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Assessing land use deviations from spatial plans amid nickel mining expansion in Central Halmahera

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ABSTRACT

The rapid expansion of industrial and nickel mining activities in Central Halmahera has driven dynamic changes in land use, often leading to conflicts with established spatial plans. This study identifies land use deviations from the North Maluku Provincial Spatial Plan (2024–2043) using spatial analysis techniques. Through the overlay method, recent land use and land cover data (from 2022) were compared with the designated spatial zoning plan. The analysis results show a generally high level of compliance, with approximately 98.13% of the total 247,596.80 hectares aligning with the spatial zoning plan. However, significant deviations were found in the Mangrove Zone (17.94%) and Marine Conservation Zone (47.98%) due to settlements and infrastructure development. These changes are driven by industrial growth, a surge in the workforce, and increased demand for housing and services. The findings reveal real challenges in the effectiveness of spatial planning instruments to control land use changes. Emphasis on the need for proactive and integrated spatial governance can be addressed through stricter zoning regulation enforcement, continuous monitoring, and active community involvement in the planning process to ensure sustainable land management amid ongoing extractive industry expansion.

Keywords: environmental zoning; land use deviations; nickel mining expansion; overlay analysis; spatial planning.

1 Introduction

According to the United States Geological Survey (USGS), Indonesia produced nearly half of the world's nickel supply in 2024, accounting for 59.4%, thereby establishing as the largest global producer [1]. Official data from the Ministry of Energy and Mineral Resources (ESDM) and the Indonesian Mining Association (IMA) indicate that North Maluku holds the largest reserves, followed by Southeast Sulawesi and Central Sulawesi [2]. The surge in global demand—particularly driven by the electric vehicle battery industry [3], has prompted the Indonesian government to accelerate the downstream processing (hilirisasi) of nickel, including the development of new smelters. According to the ESDM, the nickel downstreaming mandate under the Mineral and Coal Mining Law (UU Minerba) has led to the construction of dozens of smelters by 2024—an industrial endeavor that requires extensive land, spanning mining sites, smelter complexes, and supporting infrastructure such as power plants and ports [4].

Central Halmahera in North Maluku Province has emerged as one of the core epicenters of this transformation, hosting large-scale nickel industrial zones such as the Indonesia Weda Bay Industrial Park (IWIP). This area exemplifies the real-world implementation of the downstreaming policy, where mining activities, nickel processing, and smelter construction are conducted intensively [5]. The region yields not only economic benefits—attracting substantial investments from both domestic and international companies [6], but also triggers negative environmental impacts [7] due to significant changes in spatial planning and land use. Given that only 27% of Halmahera's territory is land while the remaining 73% is marine [8], industrial expansion in Central Halmahera exerts immense pressure on the established spatial plans. Human activity directly affects almost 70% of the world's land surface that is not covered by ice, negative climatic forcing could result from these land use changes [9].

One of the most prominent phenomena arising from the nickel mining expansion in Central Halmahera Regency is the conversion of land originally designated for conservation into mining areas. Land usage tends to favour functions that

provide the largest economic rent, according to the Land Rent Theory, which has its roots in the classical economic. In the case of Central Halmahera, lands with limited economic value as protected areas have come under increasing pressure to be repurposed due to the far greater economic gains offered by mining activities. In this context, the mining sector provides strong economic incentives for both investors and the government—in the form of taxes, royalties, and employment opportunities [10]. This disparity in land rent values has become a key driver behind land-use conversions that violate existing spatial plans (RTRW) [11]. Land use change does not only occur due to market forces, but can also be exacerbated by weak spatial planning oversight, inter-institutional conflicts, and weak local institutional capacity to enforce spatial regulations [12]. Dalam banyak kasus, perencanaan tata ruang tidak mampu mengimbangi laju perubahan fungsi lahan yang dipicu oleh ekspansi industri ekstraktif [13], [14].

This study aims to assess the alignment between actual land use in 2022 and the North Maluku Provincial Spatial Plan (RTRW) for the period 2024–2043 in Central Halmahera Regency, with a focus on deviations resulting from nickel mining expansion and industrial zone development. This research is vital as it provides empirical evidence of the pressures exerted by extractive industries on spatial governance. The findings can serve as a decision-making foundation for provincial and regency-level policymakers, particularly in evaluating the effectiveness of RTRW as a regulatory instrument for land-use control. Furthermore, the results offer valuable insights for academics interested in spatial deviations, resource governance, and land conflicts. This study is also relevant to civil society organizations and environmental advocates seeking spatial data to support environmental protection and spatial justice for local communities.

The rapid expansion of nickel mining in Indonesia, particularly in resource-rich regions such as Central Halmahera, has drawn increasing attention in academic studies due to its far-reaching environmental and spatial implications. Prior research has predominantly examined the expansion of nickel mining from environmental and social impact perspectives. The environmental consequences of mining activities—such as deforestation and habitat degradation—have been extensively documented [15], [16]. For instance, a study conducted in Sulawesi revealed that nickel mining significantly accelerated deforestation in the region. Additionally, the research highlighted mixed impacts on local communities, with improvements in living standards often counterbalanced by losses in other dimensions of well-being [16].

Land-use change and the resulting conflicts have emerged as critical issues in the mining context. A study in Xintai City, China, demonstrated that the risk of land-use spatial conflict (LUSC) was particularly high in transitional zones between urban and mining areas, with anthropogenic factors serving as the primary drivers of conflict [17]. Moreover, other studies have emphasized the importance of addressing overlapping land uses, which may signal underlying land competition—particularly between large-scale commercial operations and smallholder farmers—potentially leading to conflict and the marginalization of vulnerable groups [18]. This issue is further exacerbated in cases where mining waste forms the physical boundary between industrial sites and nearby communities, posing risks of displacement and ecological degradation if not adequately managed [19]. The literature also underscores concerns related to biodiversity. A study of Lake Galela in North Maluku, Indonesia, found that land-use changes—such as the conversion of open land into built-up areas—had negative effects on riparian vegetation, with several observed plant species listed in the IUCN Red List [20]. On the other hand, efforts have emerged to leverage biodiversity within mining contexts, as evidenced by the discovery of a new nickel hyperaccumulator plant species on Halmahera Island [7]. This finding opens up opportunities for the development of localized phytomining approaches that may offer sustainable alternatives to conventional extraction methods. Collectively, these studies highlight the complex and multifaceted impacts of nickel mining, encompassing environmental degradation, land conflict, and biodiversity implications, as well as broader effects on community welfare.

While previous literature has extensively explored the ecological, social, and spatial dimensions of nickel mining, most studies have not explicitly assessed the degree of alignment between actual land use and spatial planning instruments such as the Spatial Plan (RTRW). As a legal-formal framework, the RTRW is intended to guide spatial development and regulate land use; however, its implementation often faces substantial pressure from extractive industries. Furthermore, no existing study has specifically analyzed the context of Central Halmahera as the epicenter of Indonesia's national nickel downstreaming agenda. This study seeks to address that gap by analyzing land-use deviations from the 2024–2043 RTRW of North Maluku Province using spatial overlay. The research aims not only to enhance understanding of mining-related impacts from a spatial-formal perspective but also to contribute meaningfully to the strengthening of spatial governance in Indonesia's eastern coastal and archipelagic regions, which are increasingly vulnerable to industrial development pressures.

2 Data and Methods

2.1 Study Area

The study was conducted in Central Halmahera Regency, which is administratively part of North

Maluku Province, Indonesia. Geographically, the regency is situated between 0° 45' North Latitude – 0° 15' South Latitude and 127° 45' – 129° 26' East Longitude. The study location can be seen in the **Figure 1.** Central Halmahera covers a total area of approximately 8,381.48 km^2, consisting of 73% marine territory and the remaining 27% as land [8], making it a predominantly maritime region. Topographically, the region is characterized by extensive coastal landscapes, with most settlements and development concentrated along the shoreline. Although it is the smallest regency on Halmahera Island in terms of land area, the administrative reach of Central Halmahera stretches longitudinally across the island, from the central interior to its easternmost tip. The outermost island of the regency, Gebe Island, is located close to the Raja Ampat archipelago in West Papua, indicating the region's geographical complexity and strategic location within eastern Indonesia.

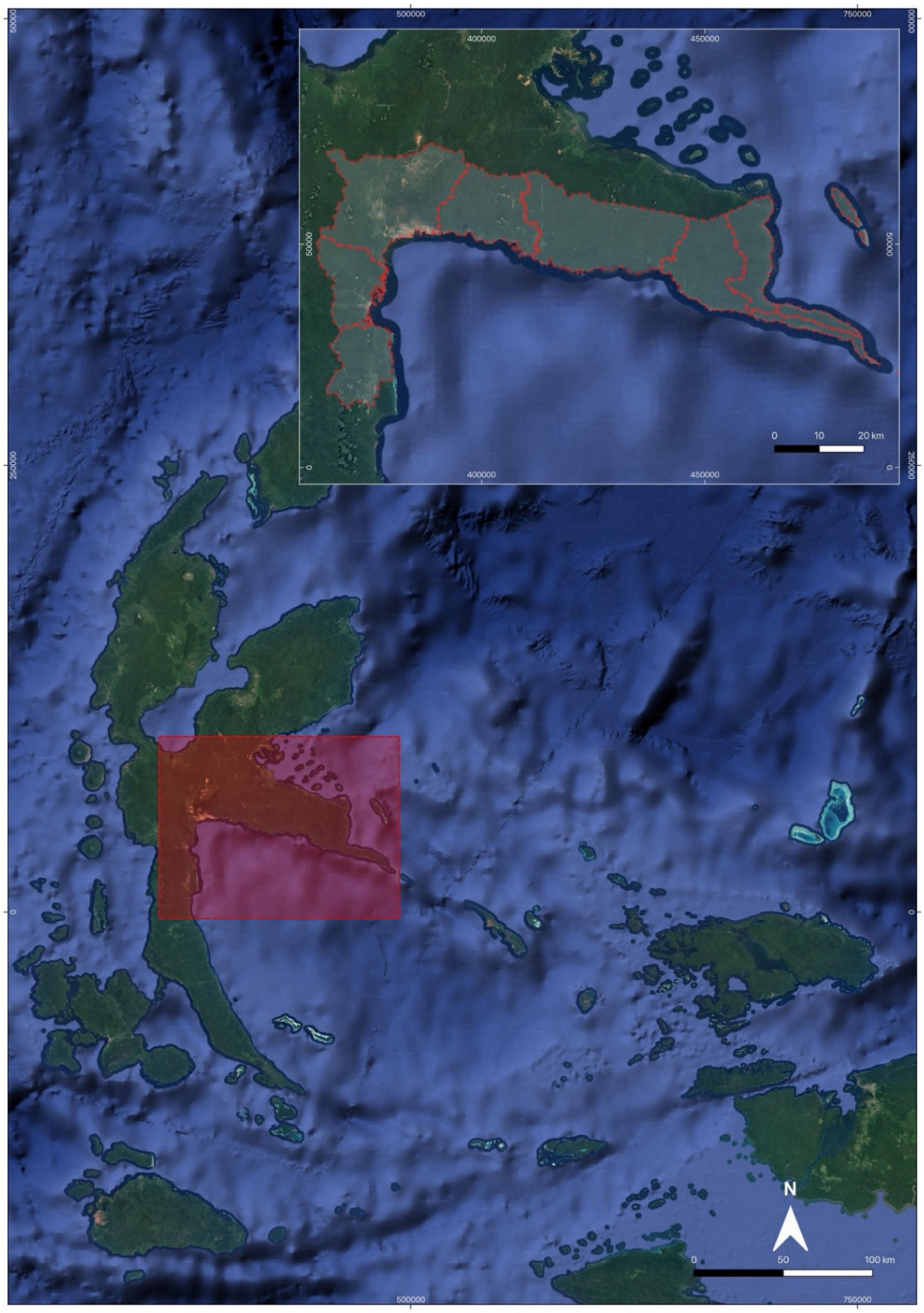

Figure 1. Study location: Central Halmahera Regency, North Maluku Province, Indonesia.
Source: Google Earth Imagery of Central Halmahera, 2025; RBI Map at a 1:50,000 Scale

2.2 Data Collection

This research utilized both spatial and non-spatial secondary data, which were obtained from the following sources: (a) Land Use – Land Cover (LULC) Data for 2022, the classification of LULC was conducted through manual digitization, in which land cover information from the RBI Map was updated and refined using high-resolution SPOT 6 imagery. This process enabled the delineation of various land cover types such as forests, plantations, settlements, mangroves, water bodies, agriculture, and other built-up areas. Remote sensing technology based on satellite imagery is one of the most effective alternatives in extracting information on land cover and it is essential to decide on regional spatial planning, climate change study, comprehension of human and environment interaction, and disaster prevention [21]; (b) Provincial Spatial Plan (RTRW) of North Maluku for 2024–2043, based on Regional Regulation of North Maluku Province No. 6 of 2024. This official document outlines spatial planning zones and land allocation policies for a 20-year planning horizon; and (c) Administrative boundary layers, topographic maps, and base maps were obtained from other relevant government institutions to support georeferencing and spatial analysis.

2.3 Data Processing and Spatial Analysis

The analysis in this study employed a spatial overlay technique, which is commonly used in geographic information system (GIS)–based land use planning analysis. The method aims to identify the level of spatial deviation between existing land use and the planned spatial designation. The analytical framework can be seen in the **Figure 2.**

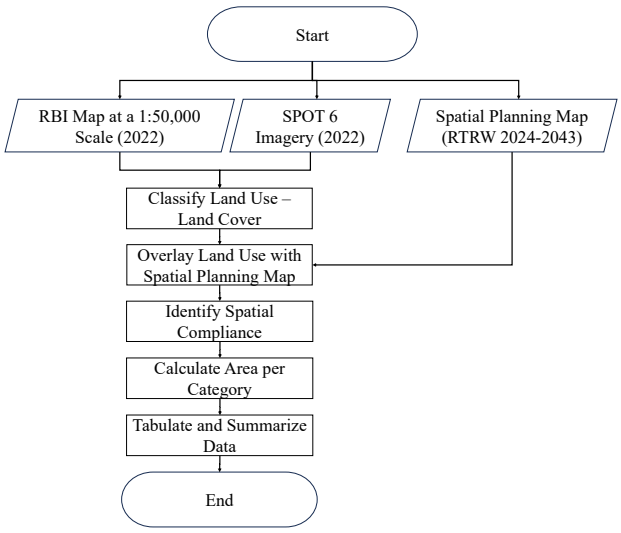

Figure 2. Analytical Framework

The data processing and spatial analysis in this study involved a series of systematic steps to assess land use compliance with spatial planning zones. First, the 2022 land cover data were classified into categories such as forest, mangrove, plantation, settlement, rice field, water body, shrubland, vacant land, industry, and transportation. This classification was conducted through visual interpretation and supervised classification techniques applied to high-resolution SPOT 6 satellite imagery. The digitization and analysis were performed using QGIS 3.16 LTR, which provided tools for on-screen digitizing, classification, and spatial operations. Following this, an overlay analysis was performed by intersecting the land use map with the spatial planning zone map. The analysis was conducted under the WGS 1984 UTM Zone 52N coordinate system, with a minimum mapping unit (MMU) of 0.5 hectares applied to maintain spatial consistency and accuracy. This procedure generated a new spatial layer that delineated actual land use types within each designated planning zone. Subsequently, a compliance assessment was carried out by evaluating whether the identified land use within each zone was in accordance with the functions prescribed in the RTRW (Provincial Spatial Plan). Land uses deemed inconsistent—such as settlements within conservation or mangrove zones—were classified as non-compliant. The spatial extent of both compliant and non-compliant uses was then measured in hectares through area calculation and tabulation, enabling a quantitative understanding of land use alignment and deviation across the region.

3 Results and Discussion

3.1 Land Use – Land Cover 2022 and Land Use Planning Zone Composition

This section presents the composition of land use and land cover (LULC) in 2022 and the designated land use planning zones. The analysis focuses on quantifying the area covered by each LULC type and planning zone, providing a baseline understanding of the spatial characteristics and distribution patterns within the study area. These compositional data are essential for identifying dominant land functions and assessing how land resources are allocated across different spatial zones.

Table 1. LULC 2022 Classification

LULC 2022 Classification	Area (ha)	%
Residential	1,424.25	0.58%
Offices	17.35	0.01%
Education Facilities	10.27	0.00%
Trade and Services	8.24	0.00%
Industry and Warehousing	355.38	0.14%
Places of Worship	2.45	0.00%
Health Facilities	1.07	0.00%
Cemetery	10.87	0.00%
Transportation	44.17	0.02%
Water Body	1,145.36	0.46%
Forest	232,880.25	94.06%
Plantation	768.17	0.31%

Rice Field	2,861.91	1.16%
Upland Field	2,701.77	1.09%
Shrubland	23.49	0.01%
Mangrove	199.56	0.08%
Vacant Land	5,142.22	2.08%
Total	247,596.80	100.00%

Source: RBI Map at a 1:50,000 Scale (2022); SPOT 6 Imagery of Central Halmahera, 2022

Table 2 shows the LULC composition in Central Halmahera Regency as of 2022 is overwhelmingly dominated by natural forest, which spans approximately 232,880.25 hectares or 94.06% of the total land area. This indicates that the region remains largely forested and underscores its ecological significance and potential vulnerability to future land use conversion, particularly given the ongoing expansion of extractive industries. Agricultural land in Central Halmahera is relatively limited, with rice fields covering 2,861.91 ha (1.16%), upland fields 2,701.77 ha (1.09%), and plantations 768.17 ha (0.31%). Vacant land spans 5,142.22 ha (2.08%), while shrubland and mangroves occupy minor areas of 23.49 ha and 199.56 ha, respectively. Built-up areas are minimal: residential (0.58%), industry and warehousing (0.14%), and other urban uses each less than 0.01%. Water bodies cover 1,145.36 ha (0.46%), with roads and cemeteries occupying only 44.17 ha and 10.87 ha. Overall, the 2022 land cover is dominated by forest, with limited agricultural and urban development, forming a baseline for evaluating future land use shifts. The land use – land cover classification in 2022 map can be seen in the figure 3.

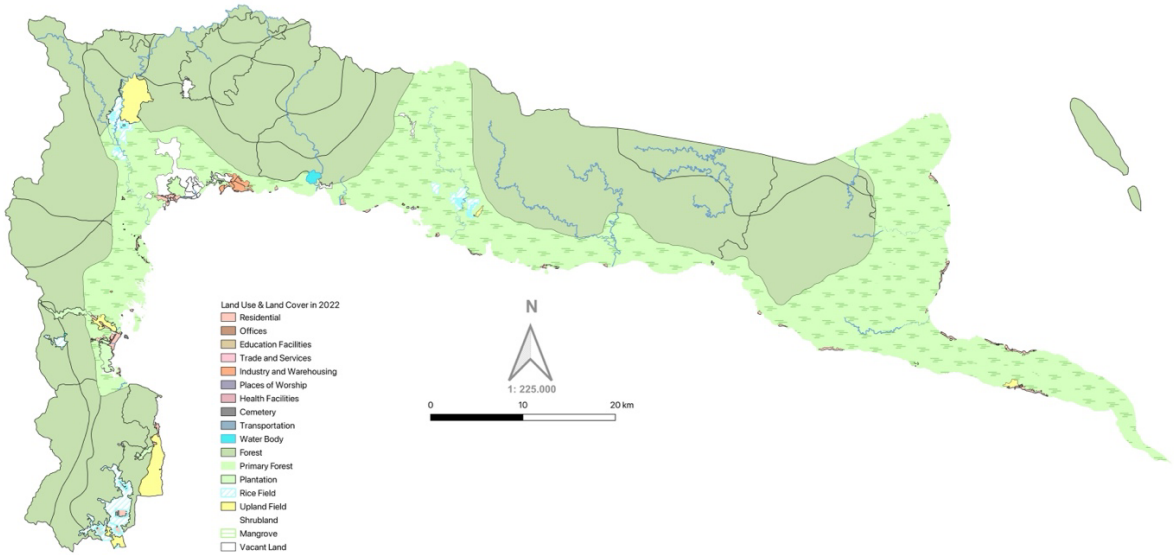

Figure 3. Map of Land Use – Land Cover Classification in 2022, Central Halmahera Regency
Source: RBI Map at a 1:50,000 Scale (2022); SPOT 6 Imagery of Central Halmahera, 2022

Table 2 shows the land use planning structure of Central Halmahera Regency in 2022 reflects a strong orientation toward environmental conservation and natural resource utilization. The Production Forest Zone dominates with 150,904.10 hectares, accounting for 60.95% of the total area, highlighting the region's emphasis on forestry-based land management. The Agricultural Zone is the second largest, covering 13.70% of the area, followed by the Upper Catchment Protection Zone at 10.99%, highlighting priorities in farming and watershed protection. The Conservation Zone (6.49%) and Industrial Zone (5.09%) show environmental and industrial commitments, while the Settlement Zone (2.51%) and Transportation Zone (0.04%) reflect a limited urban footprint. Smaller zones like Mangrove, Marine Conservation, Fisheries, Defense and Security Zone, and Tourism each cover less than 0.5%, suggesting they are not major focuses. Overall, the land use emphasizes forest protection, agriculture, and emerging industrial development.

Table 2. Land Use Planning Zone in 2022, Central Halmahera Regency

Land Use Planning Zone	Area (ha)	%
Upper Catchment Protection Zone	27,222.24	10.99%
Conservation Zone	16,077.34	6.49%
Marine Conservation Reserve Zone	11.28	0.00%
Mangrove Ecosystem Zone	523.04	0.21%
Production Forest Zone	150,904.10	60.95%
Agricultural Zone	33,926.80	13.70%
Fisheries Zone	12.36	0.00%
Industrial Zone	12,602.45	5.09%
Tourism Zone	2.39	0.00%
Settlement Zone	6,215.60	2.51%
Transportation Zone	99.21	0.04%
Defense and Security Zone	0.00	0.00%
Total	**247.596.80**	**100.00%**

The land use planning zone map can be seen in the **Figure 4**.

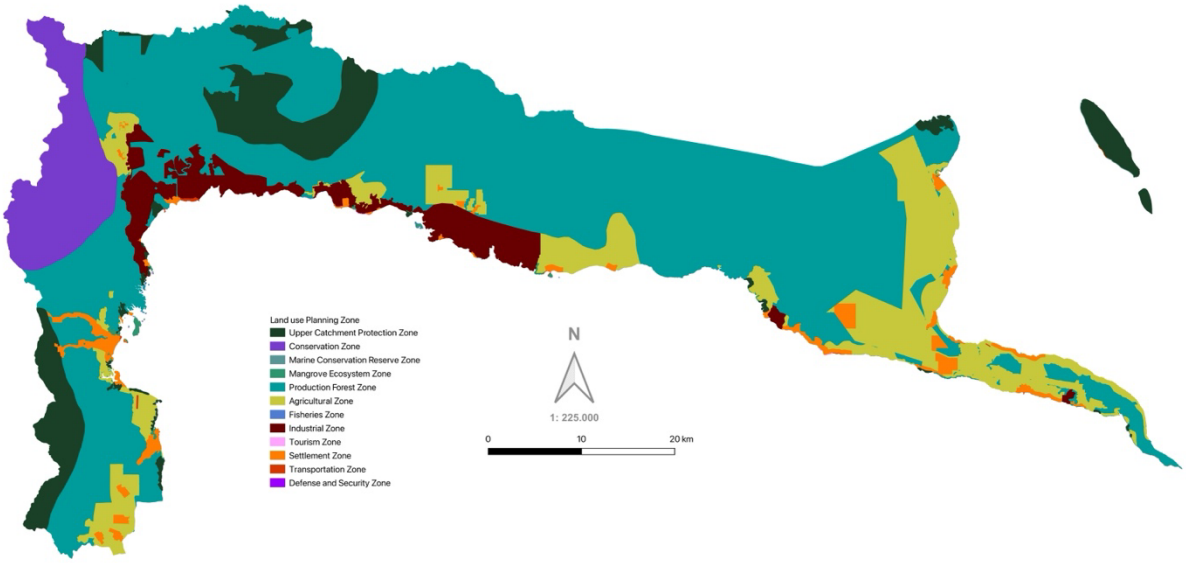

Figure 4. Map of Land Use – Land Cover Classification in 2022, Central Halmahera Regency
Source: RBI Map at a 1:50,000 Scale (2022); SPOT 6 Imagery of Central Halmahera, 2022

3.2 Spatial Compliance and Land Use Deviations

This section analyzes the suitability of 2022 land cover against designated planning zones across 247,596.80 hectares as shown in **Table 3**. Each land use type is categorized as compliant or non-compliant, highlighting areas where actual use aligns or deviates from the spatial plan.

The land use suitability analysis based on the 2022 land cover data across various designated planning zones reveals a generally high level of compliance, with approximately 98.13% of the total 247,596.80 hectares aligning with the intended land use plans. Zones such as the Industrial, Conservation, Tourism, and Defense and Security areas exhibit full compliance, indicating effective spatial planning and implementation. The Settlement and Agricultural zones also show strong alignment, with only minor instances of deviation. However, notable discrepancies are observed in the Mangrove Ecosystem Zone (17.94% non-compliant) and the Marine Conservation Reserve Zone (47.98% non-compliant), where inappropriate land uses such as residential, plantation, and transportation activities encroach upon ecologically sensitive areas. While the Production Forest Zone maintains a high compliance rate of 96.7%, it accounts for the highest absolute area of non-compliance (4,958.71 ha), primarily due to settlements, vacant lands, and small-scale infrastructure. The spatial compliance and land use deviation map can be seen in the **Figure 5.**

Table 3. Spatial Compliance and Land Use Deviations

Land Use Planning Zone	Compliant		Non-Compliant		Total (Ha)
	(ha)	(%)	(ha)	(%)	
Upper Catchment Protection Zone	26936.66	98.95%	285.58	1.05%	27222.24
Conservation Zone	16077.34	100.00%	0.00	0.00%	16077.34
Marine Conservation Reserve Zone	5.87	52.02%	5.41	47.98%	11.28
Mangrove Ecosystem Zone	429.23	82.06%	93.81	17.94%	523.04
Production Forest Zone	146719.12	97.23%	4184.99	2.77%	150904.10
Agricultural Zone	33878.68	99.86%	48.12	0.14%	33926.80
Fisheries Zone	10.78	87.25%	1.58	12.75%	12.36
Industrial Zone	12602.45	100.00%	0.00	0.00%	12602.45
Tourism Zone	2.39	100.00%	0.00	0.00%	2.39
Settlement Zone	6211.99	99.94%	3.61	0.06%	6215.60
Transportation Zone	91.57	92.30%	7.64	7.70%	99.21
Defense and Security Zone	0.00	100.00%	0.00	0.00%	0.00
Total	**242966.07**	**98.13%**	**4630.72**	**1.87%**	**247596.80**

Source: Analysis Results, 2025

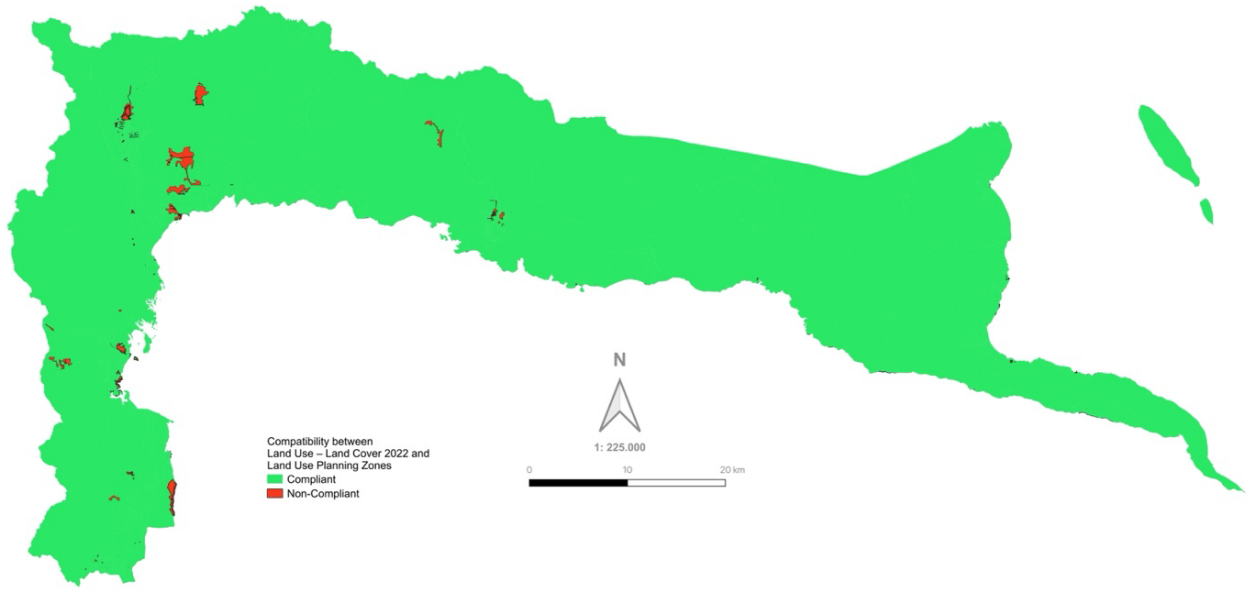

Figure 5. Map of Spatial Compliance and Land Use Deviation – Central Halmahera Regency
Source: Analysis Results, 2025

The results of the land use suitability analysis have important implications for spatial planning and environmental management in Central Halmahera. While the overall compliance rate is high, significant deviations in ecologically critical zones—such as the Mangrove Ecosystem and Marine Conservation Reserve—highlight ongoing land use pressures that threaten environmental sustainability. The encroachment of **residential** and **plantation** uses into these zones suggests weak enforcement of spatial regulations and underscores the need for stricter protection and monitoring mechanisms.

3.3 Implication for Spatial Planning and Environmental Management

The results of the land use suitability analysis highlight the spatial implications of rapid industrial development, particularly in areas surrounding mining and smelter operations in Central Halmahera. A significant driver of this spatial transformation is the dramatic increase in workforce numbers, which reflects the accelerated expansion of the nickel industry. Based on the number of employees at PT Indonesia Weda Bay Industrial Park (IWIP) from 2018 to 2023 as shown in **Figure 6**, the total workforce surged from only a few hundred to nearly 30,000, and by February 17, 2023, it had doubled again to reach 61,180 workers [5]. This workforce boom has been accompanied by a substantial influx of migrants seeking employment, placing increased pressure on land—especially for residential development.

Approximately 15% of the total workforce resides within the industrial area, where housing is provided and integrated into the master plan. However, the remaining 85% live independently outside the industrial zone, creating a growing demand for housing, services, and infrastructure in nearby communities.

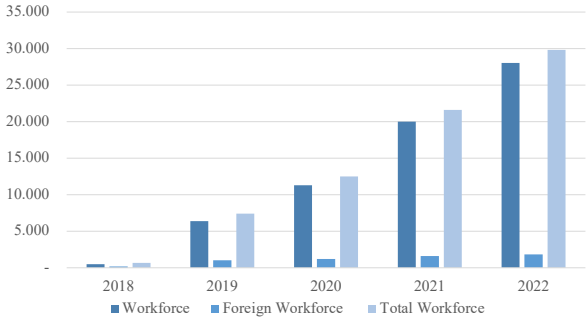

Figure 6. The number of employees at PT Indonesia Weda Bay Industrial Park (IWIP) from 2018 to 2023
Source: Rencana Induk (Masterplan) Kawasan Industri Weda Bay Rev-V, 2023

To estimate the potential land requirements for accommodating the industrial workforce in Central Halmahera, assumptions were made using the Indonesian National Standard (SNI 03-7013-2004) on apartment (rusun) planning. According to this guideline, the minimum unit size for simple rental apartments is 18–36 m^2, with an average need of 8–16 m^2 of land per person depending on building height (low-rise, mid-rise, or high-rise). If applied to the IWIP external workforce, accommodating approximately 52,000 workers and their families would require between 450 and 900 hectares of land if developed in the form of multi-storey apartment blocks (rusun), which is significantly less than the estimated land area required for horizontal housing development. This comparison highlights that the choice of housing typology (horizontal vs. vertical) has major implications for land consumption, spatial conflicts, and environmental impacts.

This growing demand has already driven land use changes that often conflict with spatial regulations, particularly in ecologically sensitive zones such as the Mangrove Ecosystem and the Production Forest Zone. The encroachment of settlements into these protected areas highlights the urgent need for proactive spatial planning and enforcement. Without such measures, continued industrial growth risks undermining environmental integrity and disrupting the balance between development and conservation. Therefore, integrating industrial growth projections, housing demand analyses, and standardized planning approaches (e.g., rusun-based housing) into spatial and environmental planning is critical to ensuring sustainable and compliant land development in the region.

4 Conclusion

This study has demonstrated that while the overall alignment between actual land use and the 2024–2043 North Maluku Provincial Spatial Plan in Central Halmahera is relatively high—at 98.13% compliance—there remain critical spatial deviations, particularly in ecologically sensitive zones. The highest levels of non-compliance were found in the Mangrove Ecosystem Zone (17.94%) and Marine Conservation Reserve Zone (47.98%), where encroachment by settlements, plantations, and transportation infrastructure threatens environmental integrity. Although the Production Forest Zone maintains a 96.7% compliance rate, it records the largest absolute area of deviation, underscoring the pressure that mining expansion and population influx exert on land use. The spatial dynamics observed are closely linked to the rapid growth of nickel mining and industrial activities, including the significant increase in workforce and associated demand for housing and services. These changes highlight the challenges faced by spatial planning instruments in managing land use amidst extractive industry pressures. The findings stress the urgent need for proactive and integrated spatial governance strategies, including stricter enforcement of zoning regulations, ongoing monitoring of land use, and meaningful involvement of local communities in planning and decision-making processes. To support sustainable spatial development, it is essential that provincial and regency-level policymakers incorporate industrial expansion trends into long-term land use planning. Future spatial policies must not only respond to current land pressures but also anticipate ongoing transformation driven by economic incentives in the mining sector. Strengthening institutional capacity, improving regulatory oversight, and reinforcing environmental safeguards will be crucial to preserving the ecological balance of Central Halmahera while accommodating economic growth.

5 Acknowledgement

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