Spatiotemporal Changes of Landuse and Landcover of Mount Data Plateau, Northern Luzon Highlands, Philippines

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ABSTRACT

Geographically, the study area lies entirely within the municipalities of Sabangan, Tadian, and Bauko in Mountain Province, Cordillera Administrative Region (CAR), centered at 16°52'41" N latitude and 120°50'18" E longitude. The plateau covers a portion of Mount Data National Park, spanning an approximate area of 3,502.10 hectares based on data generated by the Department of Environment and Natural Resources–Community Environment and Natural Resources Office (DENR-CENRO) Sabangan. Unprecedented anthropogenic activities and changing socioeconomic dynamics continue to alter land use and land cover (LULC) across fragile highland ecosystems. This study evaluated historical LULC shifts over a 30-year period (1990–2020) and projected future spatial patterns for 2030 in Mount Data National Park (MDNP) using Geographic Information Systems (GIS), remote sensing, and the QGIS Modules for Land Use Change Evaluation (MOLUSCE) framework integrated with an Artificial Neural Network–Multilayer Perceptron (ANN-MLP) model. Historical LULC thematic maps for 1990, 2000, 2010, and 2020 were classified into four standardized categories: forest cover, agricultural land, shrub/grassland, and built-up areas. Spatiotemporal transition matrices were generated to assess category conversions, while digital elevation models (DEM), slope, aspect, built-up density, and distance to roads and streams served as explanatory spatial variables for the 2030 projection. Model validation yielded a maximum Kappa coefficient of 0.76 and an overall correctness of 84.96%, confirming high predictive accuracy. Baseline assessments in 1990 revealed that forest cover (1,374.61 ha; 39.29%) and agricultural land (1,267.99 ha; 36.24%) dominated the landscape, followed by shrub/grassland (15.70%) and built-up areas (8.78%). By 2010, rapid agricultural expansion reached a peak share of 51.93%, largely encroaching into forest reserves. Between 2010 and 2020, agricultural land contracted slightly to 50.73%, whereas shrub/grassland surged from 11.42% to 17.15% (399.32 ha to 600.08 ha), aligning with regional declines in highland vegetable production reported by the Philippine Statistics Authority. Built-up area detection anomalies were attributed to spectral signatures from smart polyethylene greenhouses. Predictive modeling for 2030 indicates a continuation of long-term trajectories relative to the 1990 baseline, with forest cover and built-up areas projected to decrease overall by 14.49% and 5.37%, respectively, while agricultural land and shrub/grassland are expected to expand by 16.96% and 2.89%. These findings underscore persistent pressures on natural forest habitats and highlight the critical need for spatial land-use monitoring, boundary enforcement, and sustainable agroforestry management within the national park.

Keywords: spatiotemporal land use and land cover, agricultural land use, forest land use, shrub and grass land, and build-up area, and Predict LULC.

I. INTRODUCTION

Land use activities, driven primarily by agricultural expansion and economic growth, have transformed one-third to one-half of the planet's land surface through forest clearance, agricultural practices, settlement, and urban expansion, causing profound impacts on ecosystem services, food production, and the environment. [1] [6]. Rapid population growth and rising standards of living exert heavy pressure on key resources like soil, water, and vegetation, leading to the widespread clearance of upland forests. [2]. Data from the Department of Environment and Natural Resources shows a steep decline in forest cover from 21 million hectares (70% of land area) in 1900 to 7 million hectares (23%) by 2005. Rather than agricultural intensification, logging initially drove this shift by converting primary forests into secondary forests and grasslands, subsequently opening upland areas to shifting cultivation and intensive farming, as observed on the Mount Data Plateau [3].

Generally, land use and land cover changes can influence the socioeconomic status of the rural population [4]. The primary human driver of land use change is the urgent need to feed a rapidly growing population. To achieve food self-sufficiency, nations often expand agricultural land and allocate plots to landless farmers. Consequently, land use and land cover (LULC) changes directly impact agricultural productivity, a key determinant of rural income and wealth while severely diminishing the landscape's capacity to provide vital ecological goods and services. [5].

Furthermore, land use and land cover (LULC) changes influence local to global weather and climate conditions. By altering atmospheric composition and energy exchanges between land and the atmosphere, LULC changes contribute to global warming. Additionally, these changes drive biodiversity loss, forest fragmentation, soil erosion, and diminished ecosystem services, while exacerbating natural hazards such as flooding. Consequently, global attention is urgently needed to continuously monitor and project these spatiotemporal shifts [6]. Land cover change information is needed regarding what changes occur, where and when they occur, the rate, and the social and physical forces that drive those changes [7].

However, a comprehensive investigation into land use and land cover dynamics in and around the Mount Data Plateau (MDP) has yet to be conducted. Notably, current LULC status remains poorly documented, and few studies have examined spatiotemporal LULC changes or their underlying drivers over time. To address this gap, this study investigates land use and land cover changes and their environmental impacts in the northern Luzon highlands, Philippines.

II. LITERATURE REVIEW

Land, Land Use and Land Cover

Land resources within MDNP provide vital social, economic, and ecological functions that sustain local rural livelihoods. However, competing land demands and degradation severely compromise these key functions, making sustainable land management an urgent priority [8] [9] [10]. Consequently, monitoring local land conditions is essential to achieve targets for sustainability and ecological stability. In this context, land use and land cover (LULC) dynamics and their broader implications drive local and global environmental change, serving as critical indicators of regional environmental health and essential parameters in assessment frameworks [8] [11]. LULC data provides crucial baseline information for assessing, evaluating, and monitoring land degradation. Ultimately, shifts in LULC can highlight where degradation is most likely to occur, pointing to priority areas for sustainable land management (SLM) practices within MDNP.

LULC Change, It's Driving Forces and Implications

Land use and land cover (LULC) are closely linked but distinct characteristics of the Earth's surface [12]. Although classification schemes often combine them, they represent distinct datasets revealing how natural processes and human-environment interactions shape landscapes. The FAO defines land use as the "human modification of a natural environment or wilderness into a new environment such as agricultural fields, pasture and settlement" [14]. Land use implies deliberate human intervention for socio-economic purposes, denoting activities on the land. In contrast, land cover refers to the biophysical cover, of natural or anthropogenic origin, over the surface and immediate subsurface [10] [13], serving as a key indicator of environmental quality.

LULC change denotes the quantitative transition between LULC types via conversion or modification. Conversion represents complete category alteration, whereas modification involves structural or functional amendments within a category. Spatiotemporal LULC changes reflect evolving economic, social, and biophysical conditions, serving as primary indicators of land degradation and restoration dynamics [14] [15].

Spatial and temporal LULC patterns result from interacting biophysical and anthropogenic factors. While evidence of LULC change dates back thousands of years, recent human pressure on land and scarce natural resources is more intense than during any comparable historical period [16] [18]. This unprecedented interaction manifests as spatiotemporal changes across various scales.

Drivers of LULC change are frequently categorized into proximate and underlying causes. Proximate drivers comprise direct, human-intended land use actions that immediately alter land cover, whereas underlying forces represent broader socio-economic, political, and institutional contexts driving local actions [19]. Yesuph and Dagnew (2019) argue that proximate drivers are relatively static and quantifiable, whereas dynamic anthropogenic factors are harder to measure despite accurately reflecting landscape changes [15].

Although LULC change is global, its severity is heightened in fragile, mountainous ecosystems. While offering socio-economic benefits, LULC changes often trigger unintended, multidimensional impacts on ecosystem services across scales [19] [20]. Specifically, changes impair biodiversity, biogeochemical cycles, soil stability, livestock production, and water quality while accelerating soil erosion and land degradation [21] [22].

Consequently, periodic LULC monitoring is essential to evaluate ecosystem health, identify drivers of landscape dynamics, and assess environmental consequences [19]. These insights provide critical decision support for formulating effective land management and spatial planning strategies at national and local levels.

Historical Background and Concepts of Sustainable Land Management

In 1987, the World Commission on Environment and Development defined sustainable development as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" [23], implying economic progress that safeguards long-term environmental value.

The concept of Sustainable Land Management (SLM) emerged from a 1991 International Board for Soil Research and Development workshop in Chiang Rai, Thailand [24], and gained initial global recognition before being explicitly formalized in an FAO document titled *FESLM: An international framework for sustainable land management* [25]. Since then, SLM has become a global priority, with various definitions

proposed to expand the concept [18] [24]. Growing awareness of land degradation, food insecurity, climate change, and desertification has further driven its adoption [17] [18].
SLM entails adopting land use practices that balance increasing socio-economic benefits with maintaining the ecological support functions of land resources, pursuing these objectives simultaneously through a win-win approach. Despite varying definitions, the core consensus is that SLM uses integrated practices to maintain or enhance ecological integrity while promoting sustainable rural livelihoods [26]. Thus, SLM is a cornerstone for countering land degradation, conserving biodiversity, mitigating climate change, supporting ecosystem functions, and ensuring food security [18].
In the context of this study, SLM is defined as utilizing the land resources of Mount Data National Park (MDNP) to meet community livelihood needs while ensuring long-term socio-economic and ecological viability. It encompasses actions to prevent land degradation and reverse existing damage through appropriate technologies. These include soil and water conservation (SWC) measures, integrated water management to boost highland crop yields, local revegetation to control runoff and erosion, soil fertility enhancement, and climate adaptation, supported by active community participation, policy instruments, and intervention guidelines. As SWM (2020) highlights, adopting SLM technologies within an enabling institutional framework minimizes land degradation, restores landscapes, improves soil and water storage, enhances biodiversity, expands livelihood options, and builds resilience to natural disasters.

Sustainable Land Management Principles, Technologies and Approaches
SLM is the way out from the interwoven and mutually reinforcing problems of land degradation, climate change and variability impacts, vulnerability, and perpetual poverty at the household level of rural areas.

SLM principles
Sharma (1997) suggested the following lists of guiding principles for successful SLM planning process, such as development and management systems according to needs and capacities of people; technical appropriateness, feasibility and cost effectiveness of planed interventions; participatory planning and implementation of approaches; promotion of community management and maintenance systems; adopt holistic planning and an integrated approach; ensure gender equality in planning and decision making and make monitoring and evaluation an integrative part of the process [27].

Land management sustainability components
FAO (2006) indicated some of land management sustainability indicators including *ecological sustainability* (SLM interventions should be ecologically protective and should maintain a stable resource base of all land resources); *technological sustainability* (since every geographic area has its own unique characteristics which are mediated by the local community in intricated and often unique manner, SLM technologies should be context specific. In addition, approaches to SLM interventions should be process-oriented and flexible to the changing circumstances); *social and cultural sustainability* (SLM planning and actual implementation should be based on consideration of indigenous knowledge, experiences and cultural norms. It should ensure fairness in cost and benefit sharing mechanism among the participating communities irrespective of gender, wealth status, educational background and other parameters); *economic sustainability*: SLM interventions should enable land to produce on a continuing basis. It should also address short term economic needs without compromising long-term vision) and *institutional sustainability* (the sustainability of government institutions, advisory support service providers,

community-based organizations and their effectiveness in achieving SLM goals. This includes capacity to plan, coordinate human activities, implement and monitor SLM activities, to provide relevant and timely information in sustainable manner). Moreover, accountability, transparency, property rights and collective action and empowerment of women's group are important indicators of institutional sustainability [28] [29].

SLM technologies

Yesuph and Dagnew (2019) describe SLM technologies as "a physical practice on the land that controls land degradation, and enhances productivity and other ecosystem services," consisting of agronomic, vegetative, structural, or management measures. To ensure successful adoption, SLM technologies should ideally be simple to understand and implement; low-cost regarding financial investment, labor, and land consumption; effective for conservation and production; sustainable; resilient to risk; and adaptable [15] [29].

SLM approaches

As documented by Hurni (2000), an approach is defined as "the ways and means" (e.g., legal frameworks, technical and material assistance, stakeholder participation) used to introduce, implement, and sustainably apply proposed SLM technologies and programs in the field [29]. Confirming this, SLM technologies require approaches that empower communities to accept, adopt, and disseminate best practices [30].

Over recent decades, various strategies have been employed to reverse environmental degradation and boost productivity. To relieve pressure on land resources and foster widespread adoption, contemporary literature proposes the following key SLM approaches relevant to this study [31]:

1. Land User-Driven and Participatory Approaches

Because environmental challenges are complex and multifaceted, they require flexible, transparent, and multidisciplinary decision-making. To achieve optimal outcomes in SLM, community representation and keen interest must be integrated across all decision-making phases. Stakeholder participation actively seeks local knowledge, needs, and concerns, ensuring communities hold meaningful influence [32].

The Bureau of Soils and Water Management (2020) and Hurni (2000) identify four primary reasons for adopting participatory SLM approaches [18] [29]:

First, SLM is only sustainable when planning and implementation actively involve local populations.

Second, participatory models enable two-way communication, allowing farmers and officials to exchange perspectives, build mutual respect, and navigate trade-offs.

Third, genuine participation shifts power dynamics in favor of marginalized groups.

Fourth, it fosters a strong sense of local ownership, ensuring long-term project viability.

Overall, participatory approaches facilitate knowledge exchange, clarify localized issues, build public trust, and yield achievable, culturally acceptable solutions.

However, effective participation faces notable challenges, including top-down administrative prescriptions, exaggerated success reports, elite capture, short-term economic expectations, and public apathy [18] [29]. Similarly, Reed (2008) critiqued participatory models for lacking intellectual rigor, risking tokenism, over-privileging local views at the expense of empirical expertise, and falsely treating communities as homogeneous units [33].

Notwithstanding these critiques, research offers clear strategies to address them. Schmitt (2007) argues that participatory frameworks can be strengthened by clearly defining engagement scopes, accounting for community heterogeneity, and prioritizing marginalized voices over local elites. Furthermore, providing timely feedback regarding how community inputs influenced final outcomes builds trust and prevents unrealistic expectations [11].

2. Integrated Watershed Management Approach

A watershed is a topographically bounded hydrologic unit drained by a stream or tributary system sharing a common outlet for surface runoff (P.D. 705). Within this system, natural resources (soil, water, vegetation), human populations, livestock, and agricultural practices are inextricably linked through shared watercourses. Watershed management is interdisciplinary, seeking to balance human socio-economic needs with environmental restoration, pollution reduction, and ecosystem resilience.

Emerging in the 1980s, Integrated Watershed Management is widely accepted as a holistic framework for environmental planning and sustainable resource management [18] [27]. Integration entails managing diverse watershed components, including vegetation, soil, water, livestock, and crops through coordinated practices that align with community priorities like food security and income generation [34]. It also involves blending knowledge across academic disciplines, government institutions, and local agencies [30].

In the Philippines, Community-Based Forest Management (CBFM) and tenure security represent good practices in watershed governance. Guiang et al. (2001) note that relocating upland communities is economically, socially, and politically unfeasible. Instead, the Philippine government provides forest occupants with incentives to actively engage in forest protection and conservation (Executive Order 263 designates CBFM as the national strategy for sustainable forest management). Crucially, long-term tenure security fosters community ownership, encouraging residents to invest in land stewardship while effectively eliminating open-access exploitation in forestlands [35].

Paradigm Shifts in Sustainable Land Management Approaches

Historically, land management activities relied on narrow, sectoral approaches that focused primarily on soil conservation through physical structures and degraded hillside enclosures [37]. Unlike past soil and water conservation (SWC) interventions, modern land management emphasizes the integrated management of natural resources, actively engaging land users to improve their well-being [36] [37]. Consequently, contemporary land management is people-centered, prioritizing local communities' needs and sustainable livelihoods over the administrative requirements of donors and non-governmental organizations. Key differences between traditional and modern land management approaches are summarized in the table below.

Table 1. Comparisons of traditional and new generation views in land management Approaches

The Traditional Views	The new generation Views (Current scenario)
Top-down planning ignores community input, dismissing indigenous knowledge as inferior.	Emphasis on a participatory, community-based approach focusing on gender and social equity, integrating indigenous knowledge and traditions with new technologies to create "hybrid knowledge" systems.
Focused on single purpose (Soil conservation)	Focused on sustainable land management (Social, economic and environmental)
Sustainable land management relies on constructing sporadic physical structures or	Sustainable land management is achieved through continuous follow-up and long-term application of

biological barriers, alongside applying fertilizers.	appropriate conservation measures and management strategies.
Land users were viewed as conservative, irrational, and ignorant, with their practices blamed for land degradation; thus, coercion was used to enforce "expert" recommended solutions within communities.	Land users make rational decisions based on their constraints and are focused on land productivity. Possessing intimate local knowledge, they should be viewed as key partners in solving land degradation, driving active community participation across all intervention phases.
Emphasis on the increase of production and conservation issues within land management programs	Emphasis on livelihoods, poverty and sustainability issues within land management program
Focus on large watershed, on-site and short-term effects.	Focus on Small watershed, sub watershed, upstream-downstream linkages and long-term impacts.

Source: Adopted from FAO, 2006 [14]

Land Degradation in the International Arena

Land degradation currently affects approximately 33% of the Earth's land surface and continues to expand globally. As agricultural lands lose productivity, more forests are cleared for farming. Exacerbating this trend, rapid urbanization drives the extensive conversion of prime agricultural land into urban areas. Africa and Asia are particularly affected, leaving marginal farmers increasingly vulnerable and threatening food security and sustained agricultural productivity [18].

Within the FAO-LADA framework, land degradation is defined as "a decline in ecosystem goods and services from the land which negatively affects the state and the management of the natural resources" [30]. Land degradation remains a fundamental global environmental and development challenge due to its severe implications for environmental stability, agro-ecosystem services, livelihood options, and food security [17] [21] [38]. As defined by Blaikie (1989), it represents a gradual decrease in the actual or potential productivity of land under specific management strategies.

Broadly, land degradation signifies a temporary or permanent decline in the productive capacity of the land [18]. It has also been described as the "aggregate diminution of the productive potential of the land, including its major uses (rainfed, arable, irrigated, rangeland, forest), its farming systems (e.g., smallholder subsistence), and its value as an economic resource" [18]. Similarly, the UNCCD defines land degradation as any decline or loss in the land resource base caused by human activities and natural processes, often aggravated by climate change and variability [17].

Collectively, these definitions demonstrate that land degradation is a complex process driven by human activities and natural drivers including climate variation that degrades environmental quality and land productivity [18] [29]. In short, land degradation is not merely an ecological problem, but a complex socio-economic issue driven by intricate interactions between human and natural processes [18].

Driving forces and extents of land degradation

There are divergent views on the causes of land degradation. However, it is fundamentally a multifaceted, complex, and dynamic process involving two interconnected systems: human factors (socioeconomic, cultural, institutional, and political) and natural (biophysical) processes [15]. Drivers of land degradation are grouped into proximate and underlying causes. Proximate causes directly affect the terrestrial ecosystem; these include natural disasters, climate change, topography, unsuitable land use, unsustainable resource management, deforestation, and land use/land cover (LULC) changes.

Underlying causes fuel these proximate drivers. The most commonly cited global factors include insecure land tenure, land fragmentation, poverty, population growth (though the poverty–population–degradation nexus remains controversial), livestock pressure, weak environmental policies, lack of information on appropriate management technologies, limited access to farm inputs and credit, and unplanned land use change. Together, these drive worldwide land degradation and the associated loss of biodiversity and ecosystem services [17] [16] [19].

Although land degradation is a global risk, its extent and severity vary significantly. Two-fifths of the world's degraded lands are in regions with the highest poverty levels [39]. According to Bai et al. (2008), degradation affects over 30% of forests, 20% of cultivated lands, and 10% of grasslands, which are home to more than 3.2 billion people. Beyond physical ecosystem impacts, degradation drives severe socioeconomic consequences, including persistent poverty, water scarcity, and food insecurity [39]. Consequently, approximately 5 to 8 million hectares of previously productive land are lost to farming globally each year [28]. The loss of arable land is now 30 to 35 times the historical rate, while agricultural productivity worldwide has dropped by 40 to 75% due to degradation [17]. According to the FAO Global Land Degradation report, a quarter of the world's terrestrial land surface is highly degraded or degrading, with an additional 8% moderately affected [41].

Future projections remain concerning. Lambin and Meyfroidt (2011) hypothesized that by 2030, global demand for additional land will be met primarily by expanding into forests and converting productive, vacant lands. Similarly, UNEP (2014) estimated that by 2030, over one-fifth of terrestrial habitats in developing nations could be converted to cropland if current management practices persist, further accelerating the loss of vital ecosystem services and biodiversity [21].

<u>Global efforts to combat land degradation</u>

There is a growing conviction that national efforts to eradicate poverty and achieve sustainable development are unlikely to succeed without effectively addressing land degradation [18] [39]. However, national research reports indicate a promising potential to halt and reverse land degradation through appropriate interventions. This is supported by evidence showing that a significant portion (2.7%) of the world’s land area has improved over the past three decades [17].

Despite persistent global efforts to combat land degradation since the 1992 United Nations Conference on Environment and Development in Rio de Janeiro, progress remains small compared to the scale of the problem [17].

Recognizing the urgent need for more concerted land resource management, world leaders adopted the "The Future We Want" declaration at the 2012 UN General Assembly, prioritizing land degradation as an urgent global challenge. They agreed to strive for a land-degradation-neutral world in the context of sustainable development (UN, 2012). Furthermore, achieving land degradation neutrality and promoting sustainable land management (SLM) were established as key targets within the Sustainable Development Goals adopted at the UN summit in September 2015. Specifically, Goal 15 aims to protect, restore, and promote the sustainable use of terrestrial ecosystems, combat desertification, and reverse land degradation [17]; Olsson et al., 2019; [18]. Aligning with these goals, the Addis Accord emphasized mobilizing financial resources for SLM to protect ecosystems and restore degraded land for all [17].

<u>Land degradation in Philippine context</u>

The Philippines covers an estimated land area of 29.9 million hectares, much of which is undulating, with at least three-fifths classified as sloping uplands. The country features 419 river basins with steep, short topographies. It is among the most environmentally threatened nations due to widespread soil erosion that undermines agricultural and forestry sustainability. Nearly half (45%) of arable lands are moderately to severely eroded. Furthermore, watershed integrity has been severely compromised by inappropriate upland farming, deforestation, road construction, and mining. These activities lead to water shortages, sedimentation, and heightened vulnerability to natural disasters such as typhoons, exacerbated by rural poverty, poor watershed management, and intense El Niño and La Niña events [18] [17] [41].

According to the Philippine Statistics Authority (2020), nearly half of the country's population of approximately 109 million depends on natural resources for livelihood and income. Most of these individuals (28%) live below the poverty line. Declining plot productivity, caused primarily by soil erosion, nutrient depletion, and water scarcity, further deepens rural poverty [42]. Continued land degradation and declining productivity threaten the 35% of the labor force that relies on agriculture. It also risks lowering the sector's economic contribution, which accounted for an average of 18% of Gross Domestic Product (GDP) in 2010. Consequently, agricultural export revenues are unlikely to remain sustainable and will likely decline over the long term [18].

The saturation of lowlands (0–18% slopes classified as alienable and disposable land) forces landless farmers into public forest lands. In these areas, the Department of Agriculture (DA) cannot readily provide farm support because jurisdiction lies with the Department of Environment and Natural Resources (DENR). Even where upland areas exceeding 18% slope are agricultural suitable, legal restrictions prevent formal development [17] [36]. In many such regions, both the DA (promoting soil conservation farming) and DENR (requiring community-based agroforestry) struggle to deploy Sustainable Land Management (SLM) technologies due to remote, scattered upland communities and a lack of inter-agency coordination in extending services [11].

<u>Land degradation in the Philippine highlands</u>

As cited by Carating (2016), forests that once blanketed the uplands have been largely cleared. According to the Department of Environment and Natural Resources, the country's forest cover dropped from 21 million hectares (70% of total land area) in 1900 to just 7 million hectares (23%) by 2005. However, the loss of primary forests was not driven primarily by agricultural intensification; rather, commercial logging initially degraded primary forests into secondary forests and grasslands, opening these lands to shifting cultivation (*kaingin*) and, eventually, intensive agriculture [43] [50].

The Cordillera Administrative Region (CAR) spans 1,865,660 hectares, accounting for 6.2% of the country's total land area. It features mountainous terrain with towering peaks, plateaus, and intermittent valleys, with about 71% of its land area having steep slopes of 30 percent and above. CAR comprises six provinces (Abra, Apayao, Benguet, Ifugao, Kalinga, and Mountain Province) and two cities: the highly urbanized city of Baguio and the component city of Tabuk in Kalinga.

Soil erosion is the most prevalent form of land degradation in the region. According to PSA-CAR (2020), most of the region's land area is susceptible to slight erosion (36%), while significant areas face moderate (32%) and severe erosion (22%). Human activities, including land-use conversion, deforestation, illegal logging, *kaingin*, unsustainable farming, and poor land and water management, have degraded soil quality. The UN Food and Agriculture Organization (FAO) defines soil degradation as a decline in soil health that diminishes its capacity to provide ecosystem goods and services [42].

<u>Land management sustainability indicators and assessment method</u>

Assessing Sustainable Land Management (SLM) is challenging because establishing precise spatial and temporal boundaries is difficult. Furthermore, selecting appropriate evaluation indicators is complex, and assessing sustainability requires long-term data that are scarce, particularly in developing countries [11]. Despite these challenges, literature suggests several core indicators for evaluating SLM practices.

Indicators serve as metrics that reflect environmental conditions, quality, and trends. They are used to monitor the sustainability of land use and management systems, determining whether land quality remains stable, improves, or degrades over time [20]. Key indicators for appraising and monitoring SLM include: LULC dynamics; biodiversity status; water availability and quality; biomass productivity; socioeconomic conditions; land productivity trends (annual and perennial crops, pastures, trees); soil fertility status; and rates of runoff, soil erosion, and sedimentation [12].

Land degradation affects many parts of the world with varying severity and impacts [29]. However, no single best method exists for assessing land degradation or restoration. The most effective approach integrates multiple information sources. Through these methodological frameworks, degradation and rehabilitation dynamics are evaluated using site-based indicators (e.g., field measurements and laboratory sample analysis), geospatial analysis derived from remote sensing (e.g., GIS-based LULC and NDVI metrics), and stakeholder perspectives, including expert judgment, land-user insights, in-depth interviews, and direct observations of land productivity changes [40] [39].

Role of Remote Sensing and GIS in Sustainable Land Management

Land resource and environmental decision-makers require quantitative data on the spatial distribution, condition, and temporal changes of land-use types. Remote sensing and GIS technologies have enabled ecologists and natural resource managers to acquire timely data and monitor periodic changes effectively [40].

Consequently, remote sensing and GIS serve as powerful tools for obtaining precise, timely information on natural resource conditions before and after Sustainable Land Management (SLM) interventions. When integrated, these technologies offer an efficient, cost-effective, and indispensable system for watershed resource management and monitoring [11]. Multi-temporal remotely sensed data, combined with socioeconomic information, not only inform sustainable land management strategies but also track their progress and success. Furthermore, these tools are essential for delineating, characterizing, and prioritizing erosion-prone areas and generating specialized thematic maps [18]. As Baig et al. (2021) noted, examining environmental states and LULC dynamics using GIS and remote sensing requires careful attention to the nature, extent, spatial distribution, and relationships of land changes [5].

III. OBJECTIVES OF THE RESEARCH STUDY

The overall objective of this study is to evaluate land use and land cover (LULC) changes, specifically focusing on agricultural, forest, built-up, and shrub/grassland areas within the study site. Specifically, the study aims to determine historical LULC changes over a 30-year period from 1990 to 2020 using Geographic Information Systems (GIS) and remote sensing technologies and subsequently predict future LULC patterns for the year 2030 using the same geospatial techniques.

IV. MATERIALS AND METHODS

This section describes the methodological approach, research design, data types, and strategic frameworks guiding the data collection and analysis processes.

Methodological approach

This study emphasizes that contemporary human-environment relations and environmental studies require a holistic approach, integrating biophysical, sociocultural, economic, and institutional data, techniques, perspectives, and concepts into natural resource management. Yesuph & Dagnew (2019) suggest that research methods should derive directly from the research questions. Because no single method can address every dimension of complex environmental problems, this research applies an interdisciplinary framework combining natural and social science methodologies. Mixed methods integrate the strengths of various approaches to address multifaceted issues effectively. Customized to fit the study's objectives, qualitative methods will explore local community perceptions of land use and land cover degradation, as well as SLM practices at both household and community levels. Qualitative methods serve as ideal participatory tools to investigate perceptions, offering deeper insights into the context-specific realities of target populations [15].

Research design

In this study, a combination of ex-post (for analyzing intervention programs) and place-based case study research designs is adopted. Crossman (2019) explains that a case study is a pragmatic investigation of a contemporary phenomenon "within its real-life context," relying on data collected from multiple sources as envisaged by the mixed-methods approach. Furthermore, case studies offer explanatory insights into society-environment nexus problems that large-scale studies often overlook [44]. Yesuph & Dagnew (2019) explain that the ex post facto research design is ideal for establishing potential relationships among variables by observing present conditions and analyzing past contributory factors [15]. This research design is particularly appropriate given the long history of sustainable land management programs, specifically soil and water conservation, in the Park.

Data types, sources and methods of data collection

SLM is a complex process involving multi-level, multi-stakeholder approaches that require integrated planning to balance an area's ecological, economic, and sociocultural objectives. Consequently, biophysical and socioeconomic data will be gathered from primary and secondary sources using multiple collection techniques. As Yesuph & Dagnew (2019) and Hurni (1998) explain, complex human-environment interactions necessitate considering geographical and socioeconomic data gathered through diverse methods. The following sections detail the specific data-gathering procedures deemed appropriate for this study [15].

LULC Change Detection and Analysis

<u>Remotely sensed data type and sources</u>

Although remotely sensed data are vital in LULC change studies, they cannot fully explain why and how changes occur [15]. This study combined multiple techniques to evaluate LULC dynamics, their drivers, and their implications. First, LULC trends over the past three decades (1990–2020) were analyzed using satellite imagery and GIS techniques, complemented by field observations. Second, community members, elders, and other stakeholders were interviewed to examine local perceptions of LULC changes and their drivers. Third, the implications for the biophysical environment and local livelihoods in MDNP were linked to existing literature.

Digital Landsat imagery was used to examine LULC dynamics in MDNP. Image selection was based on quality (e.g., cloud-free conditions), long-time series availability, research objectives, and seasonal suitability for socioeconomic field data collection. The Landsat images had a 30-meter resolution. Terrain-corrected, calibrated images were accessed via online archives from NAMRIA (https://www.namria.gov.ph/download.php), PhilGIS, DA-BSWM (http://bswm.da.gov.ph/), and USGS EROS (http://earthexplorer.usgs.gov/). Metadata on platforms, sensor calibration, projections, coverage, resolution, and cloud cover were evaluated during image acquisition. Variations in solar illumination angles caused by MDNP's rugged terrain were also accounted for to prevent differing reflectance for identical cover types.

Acquisition dates were kept as close as possible to minimize seasonal variation. Dry, clear-sky months (September to October) were selected to avoid atmospheric distortion and leverage the harvest season, which makes land cover types easier to distinguish. All imagery was projected to UTM Zone 51, WGS 84 datum for dataset consistency. The datasets, sources, and specifications are summarized below.

Table 2. Landsat scenes, source and specifications used for the study

Characteristic	Landsat TM	Landsat ETM$^+$ SLC-on	Landsat 8 OLI/TIRS
Data Set Attribute	L1-L5	L7	L8
WRS Path/Raw	168/052	168/052	168/052
Number of Bands	7	8	8
Pixel resolution	30m x 30m	30m x 30m	30m x 30m
Sources	EROS/ USGS	EROS/ USGS	EROS/ USGS

TM = Thematic Mapper; ETM+ = Enhanced Thematic Mapper Plus; OLI = Operational Land Imager, TIRS = Thermal Infrared Sensor

Source: *Agharroud, 2022 [55]*

Supplementary data

To validate image accuracy and investigate the drivers and impacts of LULC changes, supplementary data, including Digital Elevation Models (DEMs), topographic maps, and socioeconomic data, were collected from various sources. DEMs were used to extract slope properties, prepare topographic maps, and delineate micro-watersheds in MDNP. High-resolution Google Earth images and mobile applications provided ground-truth photographs for LULC classification and validation. Topographic maps from NAMRIA enabled geo-referencing, base map preparation, and class verification.

Information on SWC measures, LULC dynamics, and soil erosion was gathered through key informant interviews, focus group discussions, and field observations. Local knowledge offered insights into historical LULC changes, perceived drivers, and site-specific management efforts. Supplementary documents, such as policy frameworks, proclamations, guidelines, and statistical reports, were obtained from government offices and official websites. Quantitative analysis was conducted in Microsoft Excel 2016, while spatial processing was performed using ArcGIS and QGIS softwares.

Data verification and error control

Data verification and error control received special attention in this study. To identify and interpret the main LULC types, field visits and observations were conducted at different times across MDNP. During field surveys, historical and current LULC data were recorded and georeferenced using GPS-capable smartphones. Reference sites were also photographed to bolster data reliability. GPS locations for historical LULC types were identified with assistance from local elders, the researcher's prior knowledge, and key informants from regional government departments, the Provincial Agriculture Office of Mountain Province, and DENR offices.

Digital image processing and LULC mapping

Following selection and acquisition, satellite imagery underwent preprocessing, including band resampling and layer stacking, atmospheric and geometric corrections, and temporal and topographic normalizations. Landsat images were resampled to 30 m pixels using the nearest neighbor method to ensure pixel uniformity [45]. Subsets covering MDNP were then extracted using ArcGIS or QGIS. After checking image quality, a classification scheme was developed to derive the park's LULC classes.

Training sites for recent images were generated using GPS readings supported by high-resolution Google Earth imagery. For historical images, training sites were assigned via visual interpretation of raw imagery, topographic maps, archival black-and-white ground photographs, local elders' insights, and prior research knowledge, an approach consistent with previous LULC change studies [46]. Training signatures were then evaluated for separability among LULC classes.

Supervised classification and visual interpretation were applied to all images using the Maximum Likelihood algorithm alongside change detection comparison techniques. Recoding via visual inspection in GIS was used to correct misclassified pixels and improve overall accuracy.

To simplify classification, related categories were merged. For instance, scattered rural settlements and infrastructure were aggregated into built-up areas. Similarly, intermingled shrubs and bushes were combined into shrub and grassland. The final classification modified the FAO LULC scheme, which is widely applied in developing countries, adopting four standardized categories for easy comparison: forest land, agricultural land, residential area, and grass and brush land.

Change detection and analysis

The changes in LULC that had occurred in the MDNP over the period of study were detected through post-classification comparison approach [15]. Post classification comparison (map-to-map comparison) methods is preferred in this study for a number of reasons. Firstly, these methods enable to compare multi-temporal images recorded by different sensors under different environmental and atmospheric conditions. Secondly, these methods provide the extent and nature of 'from-to' change information [47]. Based on this ground, four (4) LULC maps are compiled to display the type of LULC classes and compare between the classified images. Then the whole study period (1990-2020) was classified into four sub-periods (1990 to 2000; 2000 to 2010; 2010 to 2020; and 1990-2020 which include the entire 30 years of study periods). Then, paired overlay were performed through spatial analysis in Arc GIS or Q-GIS in order to detect, compare, and analyze patterns and directions of changes and quantify persistence, gains, losses, total change, net change, and swapping of LULC occurred during the time period considered in the MDNP [15]. The percentage share of each LULC type in a study area computed as:

$$\mathbf{Z = \frac{xi}{Y} * 100 \ (Equation\ 1)}$$

Where Z is percentage share of each LULC type, xi is area of each LULC type, and Y is the total area of the study area.

To determine the magnitude, trend, and rate of LULC changes in the Park, the area comparison analysis is used by subtracting the total area of each classes of 1990 from 2000, 2000 from 2010, 2010 from 2020 and 1990 from 2020, where the results were positive (increasing) or negative (decreasing). The percent and rate of LULC change are computed by the following formula [15] [46]:

$$\textbf{Percentage of change} = \frac{A-B}{B}\ X\ 100 \qquad \textbf{(Equation 2)}$$

$$\textbf{Percentage of change} = \frac{A-B}{C}\ X\ 100 \qquad \textbf{(Equation 3)}$$

Where, A is area of LULC (ha) in time 2, *B* is area of LULC (ha) in time 1; *C* is Time interval between *A* and B in years.

Conversion matrix was used to distinguish the changes of each category at the expense of others and its general structure is indicated on appendix table 1. The rows and columns in the table display the categories of time 1 (initial Time), and time 2 (subsequent time), respectively. The diagonal entries (that is, Pjj) portray the amount of LULC category which remain persistence of class j between the time period and use to calculate the gains and the losses of LULC classes while the off-diagonal entries show the size of the area that transition from category "*i*" to a different category "*j*" during the time interval [15]. For ease of reference, the equations and notations used to compute various components are presented as follows:

The research area Pi+ that is covered/used by class i in Time1, is given by:

$$pi+ = \sum_{i=0}^{n} pij \qquad \textbf{(Equation 4)}$$

Where n is the total number of LULC classes. Similarly, the research area of the MDNP P+j that is covered or used by class j in time 2 is given by:

$$j = \sum_{j=1}^{n} pij \qquad \textbf{(Equation 5)}$$

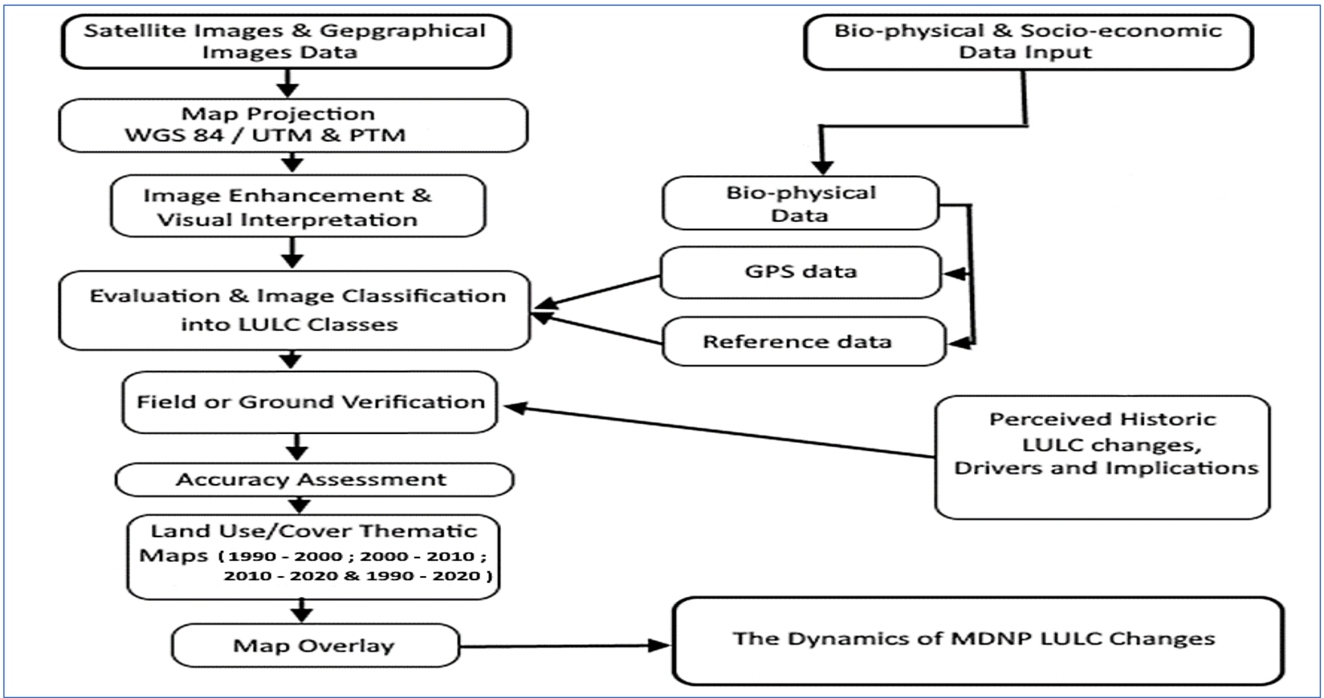


Figure 2. Methodological flow of land use and land cover analysis
Modified from DA-BSWM, 2020 [18]

V. RESULTS AND DISCUSSION

This chapter illustrates LULC changes and their associated implications by integrating remote sensing data and GIS technology for land-use conservation strategies.

Profile of the Study Area

Geographically, the study area lies within the municipalities of Sabangan, Tadian, and Bauko in Mountain Province, Cordillera Administrative Region (CAR), situated at $16°52'41''$ N latitude and $120°50'18''$ E longitude (Figure 6). The Mountain Province section of MDNP covers part of the Mount Data plateau and 100 meters on both sides of Halsema Highway, extending from Barangay Sinto, Bauko, down to Barangay Napua, Sabangan (117 km from Baguio City). It encompasses approximately 3,502.10 hectares, according to the DENR-CENRO Sabangan report (2019).

The study sites were located across several barangays: Sinto, Mount Data, Sadsadan, Monamon Sur, and Mabaay in Bauko; Lenga and Dacudac in Tadian; and Namatec and Napua in Sabangan, all in Mountain Province. Barangays Bedbed and Balili are situated in neighboring Benguet Province.

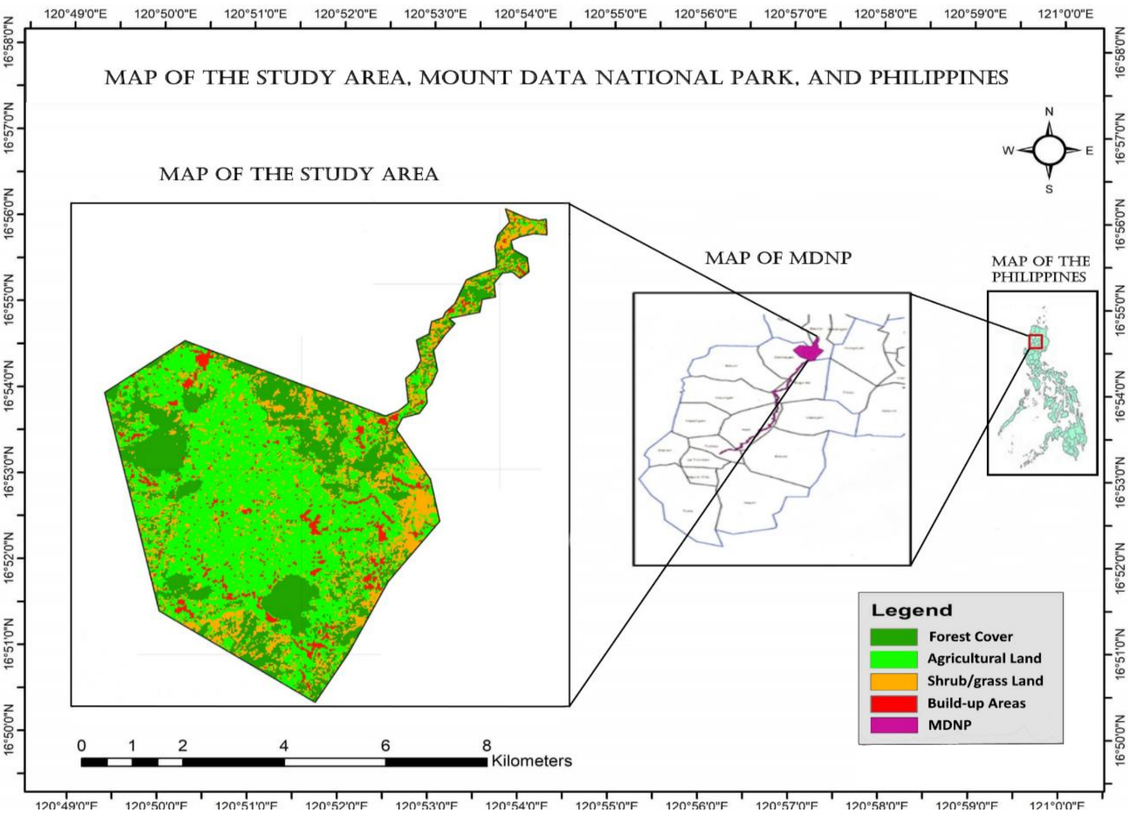


Figure 6. Location map of the study area in the Northern Philippines
(Source: Map drawn by the author, 2023)

According to Osbucan (2019) in *Seguidor.net* ("The Place Where I Belong: The Legend of Mount Data"), the area originally had no formal settlements or name; it was simply identified as Km 102 (102 kilometers from Baguio City). In 1946, the Heald Lumber Company, an American firm later assimilated into Benguet Management Corporation (BMC), established a sawmill there under a timber license covering parts of Nueva Vizcaya and the former sub-provinces of Benguet, Ifugao, and Bontoc. As the Pacific War drew to a close and livelihood options remained limited, this sawmill and Benguet's mining operations attracted workers from across the region, including Benguet, Ifugao, Bontoc, Kalinga, La Union, Pangasinan, Ilocos Sur, Ilocos Norte, and Nueva Vizcaya. The sawmill operated for 42 years until its timber license expired in 1988 without renewal.

As a licensee, the company followed forest conservation regulations, evident in the second-growth pine forests on logged-over land and active fire prevention efforts. However, two major forest fires (in 1972 and 1984) severely impacted operations, destroying bunkhouses, cottages, and the sawmill itself. Notably, the company fenced off an 80-hectare watershed that preserved the plateau's remaining solid mossy forest, which prevented its conversion into vegetable gardens. Today, surrounding barangays including Barangay Mount Data along with Mount Data Hotel and local vegetable farms, rely on this mossy forest for their water supply.

Geographic Features

The study area is generally mountainous with rolling, highly rugged terrain on steep slopes. Elevations across barangays within MDNP range from 1,448 to 2,362 meters above sea level. The Mount Data plateau is the widest section of the park, featuring rolling terrain with moderately flat to moderately steep slopes, though steep inclines line its perimeter boundary. Slopes within MDNP range from 0% to greater than 84%.

The Halsema Highway section features deep ravines and notable rock formations, including the Mount Data Cliff, which is carved into a limestone structure. According to the 2014 Ecological Profile of Bauko, based on a Mines and Geosciences Bureau (MGB) geological survey the land is characterized by thick, extensive, and transgressed mixed marine deposits. Underlain by conglomerates associated with Polaris coal measures, these deposits include wackes, shales, reefs, and limestone. Barangays Sadsadan and Monamon Sur contain undifferentiated rocks, including graywackes, metamorphosed shales, and pyroclastic formations. Oligocene-Miocene rocks occur in Mabaay, Monamon Norte, Mount Data, Sinto, and portions of Sadsadan and Monamon Sur. Six soil types are present in the area: Sabangan loam, Balili gravelly loam, Cervantes loam, rough mountainous land, Guinaoang loam, and undifferentiated mountain soil.

Climatic Conditions

The Mountain Province section of MDNP is characterized by Climate Type III, with unpronounced seasons that are relatively dry from November to April and wet for the rest of the year [42]. January through April typically form the dry season, marked by droughts exacerbated by El Niño. The rainy season spans July to September, while fewer but stronger typhoons (Categories 4 and 5) occur from October to December. Mean annual rainfall in MDNP from 1990 to 2020 was 3,831.3 mm, ranging from a low of 20.5 mm in January to a peak of 955.7 mm in August. Temperatures peak at 26°C during the dry season and drop to a low of 4°C between October and February. Relative humidity ranges from 82% in the dry season to 88%–92% in the wet season [42] [43].

Land-uses of the Mount Data National Park

The 3,502-hectare area features diverse land uses, including agricultural land, brush/shrubland, forest, built-up areas, and grassland. Main agricultural zones are located largely on the plateau and within disputed boundary areas between Bauko and Mankayan (114.89 ha) and Tadian and Bauko (192.82 ha) (DENR-CENRO, Sabangan, 2019).

The primary crops grown are potatoes (*Solanum tuberosum*), broccoli (*Brassica oleracea* var. *italica*), and cabbage (*Brassica oleracea*). Secondary crops include carrots (*Daucus carota*), Chinese cabbage (*Brassica rapa* subsp. *chinensis*), and pechay (*Brassica rapa*). Average production on 0.4–0.7 ha yields approximately 4 to 7 tons for most crops, and 6 to 8 tons for cabbage [43].

Settlement patterns are shaped by road networks, water availability, and livelihoods. Houses form clusters, often spaced over a kilometer apart. Local communities rely heavily on vegetable farming, which favors large-scale highland crop production. Small vegetable gardens, typically cleared by burning and fertilized with chicken manure, surround houses. Most residents earn income from farming. Other livelihoods include commercial enterprises (e.g., general merchandise, agricultural supplies, and sari-sari stores), farm or business labor, and employment in local public or private institutions.

Patches of open pine forest occur in Mount Data (55.46 ha), Mabaay (47.77 ha), Sinto (29.41 ha), Monamon Sur (21.89 ha), Sadsadan (13.35 ha), and Bauko and Sabangan (55.68 ha). Additional sporadic open pine forests lie along the tri-boundary of Tadian, Bauko, and Mankayan. The 87-hectare Wane watershed, spanning Monamon Sur, Mount Data, and Sinto, contains the study area's only mossy forest. Meanwhile, alienable and disposable lands have been classified under the current system as unneeded for forestry or consisting of eroded, rocky terrain.

Hydrology

The area is drained by four major basins: the Abra, Chico, Amburayan, and Agno rivers. Water resources are abundant, supplied by river systems and perennial creeks throughout the park. These sources meet domestic, commercial, industrial, and agricultural needs, though water shortages occur during the dry season. MDNP comprises two primary watershed components: the Bellang and Wane Watersheds. [43].

Eco-tourism

The Protected Area (PA) lacks recreation facilities and concentrated tourist zones, preventing the DENR and LGUs from maintaining records of park visitors. However, the LGU of Mountain Province operates an economy class hotel and restaurant within MDNP at Barangay Mount Data, Bauko. Operational since 1962, it serves as a midpoint stopover for travelers journeying from Baguio City to Sagada Cave and the famous rice terraces of Banaue, Ifugao.

Nearby tourist spots include Mount Bandilaan, a 30-minute drive from Mount Data Hotel, where a 200-step hill leads to a shrine of the Blessed Virgin Mary. Surrounded by vegetable gardens, the site offers a bird's-eye view of Bauko's barangays and Quirino, Ilocos Sur. Additionally, the Inodey Falls Viewpoint, one of Bauko's main attractions is about a 30-minute drive from the hotel, though the waterfall's flow decreases significantly during the dry season.

Socio-cultural Profile and Land Ownership

The Park is primarily inhabited by Indigenous Peoples of the Kankanaey ethnolinguistic group. Ifugao, other ethnic groups, and lowland migrants make up the remainder of the population, though exact demographic statistics are not yet established. Barangays Sinto, Mount Data, Monamon Sur, Sadsadan, and Maba-ay fall under the ancestral domain claim of the Kabatangan Ancestral Indigenous Peoples Organization (KADIPO). Through legally prescribed processes, the NCIP recognized this claim, issuing KADIPO a Certificate of Ancestral Domain Claim (CADC) on June 22, 2009.

Regarding land ownership and tenure, occupants claim full ownership of their landholdings through tax declarations. Most acquired their land by inheritance, some improved open land to apply for new tax declarations, and others purchased their property. Many serve as owner-cultivators, while some act as owner-operators who finance farm operations and supply agricultural inputs. Occupants' landholdings range from 180 m^2 to 2 hectares, with a mean size of 6,205.75 m^2 and an average occupancy of 28 years. Migration to the area was primarily driven by marriage, employment during historical sawmill operations at Barangay Mount Data, and opportunities in vegetable farming [43].

Land use and Land cover (LULC) Changes during the past 30 years and the 2030 predicted LULC using geographic information systems and remote sensing

Land use and Land cover Classification

Overall classification accuracy reports of 86.75%, 86.42%, 85.59%, and 86.59% were obtained for the 1990, 2000, 2010, and 2020 classified images, respectively. Because these values exceed the standard threshold of 85% overall classification accuracy with no single class falling below 70% we can conclude that there is acceptable agreement between the classified images and ground reality [12]. Kappa coefficients were calculated at 0.805, 0.804, 0.806, and 0.810 for 1990, 2000, 2010, and 2020, respectively (Table 5). These results demonstrate strong concurrence across all four classified images, indicating "Very Good" classification performance [12].

Table 5: Classified images assessments of the year 1990, 2000, 2010 and 2020

LAND USE AND LAND COVER TYPE	1990		2000		2010		2020	
	User accuracy	Producer accuracy	User accuracy	Producer accuracy	User accuracy	Producer accuracy	User accuracy	Producer accuracy
Agricultural Land	86.49	91.43	81.82	84.38	88.89	88.89	93.10	81.82
Forest Cover	75.86	95.65	92.31	92.31	86.36	86.36	88.89	92.31
Shrub and Grass Land	88.89	76.56	76.92	71.43	83.33	83.33	75.00	85.71
Built-up Area	83.33	100	81.82	100.00	83.33	83.33	80.00	88.89
OVER ALL ACCURACY (%)	86.75		86.42		85.59		86.59	
Kappa coefficient	0.805		0.804		0.806		0.810	

Limitation of the method

Change detection analysis carries inherent limitations, particularly regarding unrealistic land cover transitions caused by the spectral limitations of satellite imagery. For example, distinguishing forest from shrubs often relies on canopy contiguity; closely clustered shrubs or thick vegetation along agricultural fields may be misclassified as forest. Similarly, spectral limitations make it difficult to discriminate agricultural lands from shrublands and grasslands. In road analysis, road signatures closely resemble built-up areas, causing many road pixels to be classified as built-up. Other road segments particularly dirt roads may be interpreted as shrubland or bare land due to overlapping spectral signatures.

Land use and Land cover in 1990

Figure 7 presents the land use and land cover (LULC) of the study area in both quantitative values and thematic maps. In this baseline year, forest cover and agricultural land comprised the largest proportions of the total area at 1,374.61 ha (39.29%) and 1,267.99 ha (36.24%), respectively. Additionally, a considerable portion was covered by shrub and grassland (549.37 ha or 15.70%), while built-up areas accounted for the smallest share at 307.10 ha (8.78%). These baseline conditions served as the benchmark for change detection across the remaining study years.

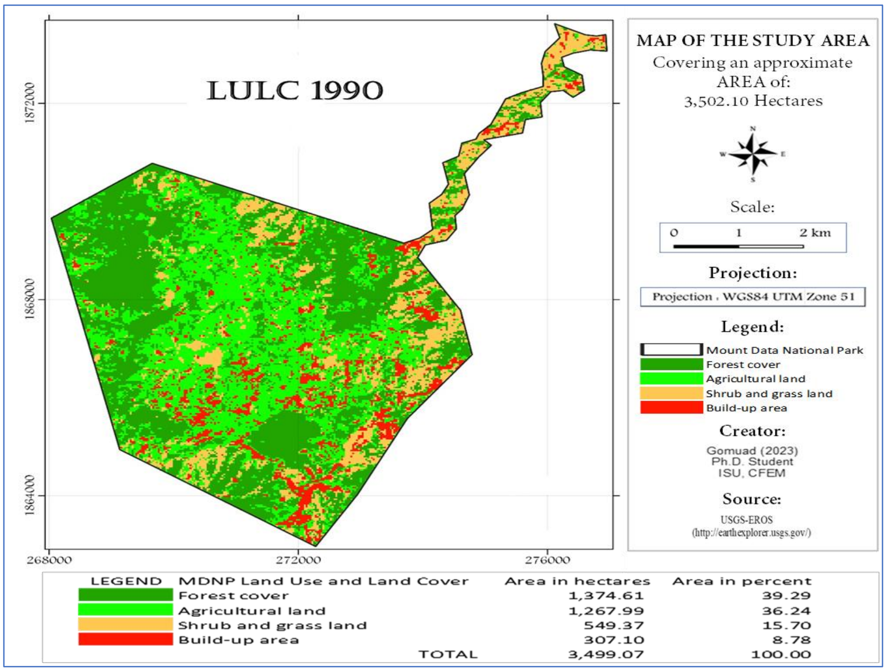


Figure 7. Land Use and Land Cover in 1990

<u>Land Use and Land Cover in 2000</u>

Ten years later (in 2000), agricultural land and forest cover remained the dominant LULC categories, showing clear shifts from 1990. Agricultural land and forest cover accounted for 44.01% and 35.12% of the total area, respectively. Shrub and grassland constituted 14.59% of the land area, while built-up areas remained the smallest category at 6.28% (Figure 8).

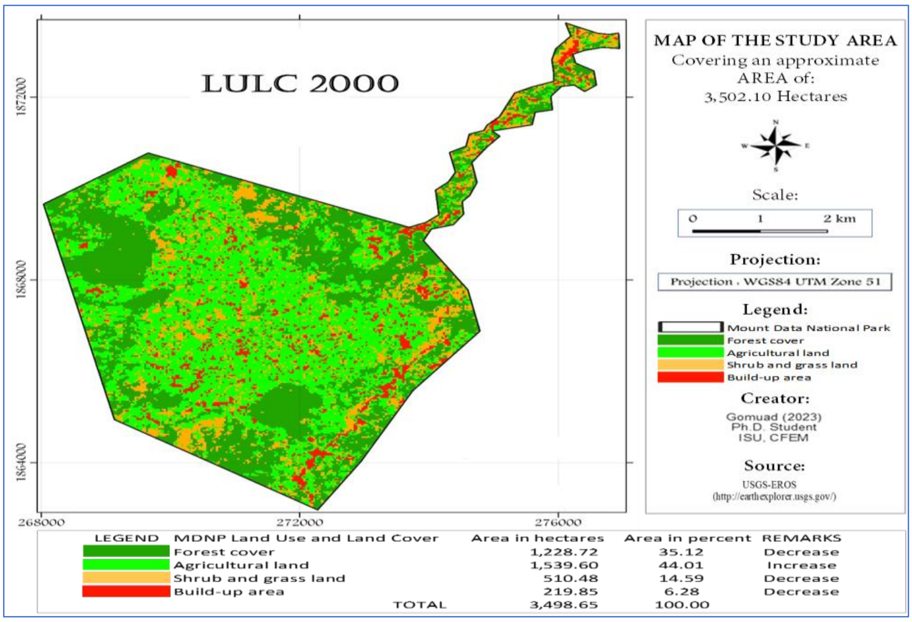
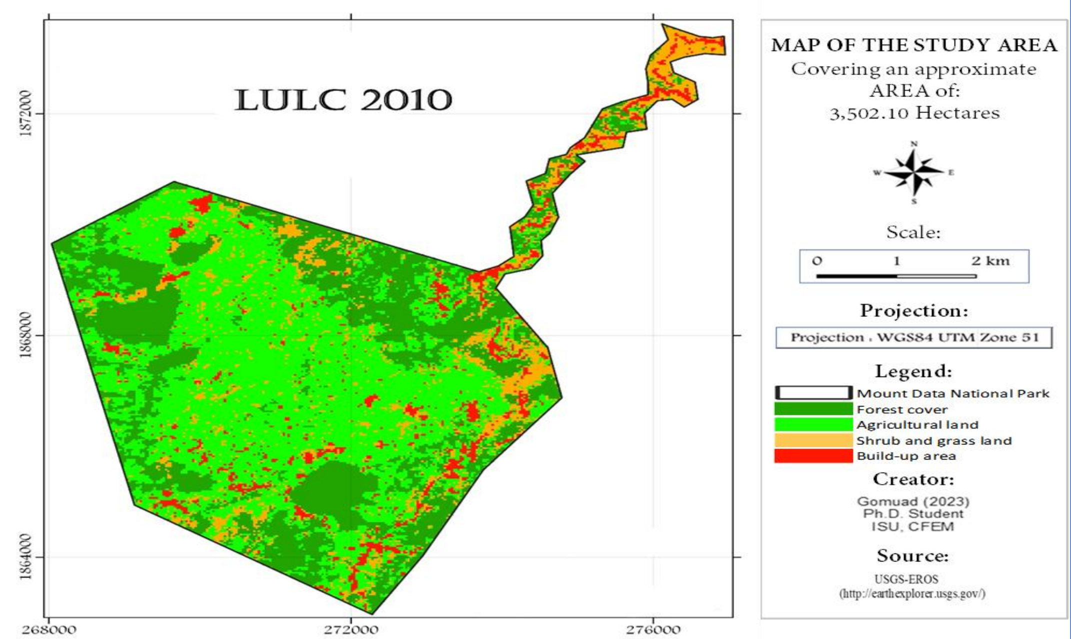


Figure 8. Land Use and Land Cover in 2000

Compared to the 1990 baseline, the study area underwent significant modifications and conversions by 2000. Forest cover, built-up areas, and shrub and grassland were converted into other LULC categories, decreasing by 145.89 hectares (10.6%), 87.25 ha (28.4%), and 38.89 ha (7.08%), respectively. Conversely, agricultural land expanded by 271.62 ha (19.76%) from 1990 to 2000. Overall, forest cover, built-up areas, and shrub and grassland experienced notable declines, whereas agricultural land expanded substantially during this decade.

Land Use and Land Cover in 2010

Twenty years later (in 2010), agricultural land dominated the study area, accounting for 51.93% of the total area. Forest cover, shrub and grassland, and built-up areas comprised the remaining 30.54%, 11.42%, and 6.12%, respectively. During this period, agricultural land expanded dramatically from 44.01% to 51.93% (Figure 9). Conversely, forest cover and shrub/grassland decreased significantly from 35.12% and 14.59% to 30.54% and 11.42%, respectively, while built-up areas slightly declined from 6.28% to 6.12% compared to 2000 levels. Agricultural land replaced former forest cover and shrub/grassland across large areas. Overall, LULC changes during 2000–2010 were far more pronounced than those observed in the initial decade (1990–2000).



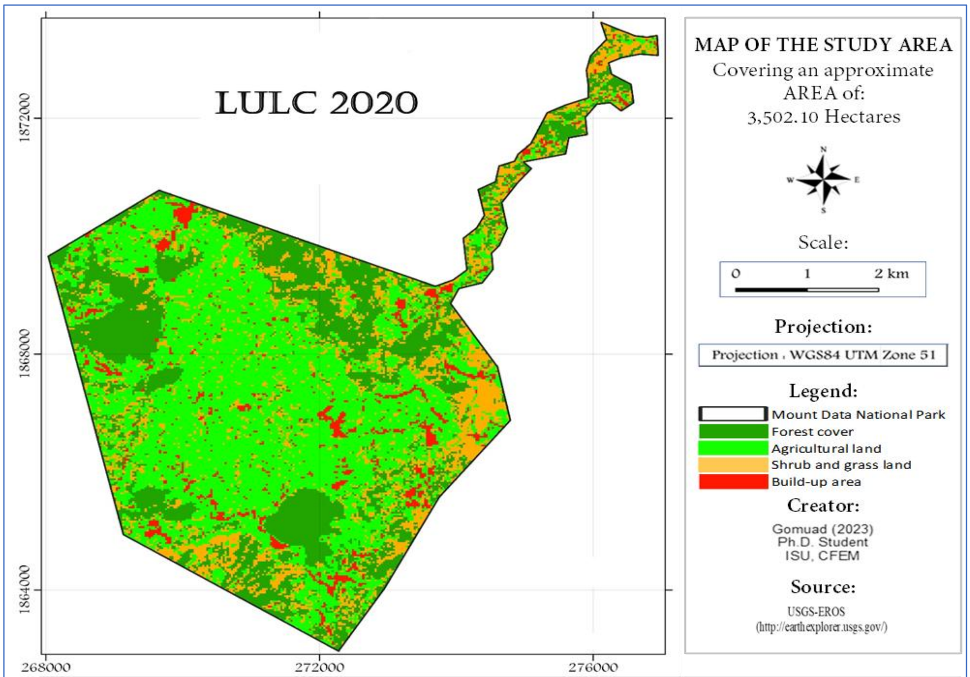
LEGEND	MDNP Land Use and Land Cover	Area in hectares	Area in percent	REMARKS
	Forest cover	1,067.99	30.54	Decrease
	Agricultural land	1,816.23	51.93	Increase
	Shrub and grass land	399.32	11.42	Decrease
	Build-up area	213.97	6.12	Decrease
	TOTAL	3,497.52	100.00	

Figure 9. Land Use and Land Cover in 2010

Land Use and Land Cover in 2020

By 2020 (30 years later), agricultural land slightly decreased from 51.93% to 50.73% (about 41.50 ha), though it remained the dominant LULC type. Forest cover and built-up areas continued their downward trend, declining from 30.54% and 6.12% to 26.93% and 5.19%, respectively. Conversely, shrub and grassland expanded substantially from 11.42% to 17.15%, a nearly one-third area increase from 399.32 ha to 600.08 ha (Figure 10).

This notable expansion of shrub and grassland may be attributed to reduced demand for highland vegetables. This trend aligns with Philippine Statistics Authority (PSA) reports showing that vegetable production in the Cordillera Administrative Region (CAR) fell by 0.6% from 368,608.2 MT in 2019 to 366,314.6 MT in 2020, with Benguet recording a 1.0% decline (from 308,218.6 MT to 305,052.7 MT). Production dropped further by 4.17% regional-wide in 2021 to 351,030.97 MT. Benguet recorded a 4.10% decrease (down to 292,535.11 MT), while Mountain Province dropped by 0.15% from 32,513.19 MT to 32,465.76 MT between 2020 and 2021 [42].



LEGEND	MDNP Land Use and Land Cover	Area in hectares	Area in percent	REMARKS
	Forest cover	941.91	26.93	Decrease
	Agricultural land	1,774.73	50.73	Decrease
	Shrub and grass land	600.08	17.15	Increase
	Build-up area	181.42	5.19	Decrease
	TOTAL	3,498.14	100.00	

Figure 10. Land Use and Land Cover in 2020

Spatiotemporal Patterns of LULC from 1990 to 2020

The spatiotemporal extent of LULC types was analyzed in terms of total and percentage area for each study period (Figures 11 and 12). Results indicate that the proportion of each LULC category varied considerably across the evaluated dates. In 1990, forest cover and agricultural land dominated the landscape, accounting for over 75% of the total area, followed by shrub and grassland (15.70%) and built-up areas (8.78%). Although individual proportions fluctuated slightly, this ranking remained unchanged in 2000. By 2010, forest cover and agricultural land still comprised the majority of the area (82.47%), though agricultural land expanded significantly by 15.69% as other LULC categories contracted. By 2020, shrub and grassland reversed their downward trend, increasing to a 17.15% share. Overall, forest cover and agricultural land remained the primary LULC classes over the 30-year period. The study also reveals a slight decline in recorded built-up areas, which may be attributed to the detection of "smart polyethylene greenhouses" on the thematic LULC maps.

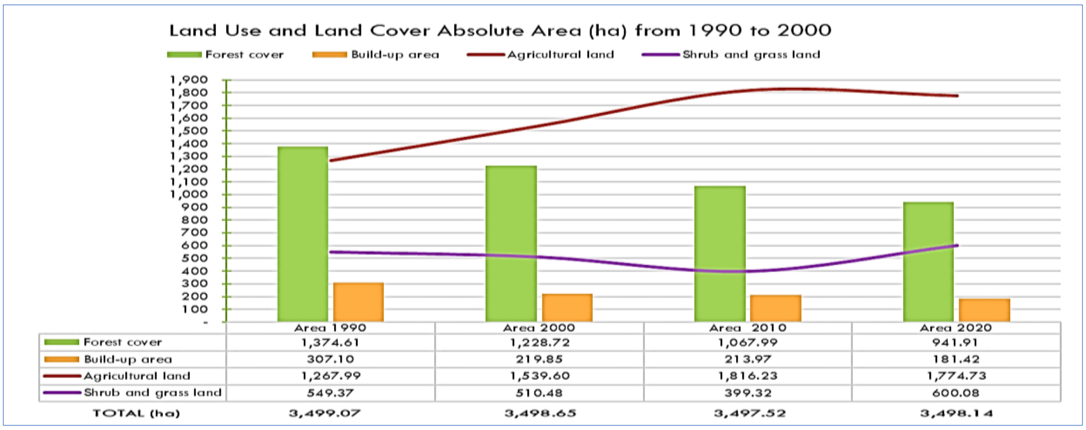
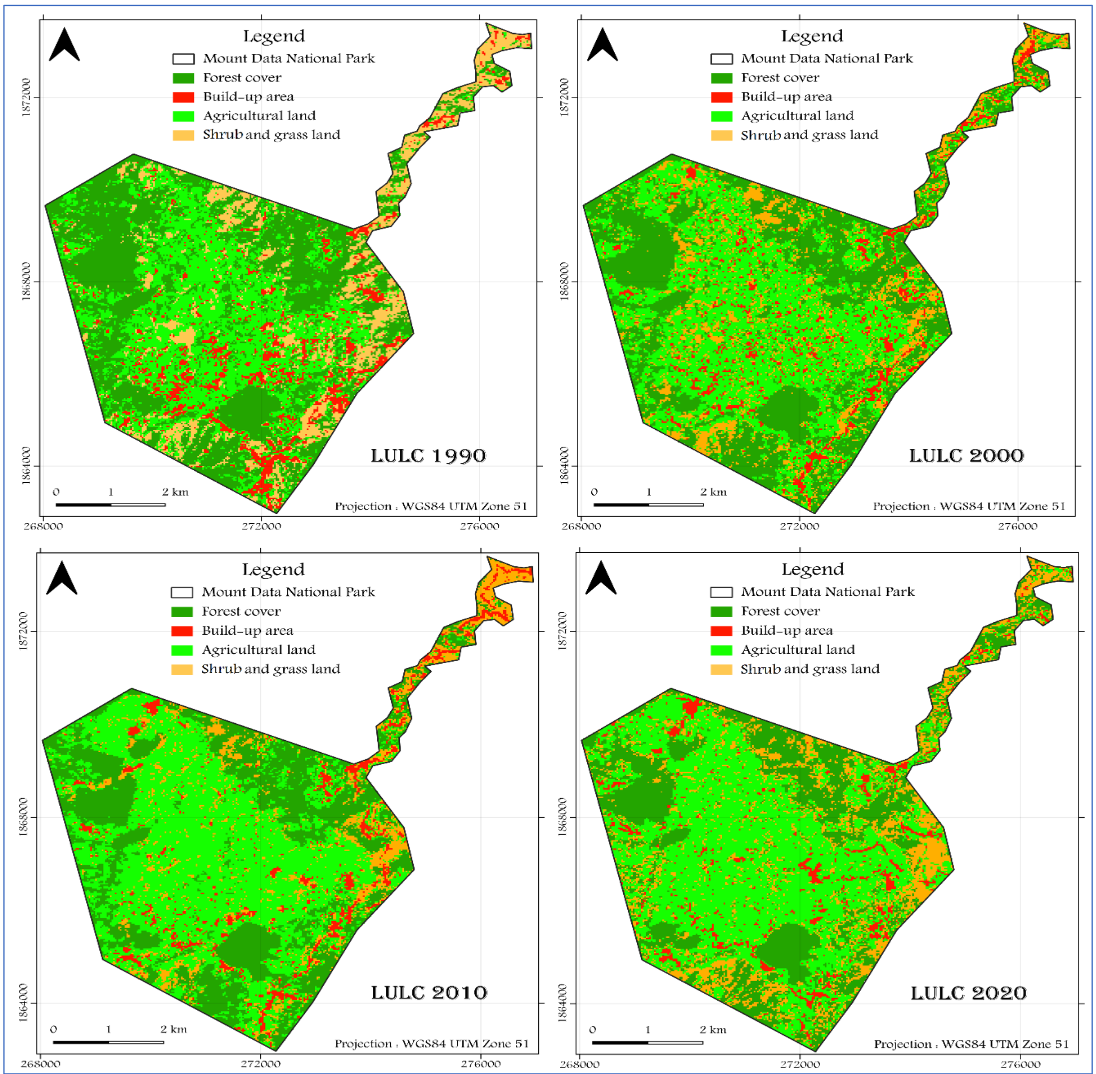


Figure 11. The spatiotemporal patterns of LULC Types between 1990 to 2020



Land use and Land cover	1990		2000			2010			2020		
	Area in hectares	Area in %	Area in hectares	Area in %	Remarks	Area in hectares	Area in %	Remarks	Area in hectares	Area in %	Remarks
Forest cover	1,374.61	39.29	1,228.72	35.12	Decrease	1,067.99	30.54	Decrease	941.91	26.93	Decrease
Agricultural land	1,267.99	36.24	1,539.60	44.01	*Increase*	1,816.23	51.93	*Increase*	1,774.73	50.73	Decrease
Shrub and grass land	549.37	15.70	510.48	14.59	Decrease	399.32	11.42	Decrease	600.08	17.15	*Increase*
Build-up area	307.10	8.78	219.85	6.28	Decrease	213.97	6.12	Decrease	181.42	5.19	Decrease
TOTAL	3,499.07	100.00	3,498.65	100.00		3,497.52	100.00		3,498.14	100.00	

Figure 12. The spatiotemporal patterns of LULC map in 1990, 2000, 2010, and 2020 (Map created by Author, 2023)

Transformation Between Land-use and Land cover Types

Land Use and Land Cover Change between 1990 and 2000

LULC in the study area underwent significant modifications and conversions across the study period. During the first decade (1990–2000), 310.8 ha, 98.79 ha, and 8.34 ha of the original 1,374.14 ha of forest were converted into agricultural land, shrub/grassland, and built-up areas, respectively.

Of the 549.54 ha of shrub and grassland, the largest share (166.88 ha) was converted into agricultural land, while 140.08 ha shifted to forest cover. Out of 1,267.74 ha of agricultural land, 119.59 ha reverted to forest cover, 174.93 ha transitioned to shrub and grassland, and the remaining 85.00 ha shifted to built-up areas.

Spatiotemporal Rate of Land Use and Land Cover Changes

LULC Class and Change Rate (1990-2020) in Hectares

The rate of change was calculated for each land use land cover using the following formula:

Rate of change (ha/year) = (A-B)/C

Where: A = Recent area of land use/ cover in ha.

B = Previous area of land use/ cover in ha.

C = interval between A and B in years

The results presented in appendix table 3 provide quantitative information regarding the spatial extent of each LULC class. Pixel counts within each class map define total coverage, while annual change rates were computed using standard formulas. A negative value indicates a decline in magnitude and rate of change.

Image analysis illustrates persistent shifts in forest cover across the study period. Agricultural land changed at rates of 27.16 ha, 27.66 ha, and −4.15 ha per year during 1990–2000, 2000–2010, and 2010–2020, respectively. Forest cover declined continuously at rates of −14.59 ha, −16.07 ha, and −12.61 ha per year over the same respective intervals.

Shrub and grassland decreased by −3.89 ha and −11.12 ha per year during 1990–2000 and 2000–2010 but expanded sharply by 20.08 ha per year between 2010 and 2020. Built-up areas maintained a declining trend, shifting to other LULC categories at rates of −8.73 ha, −0.59 ha, and −3.26 ha per year across the three successive decades.

LULC Class and Change Rate (1990-2020) in Percentage

The agricultural land and build up area which showed a rate of negative change in the year of 1990 to 2000, 2000 to 2010, and 2010 to 2020 with the gap of 10 years, 20 years, and 30 years respectively. In the year 1990 - 2000 and 2000 - 2010, forest cover showed an increment with the gap of 10 years and 20 years, however, in the year 2010 - 2020, forest cover showed a reduction with the gap of 10 years. Shrub and grass land on the other hand, conversely showed a negative change rate in the same years and gap years of that of forest cover and showed a positive change rate in years 2010 - 2020 after 10 year-gap.

Persistence and Vulnerability of LULC Dynamics in MDNP

The exposure of each LULC class for a change was assessed using the loss to persistence ratio (*Lp* = loss/persistence), which assesses the vulnerability of LULC classes for a change; gain to persistence ratio (*Gp* = gain/persistence) which evaluates the gain of a LULC in comparison to its time and size; and the net change to persistence ratio (*Np* = net change/persistence) [48] [49].

If values of *Gp* and *Lp* greater than one implies that a given LULC class has a higher probability to change to other LULC class than to persist in its current condition. If the value of *Np* was negative, the LULC class would have a higher probability to lose area to other LULC classes than to gain from them [48].
In the study period of 1990-2020, G/p and L/p values of forest cover and agricultural land are lower than 1 indication the tendency to persist rather to loss or gain. However, the G/p and L/p values of build-up area and shrub and grass land are higher than 1 implying that these LULC types have a tendency to gain than to remain persistence. This also implies the probability of higher vulnerability of the MDNP to degradation and abandonment of agricultural land to build-up areas and shrub and grass land. Similarly, forest cover has a L/p value relatively high (0.90) indicating a higher vulnerability to lose than to persist as compared to agricultural land with L/p value of 0.28. The net change to persistence ratio (N/p) of agricultural land is also relatively higher indicating its net gain increased by 40 percent of its persistence. Shrub and grass land also got a net gain of almost one-third of it persistence. The net loss (N/p) of forest cover and build-up area are higher than their respective persistence, indication that it had a higher tendency to change.

Land use and Land cover Dynamics in Relation to Slope Category

Despite the minor variations in spatial coverage, the satellite imagery analysis for the study periods revealed that more than 32% and 27% of all LULC were situated on slope categories ranging from flat rolling to moderately steep slopes, respectively (Appendix table 1). In these slope categories, agricultural land, build-up area, and shrub and grassland were the highest coverage. This is most likely because these slope categories (0-18% and 18-30%) are suitable for highland vegetable cultivation and infrastructure activities or projects supporting vegetable farming. While the largest share of agricultural land and build-up area is located from 0-18% and 18-30% slopes, a considerable agricultural area of 70.65 ha (2.09%) and 12.15 ha (0.36%) were on very steep and extremely steep slopes, respectively. Build-up areas with 10.89 ha (0.32%) and 2.43 ha (0.07%) were also on these slope categories.
These cultivated areas could suffer from accelerated soil erosion and loss of essential soil nutrients. On the other hand, build-up areas may suffer from landslides or the risk of falling debris from above.
Forest cover was mostly located on slope categories ranging from moderately steep to very steep slopes, while a few forest cover is on extremely steep slopes. Because of the nature of the terrain, much reforestation and afforestation occurred in these areas [50].
From this, it can be easy to comprehend the failure in the implementation of the Revised PD 705, otherwise known as the Forestry Reform Code of the Philippines, in Section 15-Topography, stipulates that "No land of the public domain eighteen percent (18%) in slope or over shall be classified as alienable and disposable, nor any forest land fifty percent (50%) in slope or over, as grazing land, in reality, steep slopes to extremely steep slopes of MDNP had already been utilized or transformed into vegetable farms and build-up areas with or without soil and water conservation measures or structures. This current state (Appendix table 2) accelerates the deterioration of ecologically sensitive environments and threatens the sustainability of local livelihoods, thus calling for attention to adequate soil and water management.

Predicted Land use and Land cover of MDNP for the year 2030

The following parameters which were chosen for the forecasting the LULC of the study area for the year 2030 are DEM, slope map, aspect map, build-up areas, and distance from the road map and river. From the analysis it was found that the combinations of these parameters, got the maximum Kappa value of 0.76

and the maximum percentage of correctness 84.96 %. The maximum kappa value of 0.76 was considered as a good accuracy by many researchers [12] [51] [52]. Hence it can be concluded that these variables have high influence on the predicted LULC map of the study area.
In the LULC simulation and projection, the parameters were then divided into input data and descriptive data. The four (1990, 2000, 2010 and 2020) thematic LULC maps include the initial input data, while the descriptive data includes DEM, gradient, aspect, distance from the road and river map, and build up density. These spatial variables were used as proxies that cause MDNP LULC alterations, since their impact to the LULC change mechanism is greater by using QGIS Modules of Land Use Change Evaluation (MOLUSCE) plugin and Artificial Neural Networks (ANN) - Multi layer perception) model [54].
The trend of LULC change from 1990 to 2030 is summarized in table 6, which show the percentage of area covered under each LULC class. In 1990, forest is dominated by 39.29 % of the total area, followed by agricultural land (36.24 %), shrub and grassland (15.70 %), and build up areas (8.78 %). It was observed that changes in the trend were detected for all LULC between the years 1990-2000, 2000-2010, 2010-2020, and 2020-2030. When compared to 1990, the percentage of area covered in 2030, forest cover and build-up area had decreased by 14.49%, and 5.37% respectively. An increase in percentage was observed for agricultural land and shrub and grass land by 16.96% and 2.89% respectively.

Table 6. Land use and land cover analysis from 1990 to 2030

	LULC 1990		LULC 2000		LULC 2010		LULC 2020		*LULC 2030*	
LULC Categories	Area (ha)	%	Area (ha)	%	Area (ha)	%	Area (ha)	%	Area (ha)	%
Forest cover	1,374.61	39.29	1,228.72	35.12	1,067.99	30.54	941.91	26.93	868.23	24.80
Build-up area	307.10	8.78	219.85	6.28	213.97	6.12	181.42	5.19	119.43	3.41
Agricultural land	1,267.99	36.24	1,539.60	44.01	1,816.23	51.93	1,774.73	50.73	1,862.55	53.20
Shrub and grass land	549.37	15.7	510.48	14.59	399.32	11.42	600.08	17.15	650.79	18.59
TOTAL	3,499.07	100	3,498.65	100	3,497.51	100	3,498.14	100	3,501.00	100

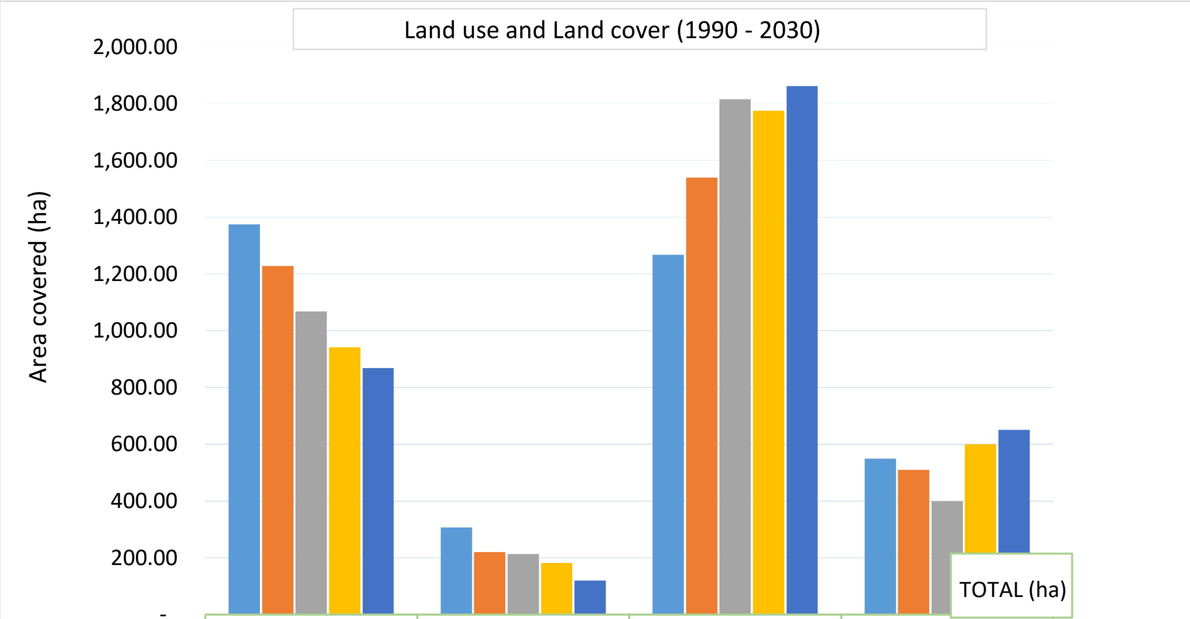
The change in land cover classes between 2020 and 2030 is depicted in table 7. It is observed that the agricultural land and shrub and grass land will increase by 87.82 hectares and 50.71 hectares, respectively, while forest cover, and build-up areas will decline by 73.68 hectares and 61.99 hectares, respectively. LULC changes as a percentage of total land area is also analyzed. A positive value implies that the categorization has improved, while a negative value denotes the categorization has deteriorated.

Table7. Distribution of LULC categories between 2020 and 2030

Land use and Land cover (LULC)	LULC 2020 Area (ha)	**LULC 2030 Area (ha)**	Change Area (ha)	2020 % area	**2030 % area**	% Change
Forest cover	941.91	**868.23**	- 73.68	26.93	**24.80**	- 2.13
Build-up area	181.42	**119.43**	- 61.99	5.19	**3.41**	- 1.78
Agricultural land	1,774.73	**1,862.55**	87.82	50.73	**53.20**	2.47
Shrub and grass land	600.08	**650.79**	50.71	17.15	**18.59**	1.44
TOTAL (ha)	3,498.14	**3.501.00**				

Figure 13 shows a graph of how the LULC classifications have changed between 1990 and 2030. Figure 14 shows the map changes of different LULC categories from 1990 to 2030 in an incremental span of ten years and the expected land-use changes in 2030.

From the analysis, it can be inferred that when the area of one classification increases, it decreases the area of other categories and vice versa. An increase in agricultural land and shrub and grassland areas in the future implies that these categories have to be given importance in designing policy formulations and in developing optimal land use planning and management for the Mount Data National Park.



	Forest cover	Build-up area	Agricultural land	Shrub and grass land	TOTAL (ha)
1990	1,374.61	307.10	1,267.99	549.37	3,499.07
2000	1,228.72	219.85	1,539.60	510.48	3,498.65
2010	1,067.99	213.97	1,816.23	399.32	3,497.51
2020	941.91	181.42	1,774.73	600.08	3,498.14
2030	868.23	119.43	1,862.55	650.79	3,501.00

Figure 13. Change of LULC areas in hectares from 1990 to 2020 and the predicted 2030 LULC

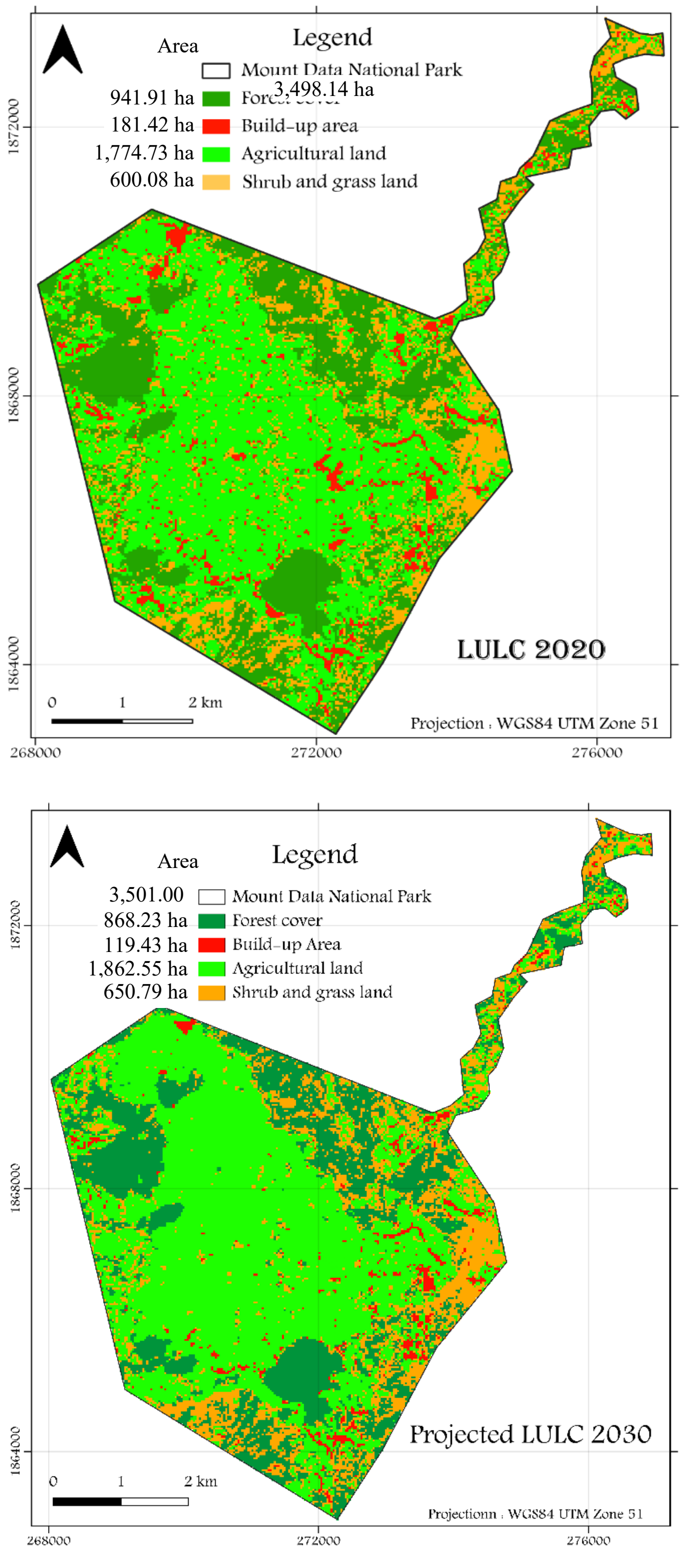


Figure 14. LULC map of 2020 and the predicted 2030 LULC map

This research demonstrates the utility of GIS and remote sensing in capturing spatiotemporal data across four distinct LULC categories over time. Particular emphasis was placed on forest cover and agricultural land, as anthropogenic activities in these classes directly influence overall landscape dynamics. Results show a continuous decline in forest cover between 1990 and 2020 at an annual rate of 0.49%, whereas agricultural land expanded over the same period. Projections suggest LULC changes by 2030 will likely follow 1990–2010 trends, all else being equal.

Remote sensing analysis reveals that agricultural land and shrub/grassland underwent shifts of varying magnitudes and rates. Agricultural land expanded during the first two decades (1990–2000 and 2000–2010) at annual rates of 2.72% and 2.77%, respectively, before declining by 0.41% annually during 2010–2020. Despite periodic fluctuations, shrub and grassland experienced an overall net increase at an annual rate of 0.14% across the 30-year period. Built-up areas exhibited a slight, continuous decline throughout the study period at an annual rate of 0.06%. Figure 15 highlights sizable greenhouse structures in 2020, while recent photographs from February 2022 depict their subsequent dilapidation (Figure 16). The observed decline in built-up area heading toward 2030 may thus reflect the degradation of these detected "smart polyethylene greenhouses" mapped in the thematic LULC analysis.

Figure 15. Aerial photo of the study area showing a sizeable area of greenhouses (build-up) of MDNP. Taken from Google Earth Pro. Date of imagery **November 11, 2020**. Place mark location BA1: 16°52'22.72"N, 120°51'44.03"E at elevation 2172masl. Eye altitude at 2.49Km.

While these are built to last, at some point, most greenhouse covers last somewhere between one and five years, but the life expectancy will vary depending on the specific material, application, and climate. The country's first 'smart greenhouses' launched in Baguio [53].

Figure 16. Recent photos showing (red arrow) the dilapidated greenhouses
(*Photo taken Dec. 2022: from the Author*)

The prediction of LULC plays a vital role in creating plans for balancing conservation, competing users, and developmental pressures. The ANN Cellular Automation model was utilized to simulate and predict the future LULC maps of the Protected area. The three spatial variable factors, viz., DEM, distance from the road and river, and built-up density, had a huge effect on predicting the LULC map of MDNP. The *Kappa* value of 0.76 shows a maximum level of accuracy between the observed and predicted 2030 LULC map. The LULC map of 2030 was predicted using 1990, 2000, 2010, and 2020 LULC maps along with the same spatial variable factor combinations. The predicted LULC for the year 2030 shows a significant increase in agricultural land and shrub and grass areas by 87.82 hectares and 50.71 hectares, respectively. Meanwhile, relative to the 2020 LULC, forest cover and build-up areas are expected to decrease by 77.68 hectares and 61.99 hectares by 2030. The results demonstrate that due to anthropogenic pressures, the conversion of forest land and other land categories would be converted to agricultural land and shrub and grass areas.

The remaining forest in the MDNP is a key forest area providing water and other ecological functions, which needs immediate preservation and conservation intervention. Forest disturbance, particularly land conversion, does, nevertheless, result in forest degradation. Rather than being retained as forest, human interests in the region drive the land to be transformed into extra creative uses, such as farmland or build-up types.

Conflicts over land interests in general, result in LULC modifications. The Department of Environment and Natural Resources (DENR), particularly the Community Environment and Natural Resources at Sabangan, for example, prefers tree planting for reforestation, whereas the Local Government Units and Office of Municipal Agriculture (LGUs-OMAG) support agricultural activities. Thus, farmers extend their plantations to boost earnings, reducing the MDNP wooded land. This situation necessitates a LULC approach that emphasizes the change's long-term consequences, notably forest biodiversity loss. The study findings assist policymakers, e.g., MDNP-PAMB, in detecting specific land use changes and projecting which land uses will be affected by future changes. The findings will also assist farmers and concerned government agencies, particularly the concerned LGUs Office of Municipal Agriculture and the DENR-CENRO at Sabangan, in developing optimal land use planning and management methods for the long-term development of the MDNP land resources.

Recommendations

Based on the findings of this study, the following measures are recommended to balance ecological conservation and agricultural livelihoods within the Mount Data National Park (MDNP):

1. Harmonize Inter-Institutional Policies and Objectives
   The Department of Environment and Natural Resources (DENR-CENRO Sabangan), Local Government Units (LGUs), and Municipal Agriculture Offices (OMAG) should align their institutional mandates. Establishing a unified inter-agency framework will reconcile conflicts between reforestation efforts and agricultural support, ensuring sustainable land management without compromising farmers' livelihoods.
2. Strengthen Collaborative Land-Use Planning
   The MDNP Protected Area Management Board (PAMB), together with DENR-CENRO and municipal agricultural offices, should utilize the spatiotemporal LULC data and predictive trends from this study to formulate a comprehensive, zoned DateTime-based land-use plan. Clear boundaries must be

enforced to prevent the encroachment of vegetable farming into remaining mossy and pine forest reserves.

3. Promote Sustainable Agricultural Practices (SLM)
 LGUs-OMAG and agricultural extension officers should encourage sustainable, high-value farming techniques that maximize yield per unit area rather than spatial expansion. Integrating agroforestry systems near buffer zones can help farmers maintain household earnings while active forest conservation is prioritized.
4. Establish Continuous LULC and Infrastructure Monitoring
 Relevant agencies should adopt regular GIS and remote sensing monitoring to track land-cover shifts, agricultural expansion, and temporary structures (such as greenhouse installations). Continuous spatial tracking will allow PAMB and local authorities to make proactive, evidence-based policy adjustments to mitigate biodiversity loss and land degradation.

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International Journal for Multidisciplinary Research (IJFMR)
E-ISSN: 2582-2160 ● Website: www.ijfmr.com ● Email: editor@ijfmr.com

Appendix Table 1

Land use and Land cover Dynamics in Relation to Slope Category

YEAR	LULC TYPES (has.)	SLOPE CATEGORIES (%)									
		0 - 18	%	18 - 30	%	30 - 50	%	50 - 84	%	> 84	%
1990	Forest Cover	276.12	8.16	337.5	9.98	397.89	11.76	250.83	7.42	53.28	1.58
	Build-up area	134.73	3.98	90.45	2.67	52.02	1.54	27.45	0.81	5.22	0.15
	Agricultural land	588.6	17.40	392.85	11.61	176.49	5.22	51.66	1.53	14.04	0.42
	Shrub and grass land	109.89	3.25	106.2	3.14	139.68	4.13	126.09	3.73	51.57	1.52
	TOTAL	1,109.34	32.80	927.00	27.41	766.08	22.65	456.03	13.48	124.11	3.67

YEAR	LULC TYPES (has.)	SLOPE CATEGORIES (%)									
		0 - 18	%	18 - 30	%	30 - 50	%	50 - 84	%	> 84	%
2000	Forest Cover	184.59	5.46	262.98	7.77	376.74	11.14	281.43	8.32	65.79	1.94
	Build-up area	108.18	3.20	63.09	1.87	34.38	1.02	19.44	0.57	7.65	0.23
	Agricultural land	657.9	19.45	475.29	14.05	244.44	7.23	63.54	1.88	8.01	0.24
	Shrub and grass land	158.67	4.69	125.64	3.71	110.52	3.27	91.62	2.71	42.66	1.26
	TOTAL	1,109.34	32.80	927.00	27.41	766.08	22.65	456.03	13.48	124.11	3.67

YEAR	LULC TYPES (has.)	SLOPE CATEGORIES (%)									
		0 - 18	%	18 - 30	%	30 - 50	%	50 - 84	%	> 84	%
2010	Forest Cover	135.99	4.02	220.59	6.52	333.18	9.85	266.76	7.89	64.35	1.90
	Build-up area	76.86	2.27	60.57	1.79	47.25	1.40	25.56	0.76	7.29	0.22
	Agricultural land	795.78	23.53	561.33	16.59	282.78	8.36	77.58	2.29	12.96	0.38
	Shrub and grass land	100.71	2.98	84.51	2.50	102.87	3.04	86.13	2.55	39.51	1.17
	TOTAL	1,109.34	32.80	927.00	27.41	766.08	22.65	456.03	13.48	124.11	3.67

YEAR	LULC TYPES (has.)	SLOPE CATEGORIES (%)									
		0 - 18	%	18 - 30	%	30 - 50	%	50 - 84	%	> 84	%
2020	Forest Cover	127.62	3.77	189	5.59	292.32	8.64	231.03	6.83	64.53	1.91
	Build-up area	89.91	2.66	57.69	1.71	29.7	0.88	10.89	0.32	2.43	0.07
	Agricultural land	788.76	23.32	540.81	15.99	262.89	7.77	70.65	2.09	12.15	0.36
	Shrub and grass land	103.05	3.05	139.5	4.12	181.17	5.36	143.46	4.24	45	1.33
	TOTAL	1,109.34	32.80	927.00	27.41	766.08	22.65	456.03	13.48	124.11	3.67

Where:

0 - 18%,	Flat to Rolling
18 - 30%,	moderately Steep
30 - 50%,	Steep
50 - 84%	Very Steep
above 84%	Extremely Steep

Appendix Table 2

The degree of erosion per soil type on slope categories in percent (upper table), and degree erosion per soil type in hectares with descriptive rating (lower table)

Soil type	*Slope (%) 0 - 18*	SOIL LOSS	Slope (%) *18 - 30*	SOIL LOSS	*Slope (%) 30 - 50*	SOIL LOSS	*Slope (%) 50 - 84*	SOIL LOSS	*Slope (%) > 84*	SOIL LOSS	TOTAL
Cervantes loam	*354.04*	**4,803.63**	191.64	**4,480.60**	*125.65*	**2,867.84**	*106.72*	**2,400.88**	*49.00*	**1,490.20**	827.05
Mountain soil undifferentiated	*31.65*	**135.54**	36.94	**85.84**	*34.71*	**143.63**	*14.94*	**35.01**	*0.28*	-	118.52
Sabangan loam	*46.31*	**634.33**	77.77	**1,440.98**	*122.68*	**3,691.60**	*85.01*	**4,124.63**	*16.98*	**2,121.43**	348.75
Rough mountainous land	*14.85*	**210.84**	24.41	**507.62**	*28.77*	**1,059.85**	*11.51*	**607.44**	*0.28*	-	79.82
Guinaoang loam	*680.24*	**10,524.08**	607.48	**16,072.26**	*456.31*	**16,691.05**	*246.11*	**10,897.64**	*60.69*	**6,587.25**	2,050.83
Balili gravelly loam	*20.88*	**272.98**	22.18	**680.44**	*24.96*	**695.35**	*6.87*	**82.11**	*0.74*	-	75.63
Total Area (ha)	*1,147.97*		960.42		*793.08*		*471.16*		*127.97*		3,500.60
Total Soil Loss (t/ yr)		**16,581.40**		**23,267.74**		**25,149.32**		**18,147.71**		**10,198.88**	**93,345.05**
Total Soil Loss (t /ha/ yr)		**14.44**		**24.23**		**31.71**		**38.52**		**79.70**	
Average Soil Loss (t /ha/ yr)											**37.72**
Descriptive Degree of degradation Class		moderate		moderate		high		very high		very high	very high

Soil type	Slope (%) *0 - 18*	Soil loss (t/h/yr)	Descriptive Rating	Slope (%) *18 - 30*	Soil loss (t/h/yr)	Descriptive Rating	Slope (%) *30 - 50*	Soil loss (t/h/yr)	Descriptive Rating	Slope (%) *50 - 84*	Soil loss (t/h/yr)	Descriptive Rating	Slope (%) *> 84*	Soil loss (t/h/yr)	Rating	TOTAL AREA
Cervantes loam	354.04	*13.57*	*moderate*	191.64	*23.38*	*moderate*	125.65	*22.82*	*moderate*	106.72	*22.50*	*moderate*	49	*30.41*	*high*	827.05
Mountain soil undifferentiated	31.65	*4.28*	*Very low*	36.94	*2.32*	*very low*	34.71	*4.14*	*very low*	14.94	*2.34*	*very low*	0.28	-		118.52
Sabangan loam	46.31	*13.70*	*moderate*	77.77	*18.53*	*moderate*	122.68	*30.09*	*high*	85.01	*48.52*	*very high*	16.98	*124.94*	*very high*	348.75
Rough mountainous land	14.85	*14.20*	*moderate*	24.41	*20.80*	*moderate*	28.77	*36.84*	*high*	11.51	*52.77*	*very high*	0.28	-		79.82
Guinaoang loam	680.24	*15.47*	*moderate*	607.48	*26.46*	*high*	456.31	*36.58*	*high*	246.11	*44.28*	*very high*	60.69	*108.54*	*very high*	2,050.83
Balili gravelly loam	20.88	*13.07*	*moderate*	22.18	*30.68*	*high*	24.96	*27.86*	*high*	6.87	*11.95*	*moderate*	0.74	-		75.63
TOTAL AREA (has)	1,147.97			960.42			793.08			471.16			127.97			3,500.60

Descriptive rating
Very Low 0 - 7 t/ha/yr
Low 7 - 12 t/ha/yr
Moderate 12 - 25 t/ha/yr
High 25 - 37 t/ha/yr
Very High > 37 t/ha/yr

Appendix Table 3

Persistence and Vulnerability of LULC Dynamics in MDNP

LULC dynamics (1990 and 2020) in hectare and their rate of changes

LULC	YEARS				RATE OF CHANGE (ha/yr)			
	1990	2000	2010	2020	1990-2000	2000-2010	2010-2020	1990-2020
Forest cover	1,374.61	1,228.72	1,067.99	941.91	-14.59	-16.07	-12.61	-14.42
Build-up area	307.10	219.85	213.97	181.42	-8.73	-0.59	-3.26	-4.19
Agricultural area	1,267.99	1,539.60	1,816.23	1,774.73	27.16	27.66	-4.15	16.89
Shrub and grass land	549.37	510.48	399.32	600.08	-3.89	-11.12	20.08	1.69

LULC dynamics (1990 and 2020) in Percent and their rate of changes

LULC	YEARS				CHANGE IN %				RATE OF CHANGE IN % / YEAR			
	1990 Area %	2000 Area %	2010 Area %	2020 Area %	1990-2000	2000-2010	2010-2020	1990-2020	1990-2000	2000-2010	2010-2020	1990-2020
Agricultural area	39.29	35.12	30.54	26.93	-4.17	-4.58	-3.61	0.56	-0.42	-0.46	-0.36	0.02
Build-up area	8.78	6.28	6.12	5.19	-2.49	-0.17	-0.93	-1.56	-0.25	-0.02	-0.09	-0.05
Forest cover	36.24	44.01	51.93	50.73	7.77	7.92	-1.20	6.57	0.78	0.79	-0.12	0.22
Shrub and grass land	15.70	14.59	11.42	17.15	-1.11	-3.17	5.74	4.63	-0.11	-0.32	0.57	0.15