Research Article

Land Readiness Analysis For Tanah Kuning Port Based On Integrated Topograhic Data

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DOI. 10.35334/be.v10i1.483

Article history:
Submitted: Nov 07, 2025
Reviewed: Jan 19, 2026
Accepted: Mar 30, 2026

Keywords:
DTM;
Land readiness;
Port;
Tanah Kuning;
Topography.

Abstract

The coastal area of Tanah Kuning, Bulungan Regency, is planned as part of the development of the Tanah Kuning-Mangkupadi Industrial Estate and International Port (KIPI) in North Kalimantan Province. This study aims to analyze port land readiness based on topographic conditions to inform technical planning for port development. The study offers an approach to evaluating land readiness by integrating terrestrial surveying using a Total Station with aerial photogrammetry using a UAV drone. The data were processed into a Digital Terrain Model (DTM) and contour maps for slope and land elevation analysis. The assessment was conducted descriptively and evaluatively, in accordance with KP.227/DJPL/2019, taking into account slope conditions, protection against the highest high-water level, and existing land use. The results show that location 1 has the most stable conditions, with dominant slopes of 0-25%, elevations above the highest high-water level, and no active settlements. Therefore, it is classified as suitable. In contrast, Locations 2 and 3 are classified as unsuitable due to the dominance of steep to very steep slopes and socio-land constraints.

Introduction

North Kalimantan Province has a highly strategic geographical position because it is traversed by the Indonesian Archipelago Sea Lane II (ALKI II), which connects international shipping routes between the Asia-Pacific and Southeast Asia regions. This location is close to the Malaysian border (Sabah-Sarawak) and to the development area of Indonesia's new capital, Nusantara (IKN), so it has strong economic and logistical potential. One of the national-scale projects being developed in this region is the Tanah Kuning-Mangkupadi International Industrial and Port Area (KIPI), with an area of ± 13,000 ha and an investment reaching USD 45.98 billion. (Saryati & Al Amrie, 2023). This area is designed as the world's largest green industrial zone, serving as an export-import center, an aluminum industry hub, a petrochemicals hub, and an electric vehicle battery powered by renewable energy from the Kayan Mentarang Hydroelectric Power Plant.

The development of the Tanah Kuning KIPI is part of the National Strategic Project (PSN) as mandated in the National Port Master Plan (Ministry of Transportation of the Republic of Indonesia, 2017). In the context of port planning, the land and water readiness phase is a fundamental stage that must be analyzed before preparing the Detailed Engineering Design (DED). The readiness assessment includes land topography, water bathymetry, and sea-level fluctuations as the basis for determining the planned elevation of the pier and reclamation area, as stated in the Technical Guidelines for the Preparation of Port Development Feasibility Studies. (Kementerian Perhubungan Direktorat Jenderal Perhubungan Laut, 2019).

Several previous studies have shown that topographic conditions are a fundamental factor in determining the initial feasibility of a port location, particularly for land facility placement, internal access, land-clearing work, and construction efficiency (Chaerul & Usman, 2016). In coastal areas, topographic analysis using Digital Terrain Models (DTMs) and geographic information systems (GIS) enables more accurate identification of elevation variations, slope directions, and potential morphological constraints during the pre-planning stage (Salameh et al., 2019).

The survey method also encourages the integration of terrestrial measurements with aerial photogrammetry to produce more detailed, efficient, and representative topographic data. This approach is relevant for developing coastal areas such as Tanah Kuning, as its land characteristics require rapid yet accurate spatial evaluation before further technical design is undertaken. A more technical study conducted by Šiljeg et al., (2019) In the Port of Ploce, Croatia, it was demonstrated that bathymetric data-based Geographic Information System (GIS) modeling is a key prerequisite for port physical work, as it precisely determines seabed morphology and dredging volumes. In the context of survey efficiency, Mateo-Pérez et al., (2021) developed a port depth estimation method using Sentinel-2 satellite data and machine learning algorithms (Random Forest & SVM), achieving over 97% accuracy. This demonstrates that remote sensing data can complement direct surveys (single-beam echosounder) in large, dynamic areas.

Advances in data acquisition methods were also demonstrated by Zhang & Al Shehhi, (2025) through a self-attention-based deep-learning Transformation model capable of predicting bathymetry down to 40 meters with high accuracy, without local calibration. This model reinforces the view that digital bathymetric mapping is increasingly moving towards full spatial integration between land and sea observations. On the other hand, Li et al., (2023) Emphasized the importance of statistical wave modeling using the Weibull distribution for coastal and port structure planning, as it can flexibly represent both normal and extreme wave conditions in coastal areas.

In the context of spatial policy, Abramic et al., (2024) introduced the concept of site-suitability zoning in Maritime Spatial Planning (MSP), which integrates environmental, oceanographic, and socio-economic data through a GIS-based decision-support system. This concept is relevant for the Tanah Kuning area, as port location selection must consider the integration of physical conditions (land-sea contours) and local socio-economic aspects.

Studies in the North Kalimantan region strengthen the technical relevance of this research. Utomo et al., (2025) Analyzed the sea level rise (SLR) trend in Tarakan using Copernicus data (1994-2024) with the Gumbel & Weibull model, and found a rise of 0.14-0.27 cm/year with a potential increase in elevation of up to 2.44 meters by 2100. This value is very important for adjusting the elevation of the pier plan and the port hinterland area.Hidayat et al., (2024) Then showed that the maximum wave height on the east coast of Tarakan reached 2.10 meters with a period of 7.63 seconds, and that the breaking wave height was 1.69 meters at a depth of 4 meters, using the 1984 SPM method and ECMWF data. These findings provide important hydrodynamic parameters that are comparable to those of Tanah Kuning waters.

Previous studies generally place topography as part of a broader coastal study, along with bathymetry and oceanographic parameters, so that the initial evaluation of port land readiness has not been discussed specifically. On the other hand, the application of Total Station and UAV integration to produce detailed DTM-based topographic data as a basis for classifying port land feasibility remains limited, especially in developing strategic areas such as Tanah Kuning. Therefore, this study offers a novel, integrated, topographic data-based approach to port land readiness evaluation, analyzing slope gradient, elevation relative to HHWL, and land use conditions to determine priority zones for port land facility development.

Research Method

Research Location

This research was conducted in the planned Tanah Kuning Port area, which is administratively located in Tanah Kuning Village, Tanjung Palas Timur District, Bulungan Regency, North Kalimantan Province. This area is one of Indonesia's strategic coastal areas included in the Tanah Kuning-Mangkupadi International Port and Industrial Zone (KIPI) project. Functionally, this area is designed as a Regional Feeder Port to facilitate the movement of industrial commodities to other ports. (Saryati & Al Amrie, 2023). This condition makes the Tanah Kuning area highly potential as an industrial logistics hub, but at the same time requires an initial land-readiness study before the port's technical design is prepared.

In this study, the study area comprised 3 locations on the same coastline, each with a land area of 3 ha. The determination of the study location and land area is based on the Technical Guidelines for the Preparation of Port Development Feasibility Studies (Directorate General of Sea Transportation (DJPLP), 2019) and the National Port Master Plan (Kementerian Perhubungan Republik Indonesia, 2017). Location 1 is indicated by coordinates E (Easting) 590883.191 meters and N (Northing) 287891.288 meters. Location 2 is indicated by coordinates E 591927.000 meters and N 287202.000 meters. Location 3 is indicated by coordinates E 591420.329 meters and N 287726.109 meters. To facilitate the analysis, the UTM (Universal Transverse Mercator) coordinate system with zone 50N is used. The visualization of the research location is shown in Figure 1.

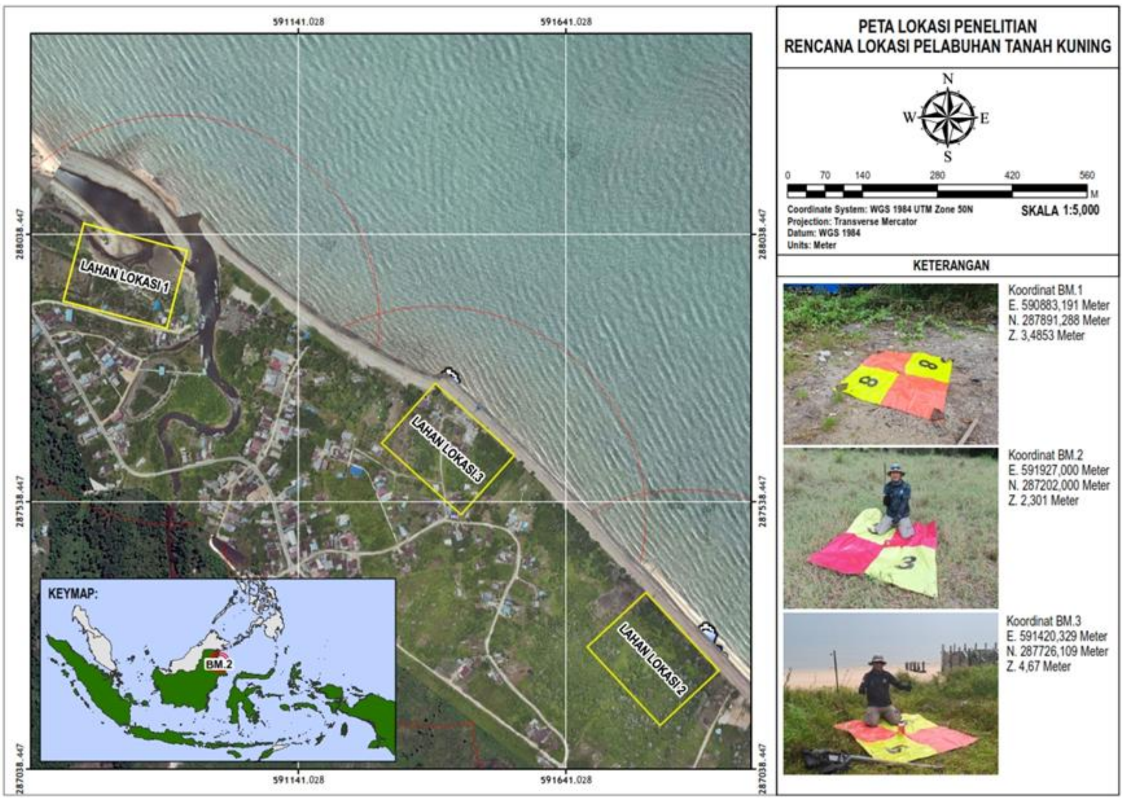

Figure 1. Map of the Tanah Kuning Port Plan Research Location

The map in Figure 1 shows three research locations along the Tanah Kuning coastline in Bulungan Regency. These three locations represent land topography measurement areas that serve as the basis for analyzing port land readiness. Each location was selected along the same coastline to allow for consistent comparison of land morphology conditions.

Land Readiness Assessment Analysis Method (Topographic Aspect)

A topographic land-readiness analysis is conducted to assess the physical condition of the land surrounding the planned port site, particularly with respect to slope and potential inundation from high tides. This assessment refers to the Technical Guidelines for Preparing Port Development Feasibility Studies (Kementerian Perhubungan Direktorat Jenderal Perhubungan Laut, 2019), which stipulates that topography is one of the primary criteria in determining the technical feasibility of port land.

The data collection and processing stages used in applying the analysis method are as follows:

1. Field Measurements
   Measurements were conducted at three alternative locations (Locations 1 to 3) using a combination of terrestrial and aerial photogrammetric methods, a Total Station for elevation point measurements and a UAV (drone) for surface image acquisition. This combined approach has proven efficient and accurate for detailed-scale topographic mapping (Utomo et al., 2022, 2023). The combination of these two methods was used to obtain complementary, detailed topographic data: the Total Station provided precise elevation and coordinate control, while the UAV enabled a more comprehensive and efficient spatial representation of the study area's land surface.
2. Digital Terrain Model (DTM) and Contour Creation
   The resulting coordinate data was processed using Agisoft Metashape, ArcMap, and Autodesk Land Desktop to generate a DTM raster and topographic and bathymetric contours at 1.0-meter intervals for major contours and 0.2-meter intervals for minor contours. This model is used to describe variations in land elevation, land slope direction, and the relationship of land elevation to the highest high tide level (HHWL).
3. Land Slope Analysis
   From the DTM data, slope gradients were calculated using the Spatial Analyst Tools in ArcMap. The slope classifications used were 0% - 8% (Flat), >8% - 15% (Gentle Slope), >15% - 25% (Moderately Steep), >25% - 45% (Steep), and >45% (Very Steep).
4. Tidal Inundation Identification
   The contours of each location were then cut into several sections to visualize the land section conditions. These were then plotted against the sea-level analysis results at the highest high water level (HHWL). This was done to determine whether the land was affected by tidal conditions. This analysis used HHWL values from tidal calculations based on ECMWF 2024 data, which had been converted to a local vertical reference system.

A topographic land readiness assessment was conducted using a descriptive-qualitative, rule-based classification method that integrated four main parameters: land slope, protection against the highest high water level (HHWL), land space availability, and land use/settlement conditions. The feasibility categories are based on the KP.227/DJPL/2019 guidelines. However, they are aligned with the slope classes resulting from the GIS analysis used in this study, namely 0-8% (flat), >8-15% (gentle), >15-25% (slightly steep), >25-45% (steep), and >45% (very steep). The final category was determined not by numerical weighting but by the dominance of each location, which best represents the land's technical feasibility for developing port facilities. Scores of 100, 70, 50, 30, and 0 were used as ordinal representations of feasibility levels, not as results of mathematical calculations. The parameters for assessing the readiness of port land plans based on topographic aspects are shown in Table 1.

In this study, the scope of the analysis is limited to land topography as the basis for the initial evaluation of port land readiness. Therefore, the parameters analyzed directly include land elevation, slope gradient, protection from high tides (HHWL), and land use conditions. Aspects of water bathymetry, wave transformation, and projected sea-level rise are not analyzed as primary variables in this article but are instead identified as necessary for further study at a more comprehensive port-planning stage.

Based on the method steps described, all analyses were conducted using land topographic data derived from integrating total station measurements and aerial photogrammetry, all referenced to a single vertical datum. The data processing produced a DTM model and slope maps, which were used to evaluate the land topographic readiness at each study location.

Table 1. Port Land Plan Readiness Assessment Parameters Based on Topographic Aspects

Kondisi Lahan	Kriteria Teknis	Nilai Skor	Keterangan
Very Worthy	The land is dominated by a 0-15% slope (flat-sloping), is quite extensive, lies above the HHWL, and has no active settlements.	100	The land is ideal for port development. It requires no reclamation and only very limited land development.
Worthy	The land is dominated by a slope of 0-25% (flat to slightly steep), is quite extensive, with the majority above the HHWL; there are no active settlements, and only light site grading/cut-and-fill is required in certain areas.	70	The land is suitable for developing port facilities, with limited land preparation required.
Less than worthy	The land has an area of >25% or limited socio-spatial constraints, but flat-sloping zones are available that can be utilized with moderate technical and/or administrative handling.	50	It can be used on a limited basis for support functions, but it is not ideal as a main port area.
Not feasible	The land is dominated by slopes >25% (steep to very steep) and/or contains active settlements, thereby requiring major cut-and-fill work, slope-stability measures, and potential relocation.	30	It is technically and economically inefficient to develop major port facilities.
Large Reclamation	Land is scarce, and development can only be carried out through large-scale coastal reclamation.	0	Not recommended except for long-term needs with very high investigation.

Source: (Kementerian Perhubungan Direktorat Jenderal Perhubungan Laut, 2019)

Results and Discussion

Analysis of Topographic Conditions of Research Land

Topographic condition analysis was conducted using Total Station measurement data and aerial photogrammetry (UAV drone), which were processed to produce a Digital Terrain Model (DTM). The mapping results show that the contours of the Tanah Kuning coastal area exhibit varied land morphology, with slopes ranging from 0% to over 45%. Land slope classification maps are presented in Figures 2, 3, and 4 for each research location. The discussion in this chapter focuses on interpreting land topographic conditions, so the results presented include elevation variations, slope classification, relationships with HHWL, and implications for port land readiness.

Topographic Conditions and Land Readiness of Location 1

Based on the integration of land slope parameters, elevation to HHWL, and land use conditions, Location 1 shows the highest level of technical readiness compared to the other two locations. Morphologically, this land is dominated by flat to slightly steep classes, namely flat (15.66%), sloping (28.81%), and slightly steep (55.52%), with no steep or very steep slopes found. This condition indicates that the need for land preparation work at Location 1 is relatively limited and does not require large-scale slope management.

In terms of elevation, the land surface of Location 1 is in the range of -0.31 m to 2.07 m, while the HHWL is recorded at -0.27 m. The comparison results show that more than 90% of the area lies above the highest tidal elevation, so the zone requiring elevation adjustment is limited to the northeastern part, with elevations ranging from -0.31 m to -0.27 m. Based on this proportion, the area requiring microsite grading can be estimated at less than 10% of the total land area, or, in other words, less than ±0.3 ha of the total 3 ha. Geometrically, the minimum elevation difference required to exceed the HHWL is approximately 0.04 m, although in technical implementation, additional tolerance is still required for operational safety and surface drainage arrangements.

In terms of land use, there are no active settlements within the study area, and the Tanah Kuning Village Government owns the land. This situation reduces socio-administrative barriers and accelerates the potential for land use for port facilities. Considering this combination of conditions, Location 1 is classified as suitable for developing port land facilities. Areas with stable elevations ranging from 0.3 to 2.0 m and slopes of 0 to 25% can be prioritized for land operations, logistics storage areas, and internal routes. While the lowest northeastern portion is more appropriately positioned as a drainage buffer zone or an area that undergoes micro-grading before full utilization.

Overall, the topography of Location 1 is the most favorable among the locations, as it is dominated by flat to moderately steep slopes, lacks steep to very steep zones, has most of its elevation above the highest tide level, and has no active settlements. Although there are a small number of low-lying areas that require elevation adjustments, their impact on land use is generally relatively limited. Therefore, Location 1 is classified in the Feasible category and is recommended as a priority area for port land development with limited land development requirements.

Figure 2. Land Slope Classification Map for Location 1

Topographic Conditions and Land Readiness of Location 2

Mapping results at Location 2 revealed more complex morphological characteristics than those at Location 1, with slopes varying from flat to steep. This 3-hectare area is dominated by steep (30.79%) and very steep (55.05%) slopes, while gently sloping to moderately steep areas only comprise approximately 14% of the total land area. The contour pattern shows a steep slope dipping eastward toward the coastline, with dense 1-meter contour intervals in the central-eastern part of the land.

Land elevations ranged from -0.76 meters to 6.89 meters relative to the observation datum, with the HHWL recorded at -0.27 meters and the LLWL at -2.91 meters. Based on a comparison between land elevation and the highest sea level, it was found that areas with elevations below 0 meters (approximately 8-10% of the total area) are potentially inundated during maximum tides, while most areas with elevations above 1 meter remain safe from direct inundation. However, the significant elevation difference (about 7 meters between the lowest and highest points) indicates a significant slope, so slope stability and land surface uniformity are major concerns.

The vegetation in this area is quite dense, consisting of coastal shrubs and small trees, indicating that the soil has not been disturbed by development activities. No permanent settlements were found within the study area, but the land is community-owned, which would necessitate administrative and social adjustments if the area is allocated for port activities.

Technically, the combination of predominantly steep-to-very-steep slopes, inundation zones in low-lying areas, and the need for extensive cut-and-fill for surface leveling results in Site 1 being categorized as Unsuitable. These conditions indicate that this land is unsuitable for developing primary inland port facilities. Therefore, Site 1 is not recommended as a priority area, except for limited uses such as vegetation buffer zones or shoreline conservation.

Figure 3. Land Slope Classification Map for Location 2

Topographic Conditions and Land Readiness of Location 3

Mapping results at Location 3 show complex morphological variations, with a combination of flat areas in the west and steep slopes to the east facing the coast. The 3-hectare study area comprises five slope classes: flat (27.29%), gently sloping (9.27%), moderately steep (7.56%), steep (11.88%), and very steep (44%). The contour pattern shows a decreasing elevation gradient from west to east, with contour lines becoming denser near the coastline, indicating a significant change in elevation along it.

Figure 4. Land Slope Classification Map for Location 3

The land surface elevation ranges from 2.53 to 7.76 meters relative to the observation date, while the highest sea level (HWWL) was recorded at -0.27 meters. This comparison indicates that the entire area of Location 3 is well above the highest tidal elevation, thus preventing flooding during both daily and extreme tides. Topographically, this indicates a very good level of protection from tidal influences and seawater runoff.

However, the slope conditions, dominated by steep to very steep slopes (more than 25%) in the eastern part, render much of the land less suitable for port construction. Furthermore, aerial image interpretation and field observations indicate that this area is an active, community-owned residential zone with medium building density and mixed vegetation, including yard trees. The individual ownership status creates potential social and administrative constraints if this area is used for port development, given the required land acquisition and relocation processes.

Based on the evaluation results, the combination of the predominance of steep to very steep slopes, the presence of active settlements, and the high need for land rezoning places Site 3 in the Unsuitable category for the development of primary port facilities. While the flat-sloping area on the western side can still be considered for limited functions such as non-structural support facilities or land service areas, Site 3 is not recommended as a primary port development zone overall due to the high risk of slope instability and social constraints.

Comparison of Land Readiness Based on Topographic Aspects

The topographic analysis of the three locations revealed quite contrasting morphological characteristics along the Tanah Kuning coast. Generally, the main differences lie in slope distribution, elevation relative to sea level, and existing land-use conditions. All three locations have a relatively similar area, approximately three hectares, but their land readiness levels differ significantly due to variations in contour shapes and surrounding socio-environmental conditions.

In terms of land slope, Location 1 is characterized by relatively gentle to moderately steep coastal slopes, with a maximum gradient of approximately 25%. This condition makes the area ideal for dry port development due to its stable contours and minimal need for land preparation. Conversely, Location 2 exhibits a predominance of steep to very steep slopes (25-45% and >45%), which can pose slope stability issues and require large-scale cut-and-fill and reclamation work. Location 3 has a transitional condition, with the western side being flat and gently sloping, while the eastern side is steep to very steep. Therefore, in terms of morphology, the topographic readiness rankings are Location 1 (highest), followed by Location 3, and finally Location 2.

In terms of tidal protection, the three locations exhibit distinct characteristics. Location 1 has a land elevation ranging from -0.31 m to 2.07 m, with a small portion of the eastern area slightly below the highest tide level (-0.27 m). This means the area only requires micro-grading to ensure the entire land is free of flooding. Location 2, with an elevation range of -0.76 m to 6.89 m, has a small area inundated at high tide. However, its steep topography allows rapid runoff to the coast, making it unsuitable for construction. Location 3 is at a much higher elevation (2.53m –7.76 m) and is completely protected from tidal influences, making it the site with the best protection against sea-level fluctuations.

In terms of land use and ownership status, socio-spatial conditions also influence the level of technical readiness. Location 1 is located on land owned by the Tanah Kuning Village Government and contains no active settlements, thus requiring no complex relocation or land acquisition processes. Location 2 is located on densely vegetated community land with no buildings. Therefore, even without physical obstacles, administrative steps are still required to convert the land. Meanwhile, Location 3 is an active residential area with medium building density, making it the highest social risk if allocated for port activities.

Based on the integration of land slope, tidal protection, and land use conditions, it can be concluded that:

1. Location 1 is categorized as Feasible, with the most stable morphological conditions, free of active settlements, and requiring only limited elevation adjustments.
2. Location 2 is categorized as Not Feasible because it is dominated by steep to very steep slopes and requires extensive land preparation work.
3. Location 3 is categorized as Not Feasible, primarily due to the combination of steep to very steep slopes and the presence of active settlements.

These results confirm that Location 1 is the most promising alternative for developing the Tanah Kuning dry port. In contrast, Locations 2 and 3 are more suitable for limited, non-structural functions or buffer zones.

Conclusion

This study shows that topographic aspects play an important role in determining the level of land readiness for port development in the coastal area of Tanah Kuning. Based on the analysis of three research locations, it was found that Location 1 has the most stable land conditions with a dominant slope of 0-25%, the majority of elevations are above the highest tide level, and there are no active settlements, so it is categorized as suitable for inland port development. In contrast, Locations 2 and 3 have limitations, including a predominance of steep and very steep slopes and significant socio-land factors, and are therefore categorized as Not Suitable for major infrastructure development. Scientifically, this study shows that integrating Total Station and UAV data can serve as an effective initial evaluation approach for inland port land readiness, leveraging detailed topographic data, particularly to support the selection of priority zones for development in strategic coastal areas.

Based on the topographic evaluation results and field conditions, Location 1 is recommended as the primary site for developing land facilities at Tanah Kuning Port, particularly for the operational zone, logistics storage area, and internal land access routes. The technical intervention required at this location is relatively limited, namely micro-site grading in the northeast zone, where the elevation is still within the range of -0.31 m to -0.27 m, ensuring that the entire area is above the HHWL. Meanwhile, other areas already within the elevation range of 0.3-2.0 m can be prioritized for initial development, as they offer better topographic stability and do not require major cut-and-fill work. Further studies are still needed on geotechnical aspects, soil bearing capacity, and surface drainage design to translate land planning into a more detailed technical planning stage.

Acknowledgments

The authors would like to thank the Lembaga Penelitian dan Pengabdian Masyarakat (Institute for Research and Community Service/LPPM) of Universitas Borneo Tarakan for the funding and research facilities provided, which made this project possible. They also thank the North Kalimantan Provincial Transportation Agency for its cooperation and technical data assistance related to port area planning, which significantly supported the analysis and preparation of this research.

Conflicts of Interest

The authors declare no conflict of interest.

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