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Plantation-driven deforestation and ecosystem degradation: Assessing the efficacy of environmental governance in tropical forest landscapes

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ABSTRACT

Background: Plantation expansion has emerged as a major catalyst of land-use transformation across tropical regions, including Bulungan Regency, North Kalimantan, where extensive deforestation and ecosystem degradation have occurred over the last two decades. This research investigates the interlinkages between plantation growth, deforestation, and environmental decline to construct a holistic understanding of ecological changes in plantation-dominated landscapes. While prior research indicates that uncontrolled development of oil palm and rubber plantations has driven deforestation, biodiversity loss, and greenhouse gas (GHG) emissions, spatially detailed assessments at the regional level remain scarce. **Method:** Employing a descriptive–quantitative approach, this study utilizes secondary spatial and temporal datasets from Global Forest Watch and the Central Bureau of Statistics (2001–2024) to evaluate changes in forest cover, tree loss caused by fire, and GHG emission trends. **Finding:** Integrated spatial-statistical analyses reveal that Regency has lost approximately 197,000 hectares of primary moist forest (19% of its total), with about 69% of tree cover loss driven by permanent land-use conversion linked to plantation expansion. Fires contributed 6.8% of total tree loss and were spatially associated with recently established plantations. GHG emissions peaked at 19.8 $MtCO_2e$ in 2012, aligning with a period of intensive deforestation, but declined to 5.52 $MtCO_2e$ in 2024 due to enhanced environmental governance. **Conclusion:** The findings indicate that plantation-induced land conversion alters hydrological processes, reduces atmospheric humidity, and accelerates carbon emissions, forming a feedback loop that amplifies regional climate effects. This study contributes an integrated spatial perspective on plantation-driven deforestation and its ecological implications, offering new insights for sustainable land-use management in tropical regions. **Novelty/Originality of this article:** This study provides a long-term (24-year) spatio-temporal analysis that specifically identifies the "feedback loop" between plantation-driven deforestation, localized fire susceptibility, and GHG emission fluctuations.

KEYWORDS: Bulungan; ecosystem degradation; plantation development.

1. Introduction

The plantation sector is one of the backbones of regional economic development in Indonesia, especially in areas with extensive land resources (Halimatussadiah et al., 2025). Plantation commodities play a significant role in increasing community income, absorbing labor, and contributing to Gross Regional Domestic Product (Belay et al., 2024; Hendrawan & Musshoff, 2024). On the other hand, unplanned and poorly controlled plantation expansion has significant ecological impacts, including deforestation, soil degradation,

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biodiversity loss, and increased greenhouse gas emissions (Bispo et al., 2023; Lan et al., 2025; Li et al., 2025). These conditions indicate that the development of the plantation sector is closely linked to the dynamics of forest and environmental degradation, thus requiring an analysis of land expansion patterns and their implications for the sustainability of forest ecosystems in Indonesia.

Kalimantan is one of the regions with the highest levels of forest degradation in Indonesia (Badan Pusat Statistik, 2025b). This is driven by a combination of anthropogenic (Feurer et al., 2025; Kala, 2023; Santika et al., 2017). The expansion of oil palm plantations, coal mining, and forest clearing for large-scale agricultural activities have caused the loss of natural vegetation cover and significant decline in soil quality (Myint et al., 2025; Sugiarto, Utaya, Sumarmi, et al., 2024). Land use changes in Kalimantan contribute to increased erosion, river sedimentation, decreased soil fertility, and disruption to the regional hydrological cycle (Acobta et al., 2025; Handyastono et al., 2025; Heo et al., 2024). Unsustainable land management practices such as forest fires for land clearing accelerate the degradation process and increase the risk of ecological disasters.

Bulungan Regency in North Kalimantan Province is one of the regions experiencing rapid growth in the plantation sector over the past two decades. Forest cover in Bulungan has decreased, accompanied by an increase in oil palm and rubber plantations (Badan Pusat Statistik, 2025a). These changes indicate land conversion, which has resulted in a decline in ecosystem quality and environmental functions, including disruption of the hydrological system, reduced carbon stocks, and increased vulnerability to ecological disasters. Deforestation in Bulungan Regency is the result of a complex interaction between national policies, regional policies, and other mutually reinforcing structural factors (Ekawati et al., 2019; Valbuena et al., 2025).

Public policy plays a strategic role, directly and indirectly impacting deforestation rates through regulatory, economic, and spatial mechanisms (Irawan et al., 2019; Purnomo et al., 2023; Tacconi et al., 2019). Policies oriented toward economic growth, such as the granting of permits for plantations, mining, and infrastructure projects, often encourage the conversion of forest areas into productive land without considering ecological carrying capacity (Galinato & Galinato, 2016). Furthermore, weak integration between sectoral policies, such as forestry, agriculture, and spatial planning, leads to overlapping permits, accelerating forest clearing (Wicaksono et al., 2022). The imbalance between economic development and environmental protection makes policy an ambivalent factor: it can serve as a conservation instrument but also becomes a major driver of deforestation if not designed with strong principles of sustainability and spatial governance. Therefore, this study aims to scientifically analyze the impact of plantation development on deforestation and environmental degradation. Using an analytical approach to secondary environmental statistical data.

2. Methods

2.1 Study area

Bulungan Regency has an area of 13,181.92 km^2. Geographically, Bulungan Regency borders Tana Tidung Regency and Nunukan Regency to the north, Berau Regency to the south, Malinau Regency to the west, and the Sulawesi Sea and Tarakan City to the east. The administrative area of Bulungan Regency consists of 10 sub-districts. Bulungan Regency is a tropical and humid climate area. Bulungan Regency has a temperature ranging from 22.8^o C - 37.0^o C and air humidity ranging from 66 - 95 percent. In addition, this regency has a relatively cool climate with an average daily sunshine of 3.1 - 6.0 hours per month.

Bulungan Regency is a region with 742,769 hectares of production forest. Almost the entire Bulungan Regency is prone to forest and land fires. On the other hand, Bulungan Regency has very high hydrological potential, primarily due to the presence of the Kayan River and its extensive network of tributaries. The large water flow in this river system reflects the ecological function of the forest that is still dominant in this region, where forest

cover plays a crucial role in absorbing rainwater through the process of infiltration. This process then contributes to increasing the volume or discharge of water in the upstream areas, thus creating the availability of abundant and sustainable water resources for the Bulungan Regency area.

2.2 Data and analysis

This study uses a descriptive-quantitative approach with spatial and temporal analysis to assess the relationship between land use change, climate conditions, and environmental dynamics in Bulungan Regency. The data used comes from several official sources with high credibility and a long temporal coverage. Data on land use change and climate conditions were obtained from the Bulungan Regency Statistics Agency (BPS), which includes variables such as land use area, plantation expansion, rainfall, temperature, and air pressure as microclimate indicators. Data on forest change, tree cover loss, tree cover loss due to fire, and greenhouse gas (GHG) emissions were taken from Global Forest Watch for the period 2001–2024 and analyzed to assess deforestation and forest degradation trends. Furthermore, data on forest fires and environmental disasters were obtained from the National Disaster Management Agency.

The analysis was conducted through the integration of spatial and statistical data, including temporal comparisons between years, identification of change trends, and correlations between anthropogenic and biophysical variables. The results were synthesized to reveal the linkages between plantation expansion, forest cover decline, fire intensity, local climate change, and increased GHG emissions. This multi-source and integrative approach enables a comprehensive understanding of the ecological impacts of land use change in Bulungan Regency in the context of sustainable development and climate change mitigation.

3. Results and Discussion

3.1 Development of plantation areas

The development of five main plantation commodities experienced dynamics during the 2020–2024 period: oil palm, coconut, rubber, coffee, cocoa, and cloves in Bulungan Regency. The graph shows that oil palm experienced the most significant increase, indicating massive land expansion and cultivation intensification. This increase reflects the high demand for palm oil as a strategic export commodity (Oliphant & Simon, 2022; Reich & Musshoff, 2025).

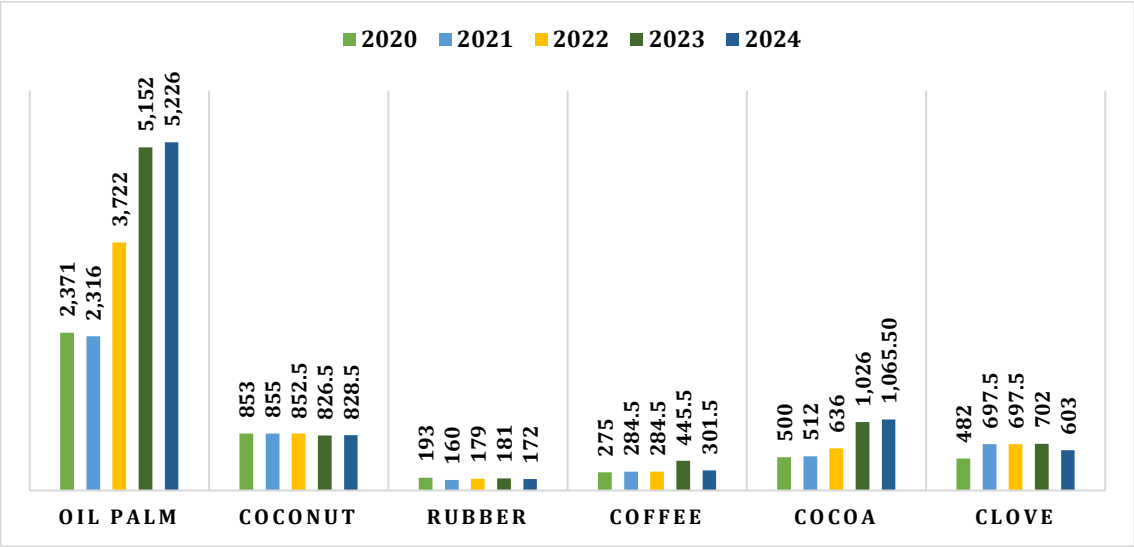

Fig. 1. Development of plantation land area in Bulungan Regency

On the other hand, the expansion of oil palm plantations often occurs through the conversion of natural forest and peatland areas, which has a significant impact on the environment. Land clearing activities, especially using burning methods, have been a major contributor to deforestation, soil degradation, and greenhouse gas emissions that accelerate climate change (de Barros & Chimeli, 2026; Jelsma et al., 2017). Furthermore, changes in land cover from forest to oil palm monocultures cause biodiversity loss, disruption of hydrological functions, and an increased risk of local flooding and drought.

3.2 Change and loss of forest areas

Between 2002 and 2024, Bulungan Regency experienced a loss of 197,000 hectares of primary moist forest, equivalent to a reduction of approximately 19% of the total primary moist forest area in the region. This condition reflects the high pressure on forest ecosystems due to human activities, particularly the expansion of land-based sectors. Based on spatial data, approximately 69% of tree cover loss in Bulungan occurred in areas dominated by permanent drivers of forest loss, with 66.3% of this being caused by permaculture activities, such as land clearing for oil palm plantations and other agricultural commodities (Pendrill et al., 2019). This pattern indicates that deforestation in Bulungan is not merely a temporary event due to timber exploitation activities, but also a form of permanent and systematic land-use change, which has implications for reducing the ecosystem's capacity to store carbon, maintain the hydrological cycle, and protect biodiversity (Parra-paitan et al., 2024).

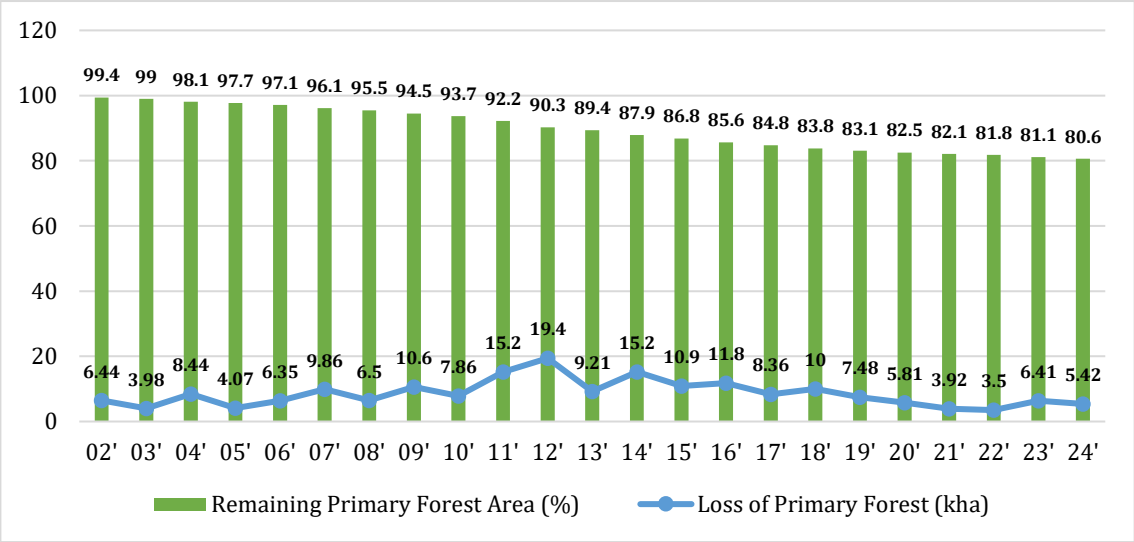

Fig. 2. Loss and remaining area of primary forest in Bulungan Regency

Between 2001 and 2024, Bulungan Regency experienced significant tree cover loss of approximately 287.5 thousand hectares, consisting of 19.5 thousand hectares due to fires and 268 thousand hectares due to various other drivers of loss, such as plantation expansion, land clearing for agriculture, and infrastructure development. 2016 was recorded as the period with the highest tree cover loss due to fires, reaching 2.74 thousand hectares or approximately 16% of the total tree cover loss that year. Overall, fires contributed approximately 6.8% of total tree cover loss in Bulungan during the observation period, indicating that, although not dominant, fires remain a significant factor in forest ecosystem degradation. This loss pattern reflects high pressure on natural forest cover in Bulungan, which has the potential to impact environmental degradation, increase carbon emissions, and disrupt ecosystem functions, especially in the context of land use changes triggered by human activities and the dynamics of land use policies in the region (Suwarno et al., 2018).

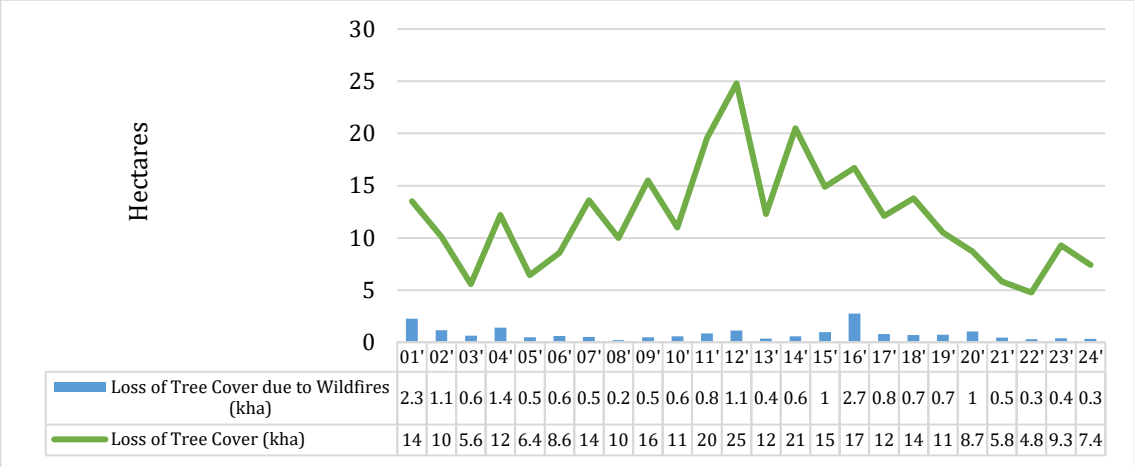

Fig. 3. Total tree cover loss and tree cover loss due to fire

3.3 Forest fires, floods, and landslides

The interrelationship between fires, floods, and landslides in Bulungan Regency reflects a complex ecological feedback system driven by anthropogenic pressures and unsustainable land-use practices. Intentional land burning for plantation expansion, particularly in secondary forest areas and drained peatlands, is a major driver of environmental degradation in the region. The loss of vegetation cover due to fires reduces soil infiltration capacity, disrupts soil structure stability, and alters the local hydrological regime.

Table 1. Number of forest fire, flood and landslide disaster incidents

Year	Forest fires		Floods		Landslides	
	Number of the Incident	Cause of the Incident	Numbers of the Incident	Cause of the Incident	Numbers of the Incident	Cause of the Incident
2019	5	Forest fires are caused by land burning carried out deliberately by people with the aim of clearing land for plantations.	1	Floods are caused by high rainfall intensity so that river basins overflow.	0	Landslides are caused by abrasion on the riverbank.
2020	11		0		0	
2021	9		6		3	
2022	2		2		0	
2023	13		0		1	
2024	3		2		0	

As protective vegetation is reduced, the soil's ability to retain rainwater decreases, increasing surface runoff and the risk of flooding, particularly along the Kayan River watershed, Bulungan's primary hydrological system. Over the long term, this process accelerates erosion and slope instability, triggering landslides and riverbank abrasion. Thus, fires act as an initiating disturbance that triggers a cascade of hydrological and geomorphological imbalances, establishing a mutually reinforcing causal relationship between disaster types (Cahyana et al., 2025; Panahi et al., 2025). This pattern shows that environmental dynamics in Bulungan cannot be understood separately, but rather as an integrated system where ecological changes in one component have a cascading impact on other components (Bos et al., 2020; Tarigan, 2016).

3.4 Microclimate conditions

Based on air temperature data in Bulungan Regency from January 2021 to November 2023, it appears that maximum, average, and minimum temperature fluctuations are

relatively stable without any significant extreme changes. Maximum temperature values ranged between 34–36°C, indicating a consistent tropical climate with high levels of solar radiation throughout the year. Average temperatures ranged between 27–29°C, while minimum temperatures ranged between 21–24°C, with a slight decrease in early 2021 and mid-2022, correlated with increased seasonal rainfall due to the La Nina phenomenon.

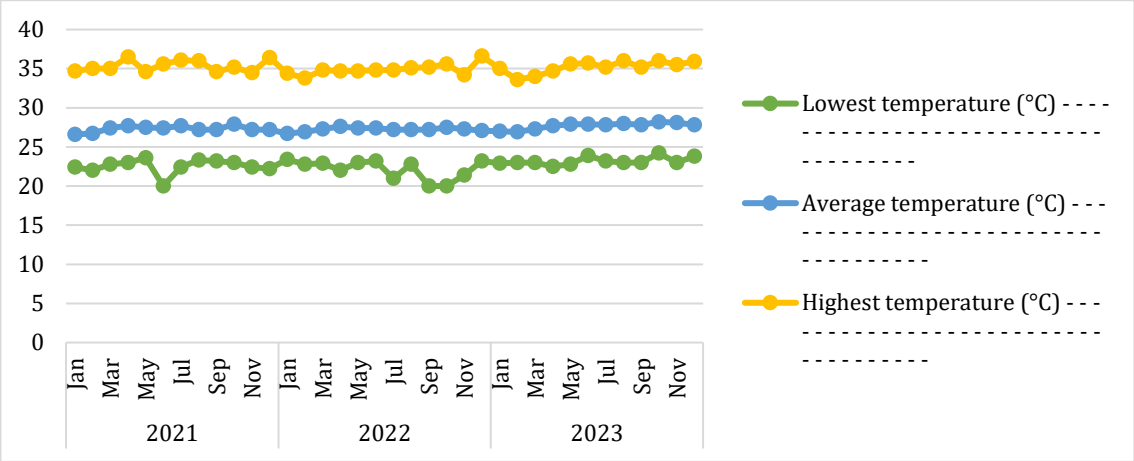

Fig. 4. Temperature changes in Bulungan Regency

This temperature stability indicates that Bulungan's climate tends to be thermally constant, reflecting the characteristics of the humid tropical climate region in northern Kalimantan. However, the relatively small difference between maximum and minimum temperatures indicates high levels of air humidity and low daily thermal amplitude, which have implications for the stability of ecosystem processes and the productivity of natural vegetation and agriculture in the region (Morsy & Aboelkhair, 2021; Wol et al., 2018).

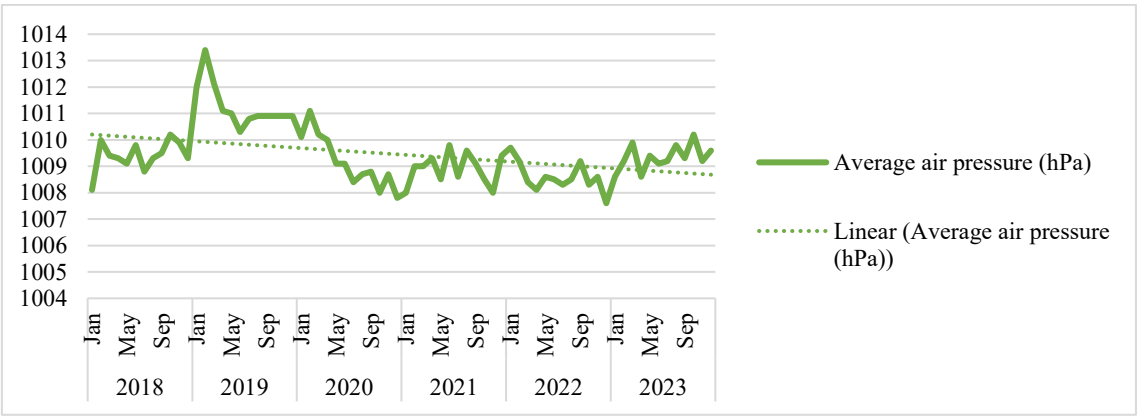

Fig5. . Air pressure changes in Bulungan Regency

Based on average air pressure data in Bulungan Regency from January 2018 to September 2023, air pressure values are relatively stable, ranging from 1008 to 1013 hPa, indicating consistent atmospheric characteristics in the tropical lowlands. Although monthly fluctuations occur, the general pattern shows a slightly decreasing linear trend, indicating minor changes in atmospheric dynamics over the medium term. The marked increase in air pressure in early 2019 was likely related to regional weather anomalies or the influence of a high pressure system in the Pacific Ocean, which resulted in a temporary increase in atmospheric stability. After that period, air pressure showed a gradual downward trend until 2021, then fluctuated slightly in 2022–2023 without any extreme changes. Climatologically, this relatively small air pressure variation reflects the stability of Bulungan's atmospheric system, where thermal conditions and high humidity maintain surface pressure balance.

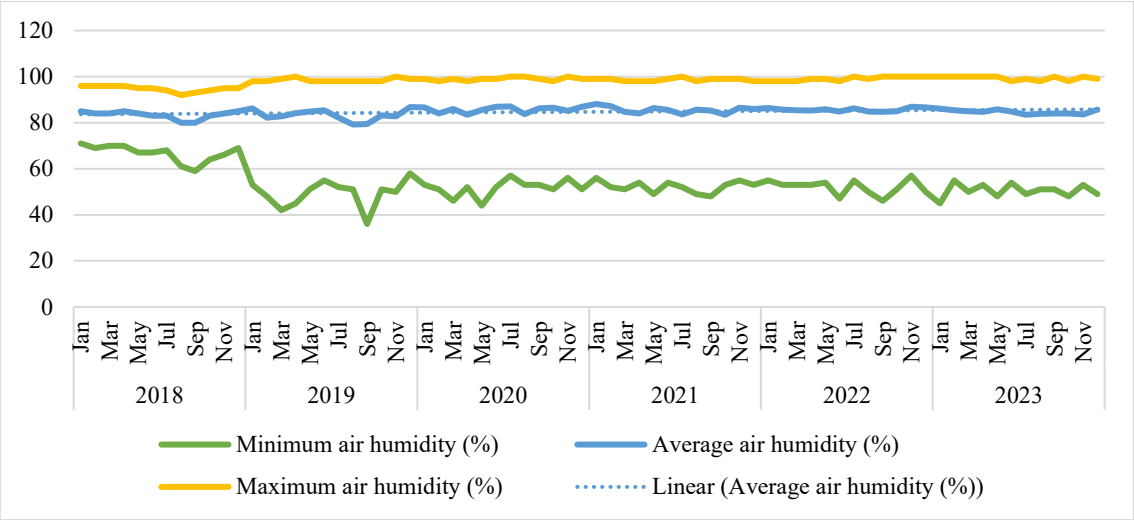

Fig. 6. Air humidity changes in Bulungan Regency

Based on humidity data in Bulungan Regency from January 2018 to October 2023, humidity levels show a relatively stable pattern with moderate seasonal variations. Maximum humidity values consistently range from 95–100%, indicating very humid atmospheric conditions and supporting the characteristics of a humid tropical climate. Average humidity is between 80–85%, with a linear trend indicating long-term stability with no indication of significant decline. Meanwhile, minimum humidity shows sharper fluctuations, particularly in the 2018–2020 period, where it briefly dropped below 50%, likely related to increased surface temperatures and decreased seasonal rainfall due to regional climate variations such as El Niño. After 2021, minimum humidity shows a more stable pattern, indicating the ecosystem is adapting to more balanced climate conditions.

3.5 Greenhouse gas emissions related to forests

Based on greenhouse gas (GHG) emissions data in Bulungan Regency from 2001 to 2024, significant fluctuations in total emissions, measured in million tons of CO_2 equivalent ($MtCO_2e$), were observed. At the beginning of the observation period, emissions showed relatively moderate values, with a sharp decline in 2003 (3.9 $MtCO_2e$) followed by a gradual increase until reaching a peak of 19.8 $MtCO_2e$ in 2012. This surge is strongly suspected to be related to the expansion of land clearing and forest conversion for plantations as well as the increasing intensity of forest fires, which directly contribute to the release of carbon into the atmosphere.

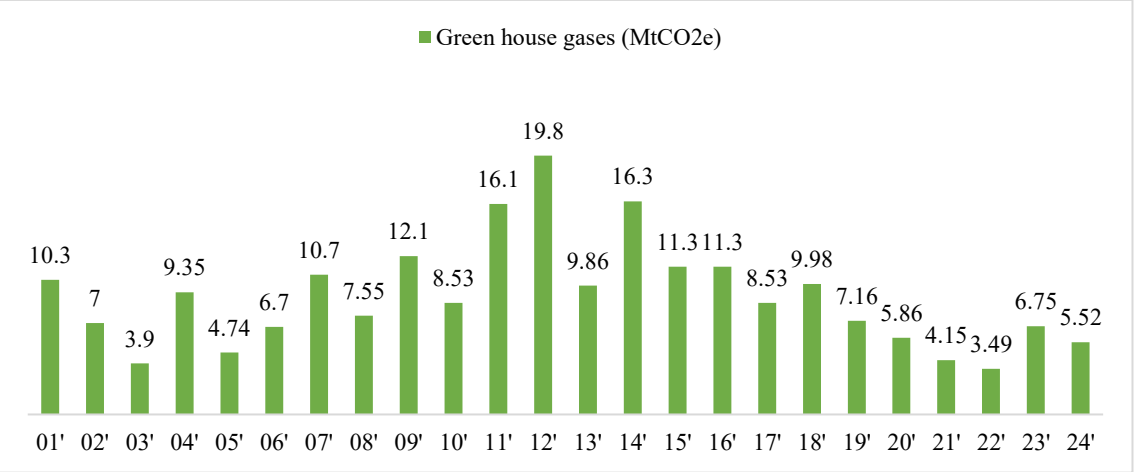

Fig. 7. Greenhouse gases changes in Bulungan Regency

After 2012, emissions showed a gradual downward trend with some moderate fluctuations, reflecting changes in land management policies and emission mitigation efforts in the forestry and agriculture sectors. By 2024, relative emissions levels have decreased to approximately 5.52 $MtCO_2e$, which can be attributed to strengthening environmental regulations, increasing awareness of sustainable land use practices, and the implementation of forest and land rehabilitation programs (Toriyama et al., 2014). Overall, this pattern suggests that GHG emission dynamics in Bulungan are strongly influenced by the interaction between anthropogenic pressures and environmental policies, underscoring the importance of ecosystem-based management in supporting the transition to low-carbon development in tropical regions (Meehan et al., 2019; Sugiarto, Utaya, Bachri, et al., 2024).

3.6 Discussion

The analysis shows that the dynamics of land-use change in Bulungan Regency are dominated by plantation expansion, which has significantly contributed to forest change and tree cover loss over the past two decades. The pattern of land conversion from primary and secondary forests to plantations reflects high pressure on forest ecosystems, resulting in a decline in the area's ecological functions, including carbon sequestration, water regulation, and soil stability (Ramirez-contreras et al., 2020). Tree cover loss due to fires also exacerbates environmental degradation in Bulungan. Data show that forest and land fires have a strong spatial correlation with plantation areas and open land. This pattern indicates that some fires are likely triggered by anthropogenic activities during land clearing. The impact of fires not only causes vegetation damage but also produces significant carbon emissions, degrades soil quality, and accelerates habitat fragmentation. This phenomenon confirms that plantation expansion without proper environmental management can create a negative feedback loop, where deforestation increases vulnerability to fire, and fires further accelerate ecosystem degradation.

Analysis of forest fire and disaster data shows that fire frequency increases during periods of high-intensity dry seasons, demonstrating a close relationship between climate pressures and human activities. The spatiotemporal pattern of fires also shows that most incidents occur around newly established plantation areas, indicating that land conversion activities are still carried out using fire. In a socio-ecological context, this practice reflects the weak implementation of sustainable environmental management principles and limited local oversight capacity for land clearing activities.

The continued impacts of land cover change and fires are evident in the changing microclimate conditions in the Bulungan region. The loss of forest vegetation leads to decreased air humidity and increased surface temperatures, gradually shifting the microclimate from stable, humid conditions to fluctuating, dry conditions. The linear downward trend in air pressure data during the 2018–2023 period indicates local atmospheric instability, which may be related to changes in vegetation cover and evapotranspiration patterns. This is important to note because an unstable microclimate can impact agricultural productivity, the hydrological cycle, and the land's ability to recover from ecological disturbances (Rum et al., 2022).

Changes in terrestrial ecosystems due to deforestation and fires are also reflected in increased greenhouse gas emissions. GHG emissions data for Bulungan Regency show significant fluctuations, with a peak of 19.8 $MtCO_2e$ in 2012, which coincided with a period of intensive land clearing for plantations. Despite a downward trend of 5.52 $MtCO_2e$ by 2024, the land use and forestry sectors remain major contributors to regional emissions. This confirms that plantation activities significantly contribute to global climate change through carbon release from deforestation and fires. Thus, the relationship between plantation expansion, forest loss, fires, and increased GHG emissions forms a complex feedback system that amplifies the impacts of environmental change both regionally and globally (Overland et al., 2021; Tarigan, 2016).

Conceptually, these results reinforce the understanding that plantations in tropical regions have multidimensional environmental impacts, including ecosystem degradation,

microclimate disruption, and increased carbon emissions. In the context of Bulungan Regency, the main challenge lies in the suboptimal integrated landscape management that balances economic needs with ecological carrying capacity. Therefore, mitigation efforts such as improving agroforestry practices, conserving remaining forests, controlling land burning, and rehabilitating degraded areas are strategic steps to reduce deforestation rates and GHG emissions (Ting et al., 2017).

3.6.1 Dilemmas and system complexity

The implementation of permanent agriculture often faces a fundamental dilemma between production demands and conservation needs, particularly in areas experiencing high pressure on forest cover. Forests serve vital ecological functions as carbon sinks, microclimate regulators, biodiversity reservoirs, and buffers for hydrological systems that underpin agricultural sustainability. On the other hand, the ever-increasing human demand for food and agricultural land has led to the conversion of forests into permanent agricultural areas, which, if not managed according to ecological principles, can lead to soil degradation, decreased fertility, and disruption of long-term ecosystem function. This tension between agriculture and conservation reflects a systemic issue involving ecological, social, economic, and institutional dimensions. In this context, it is crucial to develop an integrative approach that views forests and agriculture not as mutually exclusive entities but as interdependent components within a dynamic socio-ecological landscape. A landscape approach enables spatial planning that is more adaptive to human needs while maintaining ecological functions, through land mosaic management that accommodates intensive production areas, buffer zones, and conservation areas. This principle emphasizes that true sustainability is not achieved through extreme separation of forests and agriculture, but through spatial and functional integration that maximizes the synergy of both.

3.6.2 Ecological, social, and technological integration strategy

To achieve a balance between permanent agriculture and forest conservation, a paradigm shift in land management is needed, based on a balance of ecological and socioeconomic functions. This strategy can be built through three main pillars: first, agroecological innovation and sustainable landscape design, second, collaborative governance and institutions, and third, economic instruments and environmental incentive policies. First, the application of agroecological principles such as crop diversification, the integration of trees into production systems (agroforestry), crop rotation, and the use of organic fertilizers can reduce dependence on external inputs and enhance ecosystem functions that support long-term productivity. Agroforestry systems, for example, have been proven to integrate food production with tree vegetation conservation, provide soil cover that prevents erosion, and maintain local biodiversity. Land-sharing approaches can be implemented in areas with high biodiversity, while land-sparing is more appropriate in areas with high population pressure, with production intensification on a small portion of land to preserve other areas intact. Second, the success of integrative systems depends heavily on adaptive and participatory governance involving local communities, government, the private sector, and traditional institutions. Land rights and tenure security are key prerequisites for encouraging long-term investment in sustainable land management. Strong institutions enable monitoring mechanisms, fair benefit distribution, and conflict resolution among stakeholders. Third, economic mechanisms based on environmental incentives are needed, such as Payment for Ecosystem Services (PPE) schemes, carbon credits, and sustainable product certification. These instruments provide economic value for conservation practices carried out by farmers or local communities, ensuring they are not only responsible for protecting forests but also receive tangible benefits from these conservation efforts. Through a combination of ecological, social, and

economic approaches, permanent agricultural systems can thrive without placing undue pressure on forests.

3.6.3 Implementation, challenges, and directions for sustainability

Efforts to achieve a balance between permanent agriculture and forest conservation require the adoption of evidence-based implementation strategies that are sensitive to local contexts. A sustainable landscape approach serves as the primary framework for integrating diverse land interests and functions into a coherent socio-ecological landscape. In this approach, each landscape unit is assessed not only based on its economic output but also on the ecosystem services and socio-cultural values it generates. Implementation on the ground requires cross-sectoral and cross-scale collaboration, spanning land-use planning, forestry policies, agrarian systems, and agricultural value chains to ensure unfragmented decision-making. For example, successful integration can be achieved through the development of ecological corridors between forest blocks and agricultural land, the use of spatial technology to monitor deforestation, and land information systems that support the determination of optimal land-use boundaries without degrading environmental functions. The greatest challenges arise from conflicting economic interests, weak law enforcement, and the limited capacity of farmers to adopt sustainable practices. Therefore, transformative policies are needed that position farmers not as perpetrators of deforestation but as active conservation agents through adequate incentive systems, training, and technological support. Greenland certification programs, the integration of conservation into village development plans, and the mainstreaming of environmental education can strengthen collective awareness that productivity and sustainability are not mutually exclusive, but rather mutually reinforcing in the long term. Ultimately, a middle ground between permanent agriculture and forests can be achieved through adaptive coexistence rooted in local knowledge, supported by scientific innovation, and implemented within inclusive governance that respects the rights, functions, and values of each landscape component. Thus, sustainability is not only defined as production sustainability, but also as sustainability of life—ecological, social, and moral—that ensures the balance between humans and nature is maintained across generations.

4. Conclusions

The dynamics of environmental change in Bulungan Regency are significantly influenced by the expansion of plantation land, which triggers changes in forest cover, increased tree loss, and intensified forest and land fires. The process of converting forests to plantation areas has been proven to disrupt ecosystem stability through vegetation degradation, decreased humidity, increased surface temperatures, and fluctuations in air pressure that reflect microclimate changes. Frequent fires around plantation areas contribute significantly to carbon release and increased greenhouse gas emissions, which peak during periods of intensive land clearing. Ecologically, the link between land-use change, forest degradation, fires, and increased GHGs indicates a feedback system that amplifies the impacts of climate change at both the local and global levels. Therefore, efforts to control deforestation, manage sustainable plantations, and rehabilitate degraded land are strategic steps to maintain a balance between economic growth and environmental sustainability in the Bulungan region.

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Author Contribution
The author jointly contributed to all components of this study, including conceptualization, methodology, data collection, formal analysis, drafting of the original manuscript, review and editing, visualization, and project administration.

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Ethical Review Board Statement
Not available. This study is conceptual in nature and relies on secondary data and document reviews that are publicly accessible. It does not involve human participants, animals, or matters related to public health or safety.

Informed Consent Statement
Not available. This study did not involve human participants.

Data Availability Statement
Data supporting the findings of this study were obtained from publicly available secondary sources cited within the manuscript.

Conflicts of Interest
The author declares no conflict of interest.

Declaration of Generative AI Use
During the preparation of this work, the author used Grammarly to assist in improving the grammar, clarity, and academic tone of the manuscript. After using this tool, the author carefully reviewed and edited the content as needed and takes full responsibility for the content of the publication.

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