **0.007** for forest cover and **0.14** for shrubs/grassland (Schmitt, 2007), and **0.03** for built-up areas (BSWM, 2020) [11, 21, 40]. After assigning these values to the respective land cover classes, the layer was converted into a raster C-factor map (Figure 34).

Table 12. Estimated crop cover coefficient of *C* values adapted from various studies for the common land use and land cover condition of the Philippines

LAND USE and LAND COVER	Area coverage (ha)	% coverage	*C* value	Adopted from
Forest (Broadleaved and Pine)	941.91	26.93	0.007	BSWM (2020)
Built-up Area or Settlement area	181.42	5.19	0.03	BSWM (2020)
Agricultural land	1,774.73	50.73	0.337	Abdalrahman (2017)
Shrub land, grass land, logging land and pasture land	600.08	17.15	0.14	Schmitt (2007)
TOTAL	3,498.14	100.00		

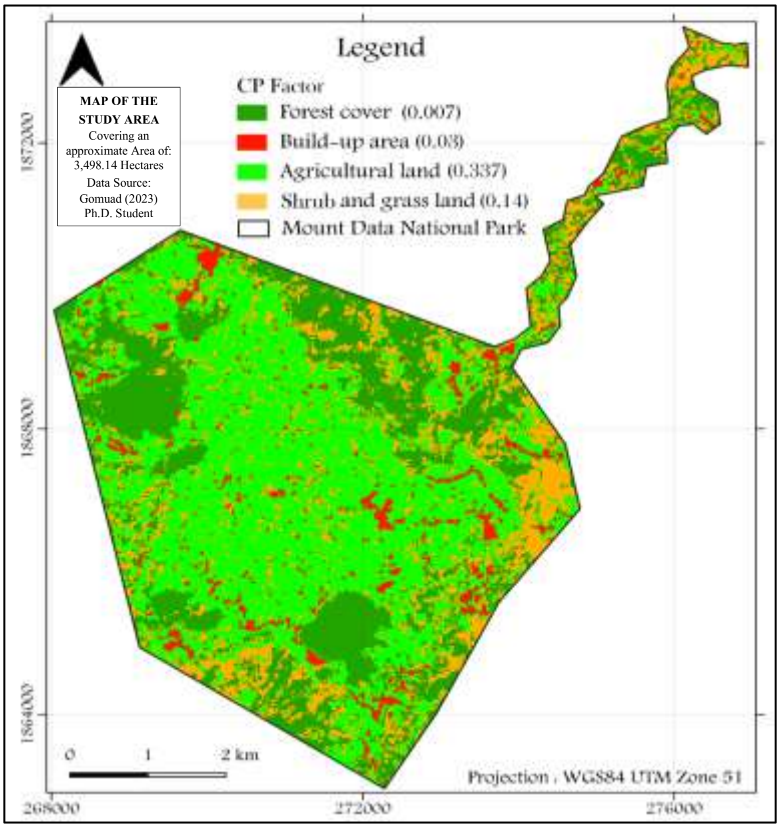


Figure 34. Map of *C* values quantified from land use and land cover classes adapted from the result of LULC in the earlier chapter

Erosion management practice (*P* factor)

The P factor reflects the impact of specific erosion management practices on the corresponding erosion rate with values between 0 and 1. Since the study method relies on satellite imagery for its surface land use information, the entire National Park is set to the *C* factor value. This means that there are no soil or water conservation measures were applied to the study area. Thus, all *P* factor areas were given the same value of *C* factor as the traditional LULC land management practices. This is done as a means of equalizing the management parameters for all pixels since in most cases the visible effects of land management practices are far too small to be detected with civilian satellite imagery. This is also to avoid the effect of overestimating potential soil loss, which is considered to be the best approach to the problem. This method is also applied by BSWM, 2020 (Composite land degradation index mapping guidebook).

Annual Soil Loss Estimation of MDNP

The study area may correspond to a local level of territorial entity, around 3,502 hectares. Since the types of degradation are visible in the field and on images, a systematic field survey was carried out to be able to validate the extent of a given type of soil and land degradation. This involves pinpointing areas in the area affected by the type of degradation, transferring the observations on a large-scale map, and then calculating the degraded area to determine its extent through geomatics and GIS software. The visual observations were supplemented by the interpretation of available high-resolution satellite images.

The ensemble spatially distributed soil loss estimates with a spatial resolution of 30m was summarized in each grid cell by employing descriptive statistical measures. The mean values were calculated in each grid cell to estimate an average soil loss from the USLE model ensemble. A common concept in the erosion literature is to relate soil loss to soil formation rates and therefore classify the soil loss as sustainable (tolerable) or non-sustainable (e.g., Blanco-Canqui and Lal, 2008; Montgomery, 2007; Van-Camp et al.,2004 as stated by Schürz, et al., 2020) or to group soil loss based on the severity of soil removal (e.g., Zachar, 1982; FAO-PNUMA-UNESCO, 1980). Literature values for tolerable levels of soil loss vary between 5 and 12 t ha^{-1} yr^{-1} on a global scale [21]. Karamage et al. (2017), Bamutaze (2015), Morgan (2009), and Lufafa et al. (2003) used 10 t/ha/yr as a threshold value to classify tolerable soil loss for studies conducted in eastern Africa [33] [45] [46] [47].

In this study low soil losses were classified by employing the same threshold. A soil loss between 0 and 10 t/ha/yr is defined as slight soil loss, as suggested by Fenta et al. (2020) as quoted by Brabant (2010) [41]. For soil loss levels larger than t/ha/yr, this study implemented the soil removal classification following FAOPNUMA-UNESCO [21], where a soil loss between 10 and 50 t/ha/yr is considered to be moderate, a soil loss between 50 and 200 t/ha/yr to be high, and a soil loss larger than 200 t/ha/yr to be severe.

Average Annual Soil Loss

All factors' layers *R, K, LS* and *CP* computed and specialized by using GIS technology were combined together to obtain average annual soil loss rate layer. The total soil loss in the study area was estimated at 93, 407.44 tons per year (Table 24) based on land use or land cover (LULC), while 93,345.05 tons per year were estimated based on slope category from the 3,502has land area of the National Park. The average annual soil loss per hectare based on LULC was estimated to be 33.93 t/ha/yr. while the average annual soil loss per hectare based on slope category was estimated to be 43.98 t/ha/yr (Table 25).

Based on LULC, the rate of annual soil loss with specific spot-on forest cover exhibits a loss of 6,689.75 t/ yr. with estimated average amount of 7.10 t/ha/yr. The highest erosion rates are found on shrub and grass land with 60,759.70 t/yr., averaging 101.25 t/ha/yr. These estimates corroborate the finding of PhilLADA (2013) with grassland estimated soil erosion of 131.7 t/ha/yr for Cordillera Administrative Region (CAR). Agricultural land contributes with 23,378.39 t/yr or 13.17 t/ha/yr. These areas are mostly at the 0 to 18% slopes of the study area. However, it can be seen from the same PhilLADA (2013) report that the BSWM estimate for CAR is about 6.0 t/ h/yr in 2000, far much lower than the estimated rates of this study. The least contributor on average soil loss is from build-up area contributing 2,579.60 t/ha but with higher amount of soil loss with agricultural land which is 14.22 t/ha/yr. Higher soil loss of build-up area could be attributed to their slope location and the lack of soil and water management technologies (Table 24 and 26).

The soil loss severity classes for the National Park were divided into four ordinal classes. These are, very low (0-5 t/ha/yr.), low (5-10 t/ha/yr.), moderate (10-50 t/ha/yr.), high (50-200 t/ha/yr.) and very high (>200 t/ha/yr.). Table 24 presents the area and proportion of each of the soil erosion potential categories of the study area. Forest cover was estimated to be low erosion rates. Meanwhile, the estimated soil to be moderate erosion rates from 10-50 t/ha/yr is found in agricultural land and build-up areas. The estimated average annual loss of 50-200 t/ha/yr. are found in shrub and grass land which indicates a high erosion value of erosion. This could be the result of the combined effects of steep slopes, high rainfall, and intensive cultivation and land clearing for infrastructure activities.

According to the average annual soil loss ranges, thus based on land use and land cover of the MDNP, the mean annual soil loss of 33.93 t/ha/yr is under the moderate class of soil erosion (10-50 t/ha/yr).

The estimated soil rates found within the different slope categories range from 14.44 to 79.70 t/ha/yr, with a mean of 45.46 t/ha/yr. After classifying the soil erosion rates, it was observed that all erosion risk classes (Appendix table 6) were present within 0-18% to 50-84% slopes for all types of soil class. While mountain soil was undifferentiated, rough mountainous land and balili gravelly loam soil classes were not present on >84% slope class erosion risk. This data coincides with the raw LULC geospatial data of LULC presented earlier. Very low and low erosion rates reflected in appendix table 6 were mainly due to the presence of forest cover based on the study area land cover. This corroborates the works of Aguilos (2021) on their study in Iloilo, Philippines, that the absence of forest in the land cover management of catchment hastens land degradation [47].

Meanwhile, moderate soil erosion rates were mostly found in 0-18% and 18-30% slope categories. This situation is consistent with field validations of the study area where vegetable farming in mountainous lands and the soil loss rates from these slope categories were in between 10-50 t/ha/yr. High soil rates were manifested at >80% slopes. These areas are mostly found in mountain sides and around rivers where the slope is very steep.
According to the average annual soil loss ranges on slope categories of the MDNP, the mean annual soil loss of 45.46 t/ha/yr is under moderate class of soil erosion (10-50 t/ha/yr.).

Using GIS and geomatics, a check on the "degree of soil erosion" in the study area is presented as Figure 18. The green colored mapping units are very low eroded areas while the light red to red colored mapping units are high and very high eroded [41]. The erosion data are overlaid with slopes greater than 80 degrees and additionally overlaid with land use map to cover the following classifications: forest cover, agricultural lands, shrub and grass lands, and build-up areas. The results are presented as tables 14 and 15 showing the *degree of soil erosion* of the MDNP. The computer-assisted estimation on the area coverage of degree of soil erosion spots can be summed up as figure 35. Since there were no soil erosion, data sets were sensibly comparable to the situation of the MDNP, and most of the soil erosion data was on national scales e.g. the terminal report of PhilLADA (2013) on Land Degradation in the Philippines. According to the report, the cost considerations to update the Philippine land degradation data, there has not been a more recent field validation of the national data set except for scattered project-based field. However, the study findings are a fairly more representative of the MDNP scenario as it includes field validations from the different study areas [52].Table 13 presents the adopted degree of erosion class.

Table 13. Degree of erosion class adapted from ERDB (2011)

Degree class	Descriptive rating	Limits of degree classes for a degradation in the concerned area (t/ha/yr.)
1	Very low	0-7
2	Low	7-12
3	Moderate	12-25
4	High	25-37
5	Very high	> 37

Table 14. Computed annual soil loss estimates in the study area based on land use or Land cover categories (degree of soil erosion in t/ha/yr.)

LULC Classes	Area (ha)	Estimated Soil Loss (t/ yr)	Estimated Soil Loss (t/ ha/yr)	Degree Rating	Degree Class
Forest cover	941.91	6,689.75	7.10	Low	2
Build-up area	181.42	2,579.60	14.22	Moderate	3
Agricultural area	1,774.73	23,378.39	13.17	Moderate	3
Shrub & grass land	600.08	60,759.70	101.25	Very high	5
TOTAL	3,498.14	93,407.44	*Average 33.93*	high	4

Table 15. Computed annual soil loss estimates in the study area based on slope categories (degree of soil erosion in t/ha/yr)

Slope (%) class	Total Area (ha)	Mean Soil erosion (t/ ha/ yr.)	Degree rating	Degree class
0 - 18	1,147.97	12.38	Moderate	3
18 - 30	960.42	20.36	Moderate	3
30 - 50	793.08	26.39	High	4
50 - 84	471.16	30.39	High	4
> 84	127.97	43.98	Very high	5
	3,500.60	26.70	High	4

Descriptive Rating ($t\ ha^{-1}\ yr^{-1}$):
1= Very low (0-7); 2= Low (7-12); 3= Moderate (12-25); 4= High (25-37); 5= Very high (>37)

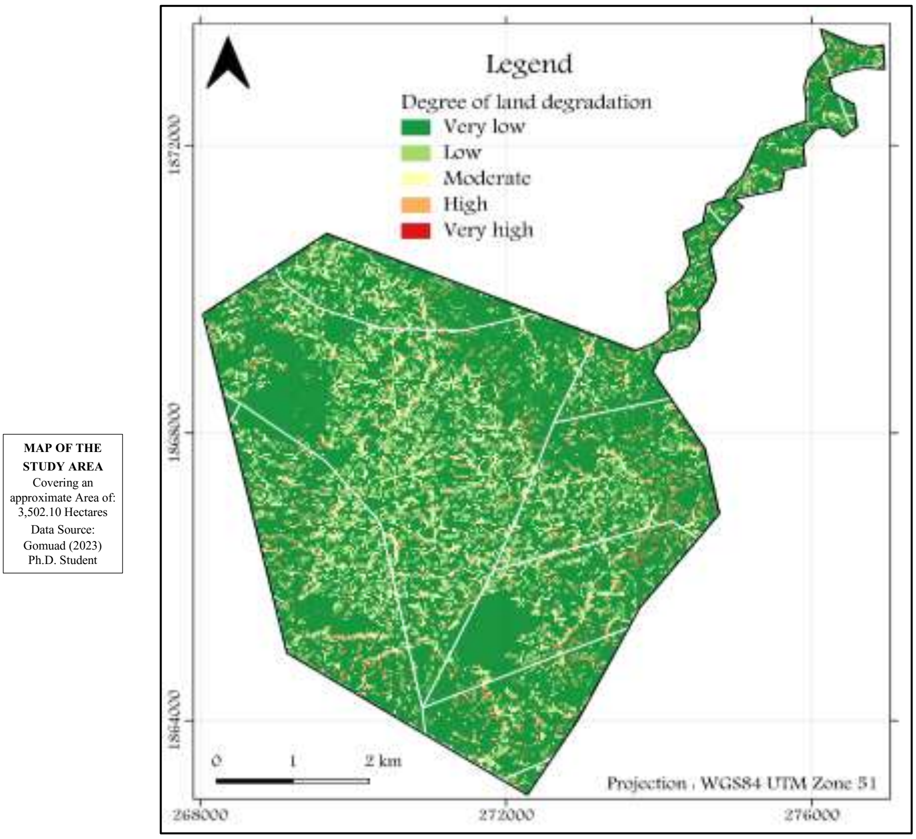


Figure 35. Map showing the annual soil loss estimates in the study area based on USLE model through Geomatics with green to red color gradient representing very low to very high erosion class

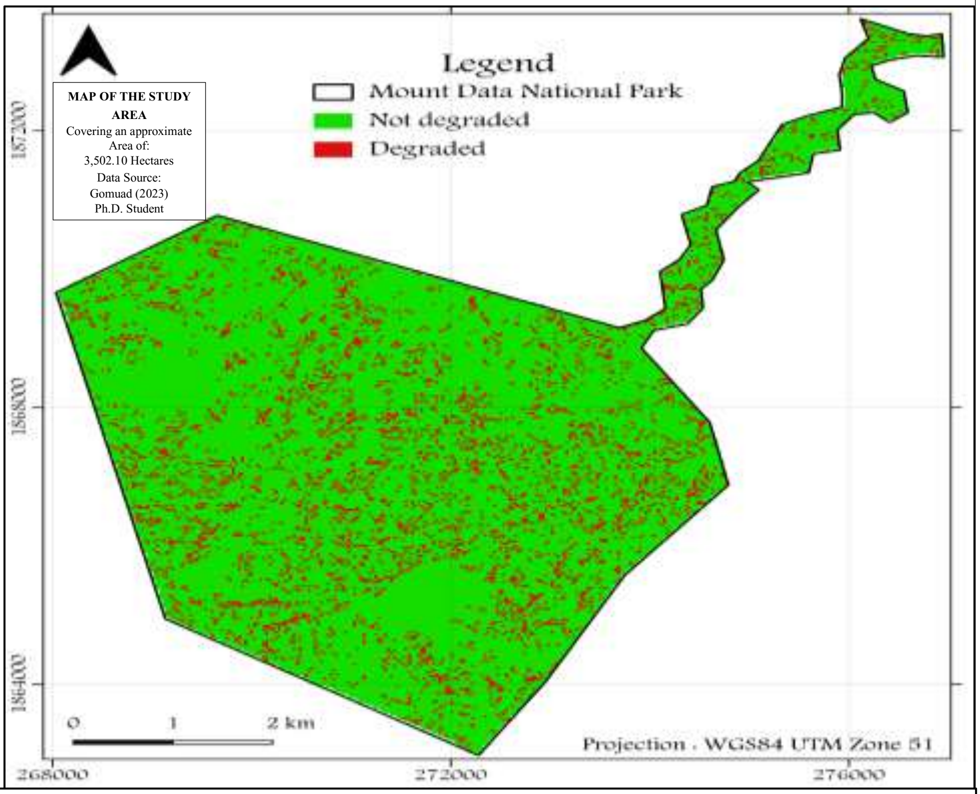
The Extent of Soil Erosion is calculated as the percentage of the area with severe land degradation, with respect to the total area under assessment (Figure 35). Five extent classes are selected according to the concerned percentage (Table 16). The extent of land degradation is classified according to the table below following the CSDF dossier, issue 8, implemented by the Department of Agriculture, Bureau of Soil and Water Management (2020). Class 5, for instance, means that over 75% of the area concerned is affected by soil erosion [3].

A query at the data set checks on the "extent of soil erosion areas" given the same parameters in terms of LULC, slope, and the barangays of MDNP. Figure 36 is hereby presented as the *extent of soil erosion spots of the MDNP.* About 459.93has of fragile land can be considered as degraded areas. This represents around 13.14 percent of the 3,501.13 hectares area of MDNP. Despite the presence of agriculture in these ecologically fragile areas, they show low soil erosion or about 5 – 25 % degraded area.

Table 36. Extent of erosion class adapted from BSWM (2020)

Extent class	**Extent rating**	**Limits of extent classes for a degradation subtype in the concerned area (in % of the field area)**
1	Very low	>5 %
2	Low	5 – 25 %
3	Moderate	25 – 50 %
4	High	50 – 75 %
5	Very high	>75 %

Figure 36 shows the extent classes per LULC and slope classes. The calculation of the extent of land degradation (LD) was to reclassify those with high and very high degree of LD as degraded, while those with very low, low and moderate land degradation as not degraded.



Percentage of MDNP area with land degradation located in four LULC

LULC class	Area (ha)	(%) Not Degraded	(%) Degraded	% of the field area	Extent rating	Extent class
Forest cover	941.92	898.23	43.69	4.86	Very low	1
Build-up areas	181.43	151.96	29.47	19.39	Low	2
Shrub and grass land	600.09	490.16	109.93	22.43	Low	2
Agriculture land	1,774.74	1,441.79	332.95	23.09	Low	2
	3,498.17	2,982.13	516.04	17.30	Low	2

Percentage of MDNP area with land degradation located in five slope

Slope (%) class	Area (ha)	(%) Not Degraded	(%) Degraded	% of the field area	Extent rating	Extent class
0 - 18	1,134.88	1,031.22	103.66	10.05	Low	2
18 - 30	944.26	770.82	173.45	22.50	Low	2
30 - 50	781.02	656.95	124.08	18.89	Low	2
50 - 84	466.89	419.56	47.33	11.28	Low	2
> 84	127.70	117.49	10.21	8.69	Low	2
	3,454.75	2,996.03	458.72	15.31	Low	2

Figure 36. Map of the MDNP showing the degraded and not degraded area

Composite Land Degradation Index (CLDI)

The Composite Land Degradation Index (CLDI) is defined as a measure which describes land degradation based on the degree and spatial extent of soil erosion occurrences. CLDI (Table 17) was based on the method of land degradation assessment proposed by Brabant (2010) as stated by BSWM (2020).

The extent and degree of soil erosion are divided into classes that are given a value ranging from 1 to 5. The subtype has no numerical value and is represented by its symbol. The extent value (1–5) and the degree value (1–5) are thus totaled, while weighting the degree value according to the soil thickness of the study area which is <50 cm. This gives a composite numerical index that is identified by a degradation value ranging from 1 to 5 and by color, as indicated in the table below.

By convention, a different color is given to each index value. The redder the color the more the land is degraded, and the greener the color the less it is degraded. Neutral shades (grey or white) indicate land that is not affected by degradation [3] [41].

Table 17. The composite numerical index for land degradation

Number of combinations of extent (bold) and *degree* (italic) indicators	Total value of the extent-degree combination	Degradation status index rating	Value of the composite degradation status index
1 + *7*	2	Very low*	1
1+*2* / **2**+*1*	3	Low	2
1+*3* / **2**+2/ **3**+1	4		
1+4 / **2**+3/ **3**+*2*/ **4**+*1*	5	Moderate	3
1+*5* / **2**+*4* / **3**+*3*/ **4**+*2* / **5**+*1*	6		
2+*5* / **3**+*4* / **4**+*3* / **5**+*2*	7	High	4
3+*5* / **4**+*4* / **5**+*3*	8		
4+*5* / **5**+*4*	9	Very high	5
5+*5*	10		

Table 18 describes a situation of water-induced sheet erosion [41]. Here, it involves a reduction in the thickness of the arable humus layer, which is commonly called topsoil. The degree of degradation can gradually vary from very low to very high.

Table 18. Degree of degradation classes for water-induced sheet erosion

CLASS	DEGREE OF DEGRADATION RATING	INDICATORS
1	Very low	Natural erosion marks which vary according to the soil type and field conditions. The land is generally uncultivated and under natural vegetation cover or located in a protected area, without human activities.
2	Low	Reduction in the thickness of the humus layer less than 1/5 the total thickness in un-cleared soil; a few sand deposits are noted on the leeward side of obstacles in the field (clumps of grass, stones). Local accumulation of fine fractions in small field depressions. Very little or no obvious decrease in productivity.
3	Moderate	Reduction in the thickness of the humus layer over 1/5 and less than 1/3 the total thickness. Clumps of grass partially uprooted; accumulation of fine sand and silt on the soil surface at sites conducive to such deposits. Some surface crusting on less than 10% of the field. Substantial decline in productivity (around 25%).
4	High	Reduction of almost half of the thickness of the humus layer. Substantial uprooting of clumps of grass. Tree and shrub roots exposed below the root collar. Many sand and silt deposits on low parts of the field. Substantial crusting on the soil surface. Bare areas without natural vegetation sometimes on 10–25% of the surface area of the field. As much as 50% decrease in productivity.
5	Very high	Reduction of almost 3/4 of the humus layer. This layer may disappear in some areas, sometimes in a large part of the field. Tree and shrub roots exposed for several centimeters or decimeters. Marked reduction in natural vegetation cover. Large bare areas. Abundant sand deposits (fine and coarse) in the lowest parts of the area and along drainage routes. Substantial crusting. Highly reduced grass cover. Bare areas sometimes on over half of the field area. Over 75% decrease in productivity. Land often abandoned.

Adapted from *Brabant*, 2008. A land degradation assessment and mapping method.
CSFD Issue 8 and *BSWM*, 2020, Composite land degradation index mapping guidebook [3].

The threshold is associated with land restoration possibilities and depends on the type of degradation concerned. It is generally located between classes 3 and 4 or between classes 4 and 5. The cost of land restoration when the degree of degradation is above the threshold is 10- to 100-fold higher than for land with a degree under the threshold. Passing this threshold leads to a quantitative increase in the economic cost of restoration and in the loss of crop productivity induced by the degree of degradation.

Table 19 presents the five classes for each degradation type. Generally, MDNP soil depth falls on lesser than 50 cm depth in reference to reports from PhilGIS, BSWM, DENR. Soil depth was also validated in the field by the researcher and interviews from farmer.

Table 19. MDNP adjusted degree of soil erosion (< 50 cm soil thickness)

Soil thickness > 100 cm		**Soil thickness 50 - 100 cm**		**Soil thickness < 50 cm**	
Reference class	Degree rating	Equivalent Reference class	Degree rating	Equivalent Reference class	Degree rating
1	Very low	2	Low	3	Moderate
2	Low	3	Moderate	4	High
3	Moderate	4	High	5	Very high
4	High	5	Very high	5	Very high
5	Very high	5	Very high	5	Very high

Adapted from *Brabant*, 2008. A land degradation assessment and mapping method.
CSFD Issue 8 and *BSWM*, 2020. Composite land degradation index mapping guidebook [3].

Table 20 presents the adjusted degree of soil degradation and the extent of soil erosion categorized by LULC (upper table) and slope classes (lower table), along with their respective CLDI values.
Based on the LULC categories, the **agricultural area** (1,774.73 ha), **shrub & grassland** (600.08 ha), and **built-up area** (181.42 ha) exhibit high land degradation indices. Together, these categories cover **2,556.23 ha**, representing **73%** of the total study area. Most of these LULC types are situated in relatively flat to rolling areas (plateaus) and along roadsides, where human activities are concentrated. These high indices are key drivers triggering land degradation in the MDNP.
These indices suggest that long-term, intensive land cultivation and land-use changes in MDNP have reduced the thickness of the humus layer by nearly half, leading to a productivity decrease of up to 50%. Furthermore, substantial uprooting of grass clumps has left tree and shrub roots exposed below the root collar. In contrast, the forest cover (941.91 ha) shows a moderate land degradation index, as the forest floor is protected by litter and ground cover that reduce runoff and enhance water infiltration. This index indicates that the forested areas remain largely unaffected by degradation.
Based on the slope classes presented in Table 20 (lower table), high degradation indices are observed across all slope categories in the study area. The 0–18% slope class covers the largest area at **1,147.97 ha** (**33%** of the total study area), followed by **18–30%** with **960.42 ha** (**28%**), **30–50%** with **793.08 ha** (**23%**), **50–84%** with **471.16 ha** (**14%**), and **>84%** with **127.97 ha** (**4%**). Similar to the LULC findings, these indices reflect widespread land degradation risks across all topographies.
Farmers who lack awareness of sustainable land management practices may fail to manage their fields properly, accelerating further degradation. To mitigate this, targeted interventions are essential—such as terracing, appropriate slope-farming technologies, and standard engineering designs for built-up areas. These measures are critical to minimizing land degradation and restoring the land to a functional state where its properties meet the requirements for specific land uses following rehabilitation.

Table 20. The composite degradation index of LULC categories (upper table), and the composite degradation index on slope classes (lower table)

LULC class	Degree of soil erosion (t/ ha/ yr.)	Degree Rating	Degree Class	**Equivalent reference Class (<50 cm, soil thickness)**	Extent of soil erosion (% Degraded)	Extent rating	**Extent class**	Number of CLDI combination	Total value of the extent-degree combination	Degradation status index rating	Value of the composite degradation status index
Forest cover	7.1	low	2	**4**	4.86	Very low	**1**	**1** + *4*	5	Medium	3
Build-up areas	14.22	moderate	3	***5***	19.39	Low	**2**	**2** + *5*	7	High	4
Shrub and grass land	13.17	moderate	3	***5***	22.43	Low	**2**	**2** + *5*	7	High	4
Agriculture land	101.25	very high	5	***5***	23.09	Low	**2**	**2** + *5*	7	High	4
	Mean 33.93	high	4	**5**	Mean 17.3	2	**Low**	**2 + 5**	7	High	4

Slope (%) class	Degree of soil erosion (t/ ha/ yr.)	Degree Rating	Degree Class	**Equivalent reference Class (<50 cm, soil thickness)**	Extent of soil erosion (% Degraded)	Extent rating	**Extent class**	Number of CLDI combination	Total value of the extent-degree combination	Degradation status index rating	Value of the composite degradation status index
0 - 18	12.38	moderate	3	**5**	10.05	Low	**2**	**2** + *5*	7	High	4
18 - 30	20.36	moderate	3	**5**	22.5	Low	**2**	**2** + *5*	7	High	4
30 - 50	26.39	high	4	**5**	18.89	Low	**2**	**2** + *5*	7	High	4
50 - 84	30.39	high	4	**5**	11.28	Low	**2**	**2** + *5*	7	High	4
> 84	43.98	very high	5	**5**	8.69	Low	**2**	**2** + *5*	7	High	4
	Mean 26.7	high	4	**5**	Mean 15.31	low	**2**	**2 + 5**	7	High	4

Figure 37 is a single map showing moderate and high areas of CLDI having two attributes—an index and a corresponding color—to give a glimpse of the land degradation status of MDNP. The map also shows the observed indicators on the respective descriptive ratings.

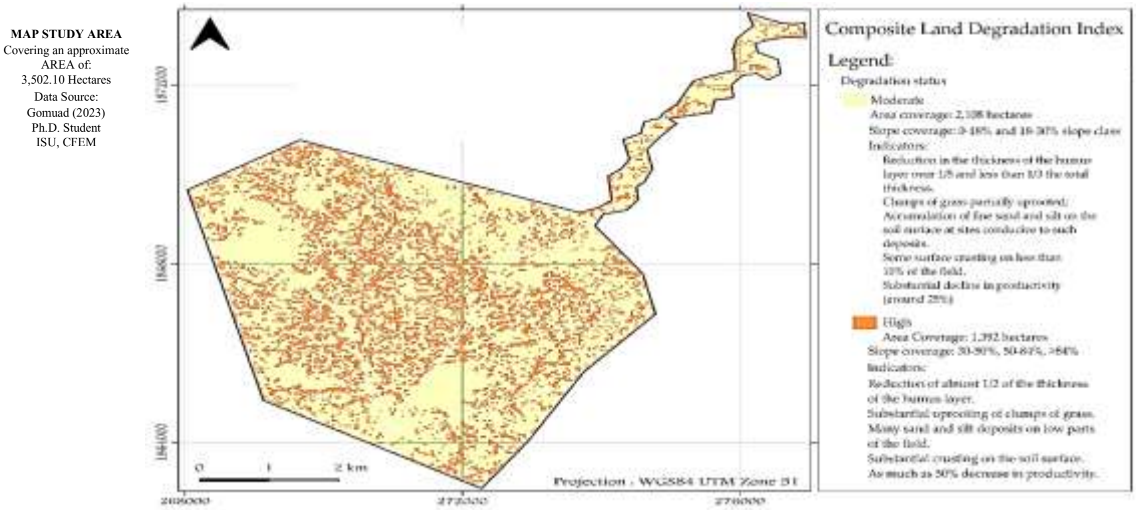


Figure 37. Map showing the composite land degradation index calculated as the sum of the degree and extent of soil erosion, with two legend colors representing moderate and high

Simulating the usle parameters of agricultural areas
And forest for soil conservation strategies
Actual soil erosion using usle model of mdnp

Even with its limitations, the USLE can give an insight of the methodological changes connected to the topographic factor estimates and the land use and land cover of map to overlay the layers of the USLE equation in a GIS environment. As stated earlier, soil erosion by USLE was done with the product combination of six factors that are expressed numerically in Equation 6 ($A = R \times K \times LS \times C \times P$). The soil loss was estimated in tons per hectare per year (t/ha/yr). The model was designed with some enhancements for the estimation of major factors related to soil erosion, specifically the topographic factor and the impacts of climate change on soil erosion, which have also been evaluated since long-term average rainfall data were used in computing the rainfall erosivity [7] [21] [34]. It is an empirical and parametric model which is built on the most appropriate water erosion process at MDNP.

Generally, erosion depends on the intensity and amount of rainfall, and the cover given to the soil through LULC on the forces exerted by rainfall impact and that of surface runoff. In other words, the susceptibility of a soil to the influence of erosion is dependent upon soil properties, the manner in which LULC modified the soil properties, and the topography of the land-scape which is defined by slope length, steepness, and shape. The value of *CP* factor has been allocated based on the thorough evaluation of the ground conditions and similar previous studies. Thus, the forest with 20-40 percent cover has a value of *CP* equal to 0.007 BSWM (2020). Likewise, agricultural lands *P* factor is allocated with the same *C* values equal to 0.337. The spatial analysis tool was used to generate the MDNP LULC maps for 1990, 2000, 2010 and 2020 LULC condition.

Simulating USLE model parameters for Potential soil erosion

To evaluate strategies for reducing soil loss and mitigating land degradation in Mount Data National Park (MDNP), model simulations were conducted. Uncertainty analysis of the combined cover management (C) and support practice (P) factors revealed distinct shifts in temporal soil loss patterns across both forest cover and agricultural land, reflecting potential spatial shifts in the study area's overall LULC distribution (**Table 21**). The aggregate *CP* factor exhibited substantial changes across both land cover types. **Figure 37** illustrates these input *CP* factor adjustments and their spatial impacts on soil loss calculations across MDNP.

Model realizations were evaluated using two distinct *CP* factor scenarios:

Model 1 (Baseline Scenario) evaluated soil loss using a factor of 0.337 for agricultural land adapted from Abdalrahman (2017) and Schmitt, 2007, and 0.007 for forest cover adapted from BSWM (2020).

Model 2 (Conservation Scenario) incorporated improved soil and water conservation (SWC) practices, reducing the agricultural *CP* factor to 0.22 to reflect the adoption of vegetable terracing and contour farming based on recommendations of Schmitt, 2007. Meanwhile, the forest cover *CP* factor was adjusted to 0.0005, corresponding to 70–100% tree canopy and undergrowth cover based on recommendations from ARC (1999) [7] [21].

The conservation scenario (Model 2) significantly reduced predicted soil erosion across both land cover types (**Figure 37**). Under Model 1, baseline annual soil loss was **7.10 t/ha/yr** for forest cover and **13.17 t/ha/yr** for agricultural land. In Model 2, these values decreased significantly to **2.61 t/ha/yr** for forest cover and **9.41 t/ha/yr** for agricultural land.

These modeled outputs align well with empirical field observations from literature. Undisturbed primary forests consistently exhibit minimal erosion, with reported rates as low as **0.2 t/ha/yr** [50] and **1.0 t/ha/yr** [51]. Conversely, unmitigated agricultural and shifting cultivation practices (*kaingin*) trigger severe land degradation, with erosion ranging from **100 t/ha/yr** in *kaingin* plots to **300–400 t/ha/yr**, **421 t/ha/yr** under banana-coffee-pineapple intercropping, and up to **489 t/ha/yr** in just six months on cultivated hillside farms in Leyte [50, 51].

Table 21. Comparison of soil loss simulations from the USLE model between 1st model across different slope class

		FOREST COVER		
		1st Model (*P value 0.007)*	2nd Model (*P value 0.0005)*	Average Decrease on Soil Loss
Slope Class	Area (ha)	Soil loss (t/h/yr.)	**Soil loss (t/h/yr.)**	(t/h/yr.)
0 - 18	132.90	*6.20*	*2.47*	3.73
18 - 30	196.82	*7.69*	*2.62*	5.07
30 - 50	304.41	*8.08*	*2.69*	5.39
50 - 84	240.58	*7.78*	*2.78*	5.00
> 84	67.20	*5.73*	*2.47*	3.26
Total	941.91	35.48	*13.03*	22.45
Average Soil Loss		7.10	*2.61*	4.49
Degree of soil rate		LOW	*VERY LOW*	
		AGRICULTURAL LAND		
		1st Model (*P value 0.337)*	**2nd Model** (*P value 0.22)*	Average Decrease on Soil Loss
Slope Class	Area (ha)	Soil loss (t/h/yr.)	**Soil loss (t/h/yr.)**	**(t/h/yr.)**
0 - 18	837.65	11.39	*8.09*	3.30
18 - 30	574.34	14.65	*10.48*	4.17
30 - 50	279.19	17.04	*12.20*	4.84
50 - 84	70.65	16.28	*11.66*	4.62
> 84	12.90	6.51	*4.62*	1.89
Total	1,774.73	65.87	*47.05*	18.82
Average Soil Loss		13.17	*9.41*	3.76
Degree of soil rate		MODERATE	*LOW*	

Degree Rating Description (ERDB, 2011)*: 0-7 Very low; 7-12 Low; 12-25 Moderate; 25-37 High; >37 Very high*

The degree of soil erosion potential for forest cover was altered from low to very low degree rating while agricultural land was altered to low from moderate degree of soil erosion (Figure 38). Overall, it was concluded that the results have shown the significance of forest and agricultural land uses in the control of erosion.

In general, for long-term sustainable soil resources management and erosion control particularly in steeper parts of the MDNP, SWC conservation e.g., appropriate terracing and contour farming of existing cultivated areas and replanting vegetation's for forest cover should be done.

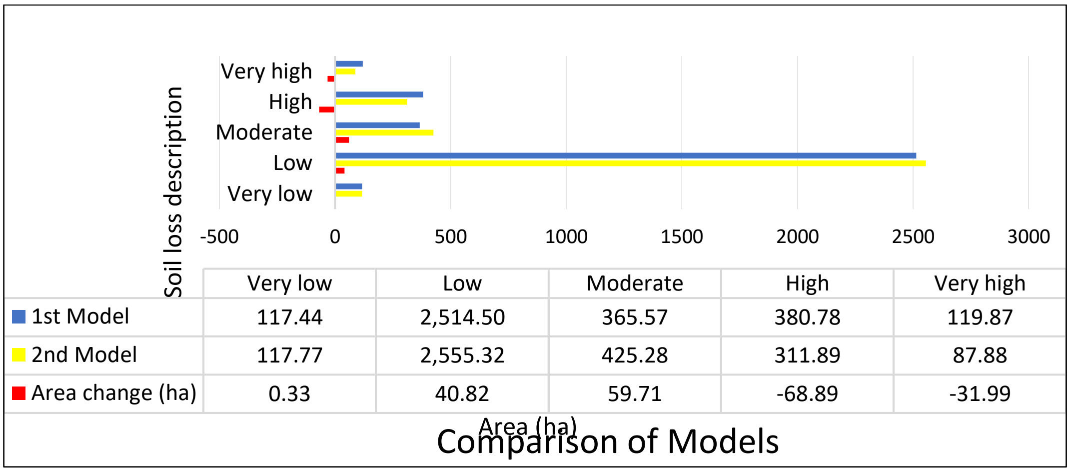


Figure 38. Visual comparison of soil loss changes showing gains and loss between the two models along the different soil loss description

6. Summary and conclusion

Summary

This study utilized the Universal Soil Loss Equation (USLE) with Geographic Information System (GIS) techniques to assess annual soil loss and identify the primary erosion-contributing areas in Mount Data National Park (MDNP). Soil loss estimation was carried out based on USLE principles, incorporating rainfall erosivity, soil erodibility, slope length and steepness, land management, and conservation practice factors. The model's input parameters were compiled as raster datasets with a 30-meter grid resolution.

Based on slope classes, a spatial distribution map depicting the degree of soil loss in MDNP was generated, yielding an estimated total annual soil loss of **93,345.05 t/yr**. The average annual soil loss was **37.72 t/ha/yr**, placing it within the moderate class of soil erosion. This estimate is slightly higher than the **33.93 t/ha/yr** calculated using land use and land cover (LULC) categories. These high rates stem from a combination of steep slopes, heavy rainfall, intensive cultivation, land clearing by fire, and built-up developments in MDNP.

However, the spatial distribution map of soil erosion extent indicates that only about **459.93 hectares** (or **13.14%** of the total study area) can be classified as degraded or having a low erosion extent. These degraded areas correspond primarily to the nearly flat or rolling landscapes of MDNP. Because the USLE is restricted to water-induced sheet and rill erosion—whereas actual soil loss in MDNP likely encompasses all types of water erosion—the modeled values may naturally deviate from actual observed values. Nevertheless, this methodology remains a practical tool for data-scarce regions in Western Mountain Province to assess erosion-prone areas, delineate risk zones, and prioritize conservation efforts.

Evaluating the Composite Land Degradation Index (CLDI) across the four LULC types and five slope categories revealed varying impacts on the environment, soil, and local community livelihoods, making overall soil conditions difficult to summarize with standard measures alone. Applying the CLDI revealed that nearly all LULC types and slope classes in the study area exhibit high degradation indices, except for forest cover, which showed a moderate degradation index.

To improve soil quality across MDNP, targeted measures must be implemented to enhance vegetative cover, soil organic matter (OM), and other health indicators in agricultural and shrub-grass lands. Agroforestry systems should integrate perennial trees—specifically nitrogen-fixing species—to improve soil properties by increasing OM, elevating nitrogen levels, and providing adequate ground cover. In agricultural zones, farmers should adopt conservation tillage and crop diversification (including leguminous crops) to rebuild soil structure. Furthermore, both cultivated land types should prioritize organic over inorganic fertilizers to boost OM and regulate pH levels. Because agroforestry is generally a more sustainable system than monoculture agriculture, government land-use programs should actively promote its adoption to maintain and restore soil health in MDNP.

The primary objective of this USLE simulation modeling was to establish an indicator framework capable of accounting for the impacts of human activities on soil erosion in MDNP, addressing the complex interactions across spatial scales, temporal scales, and management practices. Practical field conditions were carefully integrated at every step, confirming that a conservation practice (P) factor similar to those implemented elsewhere in the country can be successfully recommended for MDNP. The core hypothesis was that land cover and management strategies described by the USLE model can significantly modify both the nature and intensity of soil erosion.

The scenarios evaluated successfully demonstrated erosion reduction. The first model scenario yielded a soil loss of **7.10 t/ha/yr** on forest cover and **13.17 t/ha/yr** on agricultural land. In the second model scenario, these values were significantly reduced to **2.61 t/ha/yr** and **9.41 t/ha/yr**, respectively. Consequently, the potential soil erosion rating for forest cover improved from "low" to "very low," while agricultural land shifted from a "moderate" to a "low" erosion rating.

These simulated scenarios demonstrate that dedicated tree-planting campaigns to expand forest cover will yield substantial soil conservation benefits. Similarly, implementing proper terracing on agricultural land is far more effective than the prevailing sloping farming practices. However, even under these conservation scenarios, soil loss continues to threaten upland agriculture in MDNP, underscoring the ongoing challenge of sustaining this protected area's land resource.

The spatial maps generated by this study provide valuable tools for decision-makers, urban planners, land resource managers, field technicians, and researchers. They offer actionable insights for designing soil conservation strategies, assessing land suitability, and formulating comprehensive forest rehabilitation and ecosystem restoration plans.

7. Conclusion

1. The current total estimated annual soil loss is **93,345.05 t/yr**, with an average rate of **37.72 t/ha/yr**. This moderate erosion classification is driven by steep slopes, high rainfall, intensive cultivation, and land clearing.
2. Approximately **459.93 hectares** (**13.14%**) of the study area is classified as degraded. The Composite Land Degradation Index (CLDI) reveals that all land-use categories and slope classes exhibit a high degradation index, with the exception of forest cover, which maintains a moderate level.
3. Baseline model simulations show that forest cover loses **7.10 t/ha/yr**, whereas agricultural land experiences significantly higher soil loss at **13.17 t/ha/yr**.
4. Conservation simulations demonstrate that expanding forest cover and adopting soil conservation practices can reduce erosion to **2.61 t/ha/yr** for forests and **9.41 t/ha/yr** for agricultural land, effectively lowering their overall erosion risk ratings.

Vii. Future enhancements or recommendations

1. Forest Ecosystem Restoration and Enhancement

To effectively address plateau degradation in Mount Data National Park (MDNP), it is essential to implement comprehensive tree-planting programs designed to expand vegetative cover and improve forest density. Simulated models demonstrate that increasing forest cover is the most effective approach for soil conservation. These restoration efforts should be data-driven, leveraging spatial distribution maps to precisely delineate and prioritize critical erosion hot spots and high-risk zones for immediate rehabilitation. By targeting these specific locations, planners and land managers can execute focused forest ecosystem restoration plans that maximize ecological impact.

2. Transition to Sustainable Farming Systems

To improve soil quality, sustainable land-use programs should actively promote agroforestry as a superior alternative to traditional agriculture. Integrating perennial trees—particularly nitrogen-fixing species—will boost soil organic matter (OM), manage nitrogen (N) levels, and provide vital ground cover. Additionally, farmers should adopt conservation tillage and crop diversification with leguminous crops to rebuild soil structure. Complementing these practices with organic fertilizers rather than inorganic options will further enhance organic matter and stabilize soil pH across cultivated lands.

3. Structural and Management Interventions

To address high soil displacement in Mount Data National Park (MDNP), decision-makers must promote appropriate terracing on steep agricultural plots to replace current sloping farming systems. These structural interventions are vital, as steep topography combined with intensive cultivation severely threatens the sustainability of upland agriculture. Furthermore, land managers should prioritize proven conservation practice (P) factors successfully implemented in other regions of the country. Incorporating these P factors into the USLE framework enables the creation of an indicator system to assess and mitigate human-driven soil erosion across the protected area.

4. Policy and Planning Integration

To ensure the long-term sustainability of Mount Data National Park (MDNP), planners and land managers must utilize LULC and soil loss maps to guide forest and land rehabilitation. These maps are essential for scientists and technicians to evaluate land suitability and target ecosystem restoration. Furthermore, establishing a USLE-based indicator system allows MDNP-PAMB and relevant agencies to track the complex, multi-scale impacts of human activities on soil erosion. This monitoring framework enables proactive management of anthropogenic pressures and ensures conservation efforts are prioritized where they are needed most.

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