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An Integrated Approach of Geographic Information System and Multi-Crite Decision-Making Methods for Optimal Berth Site Selection in Pangandaran, Indonesia

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Abstract Indonesia has approximately 500 navigable rivers, yet their utilization as Inland Waterway Transport (IWT) routes remains minimal. One promising IWT potential lies in the Citanduy River, Pangandaran Regency, West Java, which holds historical significance, vital functions for the local community, and tourism opportunities. This study aims to determine the optimal location for IWT docks using a comprehensive multimodal parameter-based approach encompassing spatial, infrastructural, economic, social, environmental, and regulatory aspects. The research process involved four main stages: identifying key parameters, conducting geographic information system (GIS)-based geographical analysis to determine alternative locations, parameter weighting using the Decision-Making Trial and Evaluation Laboratory (DEMATEL), and ranking with the Measurement Alternatives and Ranking According to the Compromise Solution (MARCOS) and Root Assessment Method (RAM). The analysis identified dominant parameters such as alignment with spatial planning, road accessibility, land cost, land use, and road width. Additional parameters included elevation, slope degree, landslide risk, flood risk, water depth, and sediment conditions. The geospatial analysis evaluated six potential IWT locations alongside three existing docks to determine the best dock location. MARCOS and RAM methods, known for their robustness in multi-criteria decision analysis (MCDA), ranked the locations based on established criteria. The study recommends three optimal dock locations: IWT-6, IWT-1, and IWT-4, which scored highest in technical and strategic terms. This research provides critical guidance for developing sustainable waterway transport infrastructure in Pangandaran Regency, promoting the local economy, transportation efficiency, and tourism potential. Additionally, it highlights opportunities for creating similar IWT systems in other Indonesian regions with strategic river potential.

Keywords Inland Waterway Transportation, Geographic Information System, MCDM, Site Selection

1. Introduction

Inland Waterway Transportation (IWT) is recognized as sustainable transportation that plays an important role in all aspects of development, including economic, social, and environmental aspects [1]. IWT stands out due to its unique characteristics compared to other modes of transportation, such as higher capacity, lower energy consumption, and minimal environmental impact [2], [3]. Additionally, IWT is deeply rooted in local customs and traditions, making it the customary form of transportation used by local communities and has traditional characteristics [4]. IWT has significant potential in Indonesia, with approximately 500 navigable rivers across the country. However, the utilization of rivers as transportation remains limited. An example of IWT in Indonesia can be found on the Citanduy River in Pangandaran Regency, West Java. Here, IWT serves as an essential part of community transportation, evolving over generations to meet the needs of local residents. The boat, also known as "Perahu Compreng", is transportation that ferries passengers from Pangandaran Regency in West Java to Cilacap Regency in Central Java, taking approximately one and a half hours. The Compreng boats are traditional boats without outriggers, belonging to Javanese boat types originating from Cirebon [5]. Therefore, the rich history and significance of IWT not only support the daily activities of the local community but also present the potential opportunity to attract tourists interested in exploring the natural and cultural attractions of Pangandaran Regency, Indonesia. Consequently, the development of IWT infrastructure, particularly the IWT berth in Pangandaran Regency, needs to be done. The government has given its commitment to the framework of the development of the Pangandaran Regency IWT berth by including the Pangandaran Regency IWT berth development program in the Pangandaran Regency Regional Government Work Plan for 2023, as stated in the Regulation Number 48 of 2022. Additionally, the transportation sector has incorporated this project into the traffic safety and road transportation action plan of Central Java province for the period 2023 - 2028.

The development of IWT in Pangandaran Regency, West Java, Indonesia, faces several challenges, including sedimentation problems that prevent ships from operating efficiently [6], [7]. Additionally, the outdated condition of the current berth infrastructure causes delays and inconvenience for passengers, prompting many to switch to longer land routes.

IWT berths must be constructed in suitable locations determined through a comprehensive site selection process. The site selection problem is inherently complex, involving multiple criteria and dimensions such as time, capacity, infrastructure, accessibility, and various geographic, social, and environmental factors. This study comprehensively establishes multimodal parameters (spatiotemporal, infrastructure, economic, social, environmental, and regulatory) from various aspects. To our knowledge, no previous research has combined such a wide range of parameters for determining IWT berth locations.

Some previous studies related to the selection of riverport locations include Nguyen's research on Vietnamese riverports [8], research on the Yangtze River [9], [10], research on the Odra River Waterway [11], Yangzi River research [12], and analysis of selection parameters using The Decision-Making Trial and Evaluation Laboratory (DEMATEL) method [13]. However, these studies have not comprehensively utilised multimodal parameters (spatiotemporal, infrastructure, economic, social, environmental, and regulatory) across various aspects.

In addressing these gaps, this research proposes an integrated method combining Geographic Information System (GIS) analysis with the Multi-Criteria Decision-Making (MCDM) methods. The study begins by identifying potential berth locations using GIS-based spatial analysis. The weighting of these parameters is then performed using the DEMATEL method, which is capable of evaluating complex relationships between factors. Finally, Measurement Alternatives and Ranking According to the Compromise Solution (MARCOS) and the Root Assessment Method (RAM) are employed together for the ranking process, offering a structured and robust approach to prioritizing the identified berth locations.

The selection of the DEMATEL method for parameter weighting is based on its ability to identify complex inter-factor influences, which is particularly important in the context of IWT site selection. Meanwhile, MARCOS and RAM are used to provide a more accurate and stable evaluation in ranking the best sites, as they offer a more efficient multi-criteria approach than conventional methods. In this study, we adopt the advantages of the four-step approach to determine the optimal location of IWT berths, utilising GIS as a tool for site selection that has proven effective in various sectors, such as power plants [14], [15], [16], [17], [18], city park [19], landfill site [20], business location [21], [22], [23], electric vehicle charging stations [24], [25], irrigation [26], highway passenger stations [27], airports [28], and seaports [8], [11], [29].

The main advantage of this combined approach is its ability to evaluate and prioritise the various factors that influence site selection. Compared to traditional methods, which may provide less comprehensive or less robust results, our proposed approach integrates GIS with sophisticated decision-making techniques to provide reliable recommendations for determining optimal berth locations.

This research not only offers insights to optimise river transport in Pangandaran Regency, but also builds a methodology that can be adapted for similar site selection problems in other areas with strategic river potential.

2. Materials and Methods

This research consists of four main sub-stages: Determination of Site Selection Parameters, Analysis of Selection Potential (GIS Analysis), Analysis of Parameter Weighting Calculation, and Ranking Assessment. (Figure 1 shows the steps of the proposed methodology). To support the Ranking Assessment stage, the combination of DEMATEL, MARCOS, and RAM methods was selected. DEMATEL is used to analyze the causal relationships between criteria, ensuring that dependencies and influences among the site selection parameters are accurately captured [30], [31]. MARCOS provides a systematic framework for ranking alternatives based on a compromise solution, allowing for a balanced assessment of the site's potential [32]. Lastly, RAM is employed to aggregate the ranking results and ensure a robust final assessment [33]. The combination of these methods was chosen because of their complementary strengths in addressing the complexity of multicriteria decision-making, making them more suitable for this research compared to other MCDM methods such as AHP or TOPSIS, which may not fully account for interdependencies between criteria or provide as effective a ranking mechanism.

2.1. Research Location

The IWT research site is located along a 7 km stretch of the Citanduy River, covering the Kalipucang and Pamotan Villages in Kalipucang District, Pangandaran Regency, West Java Province. Astronomically, the site lies between 108°44'57.20" east to 108°48'5.54" east and 7°38'0.15 " south to 7°40'25.40" south. The locus of this research can be seen in Figure 2.

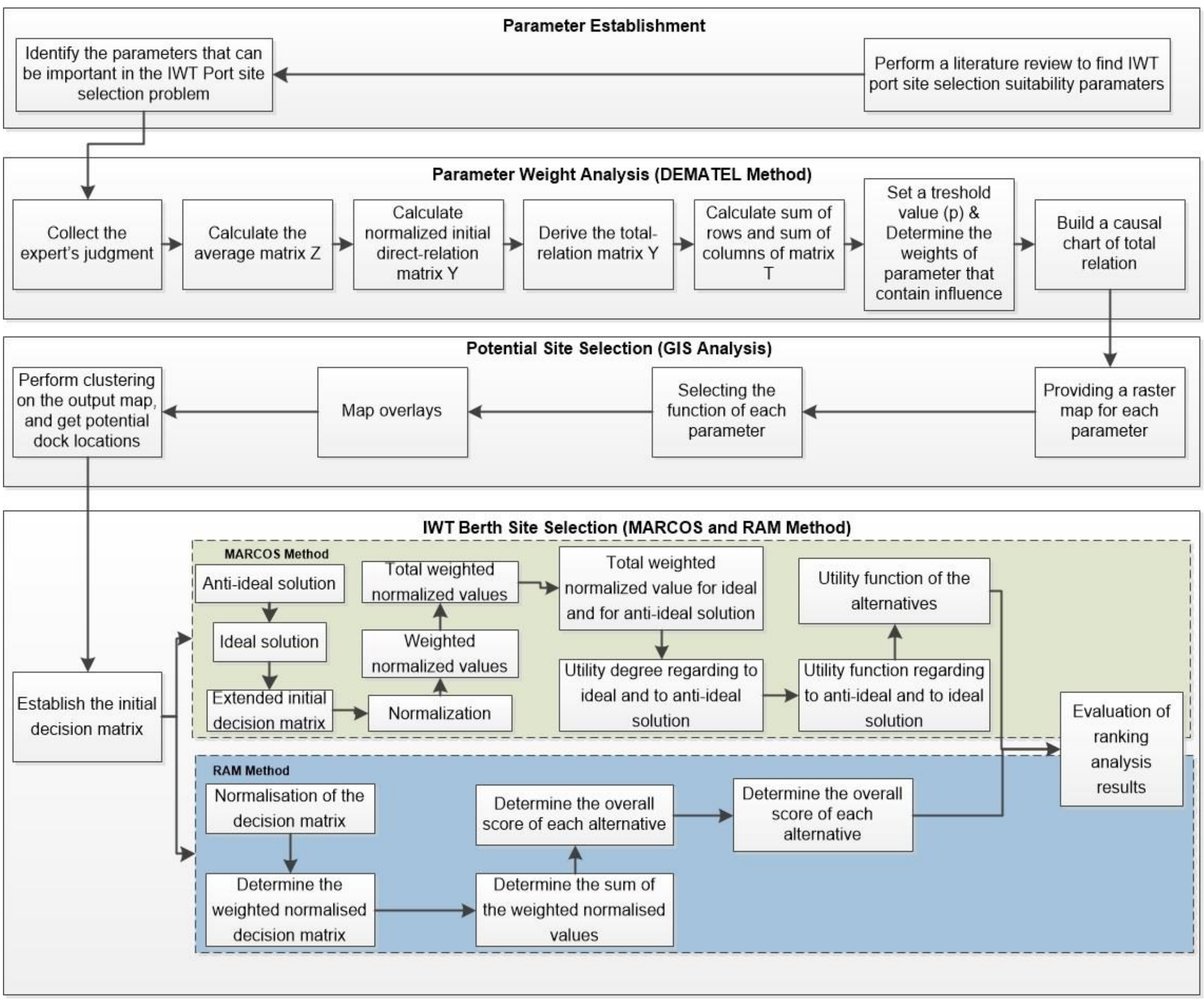


Figure 1. The Proposed Methodology

Figure 2. The Research Site is Located on the West Side of the Citanduy River in Pangandaran Regency, West Java Province

This locations was selected due its strategic potential for Inland Waterway Transport (IWT) development, given the river's significance to local communities, historical value, and tourism potential. The area allows for a thorough study of IWT infrastructure, factoring in environmental, economic, social, and regulatory aspects.

Pangandaran Regency, with a population of 431,46 thousand in 2023, has a higher life expectancy (74.88 years) compared to the national average, though its population (0.67%) and human development index (70.57) remain below national figures. The regency's economic growth rate of 5.26% surpasses, both provincial and national growth rates [34], [35], [36].

2.2. Determination of the Site Selection Parameters

As described above, this study's objective is to select an IWT berth location based on a comprehensive set of parameters. The parameters were defined and classified in the first step based on a systematic literature review of previous research, as in (Table 1). The parameters identified in this study are described in full below.

The parameters used in this study's MCDM approach are quantitative. Quantitative parameters can generally be divided into two types of characteristics, as shown in the Table 1 column characteristics, namely cost characteristics and benefit characteristics [37], [38].

2.3. Analysis Potential Selection (GIS Analysis)

Potential site selection was analysed using GIS through the multi-criteria classification overlay method in the second step. The parameters used were elevation (P1), degree of slope (P2), landslide risk (P3), flood risk (P4), land use (P5), and road accessibility (P6) as listed in (Table 1). The following are the stages in determining the parameters for determining potential IWT locations.

Table 1. IWT Berth Site Selection Parameters

Parameters	P	Value - Score	Characteristics	Source
Elevation	P1	2,5 – 4 (m) Profitable – 3; 1,5 – 2,5 (m) Somewhat Favorable – 2; 0,5 – 1,5 (m) Harmful – 1	Benefit	[8], [29]
Degree of Slope	P2	<1 Level – 5; 1 – 3 Very Gentle Slope – 4; 3 – 5 Gentle Slope – 3; 5 – 10 Moderate Slope – 2; >10 Strong Slope – 1	Benefit	[29], [40]
Landslide Risk	P3	Low – 1; Medium – 2; High - 3	Benefit	[29], [41], [42]
Flood Risk	P4	Low – 1; Medium – 2; High - 3	Benefit	[29], [41]
Land Use	P5	Bare land – 1; Small Cultivated lands – 2; Small urban areas – 2; Major cultivated lands – 3; Major built-up areas – 3	Benefit	[29], [41], [42]
Road Accessibility	P6	Primary Collector Road – 3; Local Road – 2; Other Road – 1	Benefit	[29], [41], [42]
Depth of Water	P7	Using the actual value	Benefit	[43]
Sediment condition of the Waters	P8	Using the actual value	Cost	[43]
River Width	P9	Using the actual value	Benefit	[43]
Road Accessibility Based on Width	P10	Using the actual value	Benefit	[44]
Road Distance to Primary Collector Road	P11	Using the actual value	Cost	[29]
Accessibility Distance to Main Port (km)	P12	Using the actual value	Cost	[45]
Accessibility Distance to Railway Station (km)	P13	Using the actual value	Cost	[45]
Terminal Accessibility (km)	P14	Using the actual value	Cost	[45]
Availability of Clean Water Supply	P15	Available – 3; Available with Notes – 2; Not Available – 1	Benefit	[8], [29]
Availability of Electricity Network	P16			
Land Cost	P17	Using the actual value	Cost	[46], [47]
Potential Demand for Transportation	P18	Location with 5 Activities: 4; Locations with 4 Activities: 3; Locations with 3 Activities: 2; Locations with 2 Activities: 1	Benefit	[46], [48]
Transportation Time	P19	Using the actual value	Cost	[46]
Water Situation and Conditions	P20	No Interference with Water Conditions: 3; There is 1 Type of Disturbance: 2; There are 2 Types of Disturbance	Benefit	[46]
Community Acceptance	P21	Accepted – 2; Not Accepted – 1	Benefit	[3], [49], [50]
Conformity of the Location with the Provincial and or District Spatial Plan	P22	Appropriate – 2; Not Appropriate – 1	Benefit	[44]

2.3.1. Providing a Raster Map for Each Parameter

The parameters used are sourced from primary and secondary data collected, processed, analysed and integrated into the GIS database. The parameter data sources include:

- The 1:25,000 scale digital Rupa Bumi Indonesia (RBI) map was obtained from the Geospatial In-formation Agency (BIG) InaGeoportal. The layers used are the administrative boundary layer to determine the region of interest (ROI) of the study area, the land use layer used to guide digital supervised classification on Landsat 8 OLI images to create factual actual land cover parameters, and the road layer to create road accessibility parameters.
- The 2023 Landsat 8 OLI image obtained through Google Earth Engine was used to obtain factual actual land use cover data.
- USGS global 1 Arc-second SRTM data acquired on the Google Earth Engine platform was used to obtain elevation and slope degree data.

Digital Flood Risk Maps and Landslide Risk Maps of Pangandaraan Regency obtained from InaRisk of the

National Disaster Management Agency (BNPB) were used to obtain flood risk and landslide risk parameters.

2.3.2. Selecting the Function of Each Parameter

Elevation is divided into five classes namely < 1 m, 1 - 2 m, 2 - 3 m, 3 - 4 m and > 4 m where the most potential elevation class as a candidate location is at 3 - 4 m. The data processing results show that the study area's elevation is dominated by elevation classes > 4 m. For slope, it is categorised into 5 classes: < 1 °, 1 - 3 °, 3 - 5 °, 5 - 10 ° and > 10 ° [29], [38].

Landslide risk is reclassified into four classes: no risk, low risk, medium risk and high risk. However, in InaRISK BNPB, the landslide risk of the study area only contains low, medium-high classes [29], [37]. Landslide risk reclassification results show that most of the study area is in the no-risk class and is the most potential landslide risk class for land suitability. Meanwhile, the reclassification of flood risk classes was also categorised into four classes: no risk, low risk, medium risk, and high risk, from 3 classes in BNPB's InaRISK data [29], [37]. The most potential flood risk class for land suitability is the no flood risk class, which dominates the study area.

Actual land use is categorised into four classes: bare land, small cultivated land and urban areas, main cultivated land and urban areas, and water bodies where bare land is the most potential land use type for land suitability [8], [29], [38]. Digital land use classification refers to SNI 7645: 2010 concerning Land Cover Classification, which refers to the Land Cover Classification System of the United Nations Food and Agriculture Organization (LCCS-UNFAO), which is then re-classified into the 4 classes above [39].

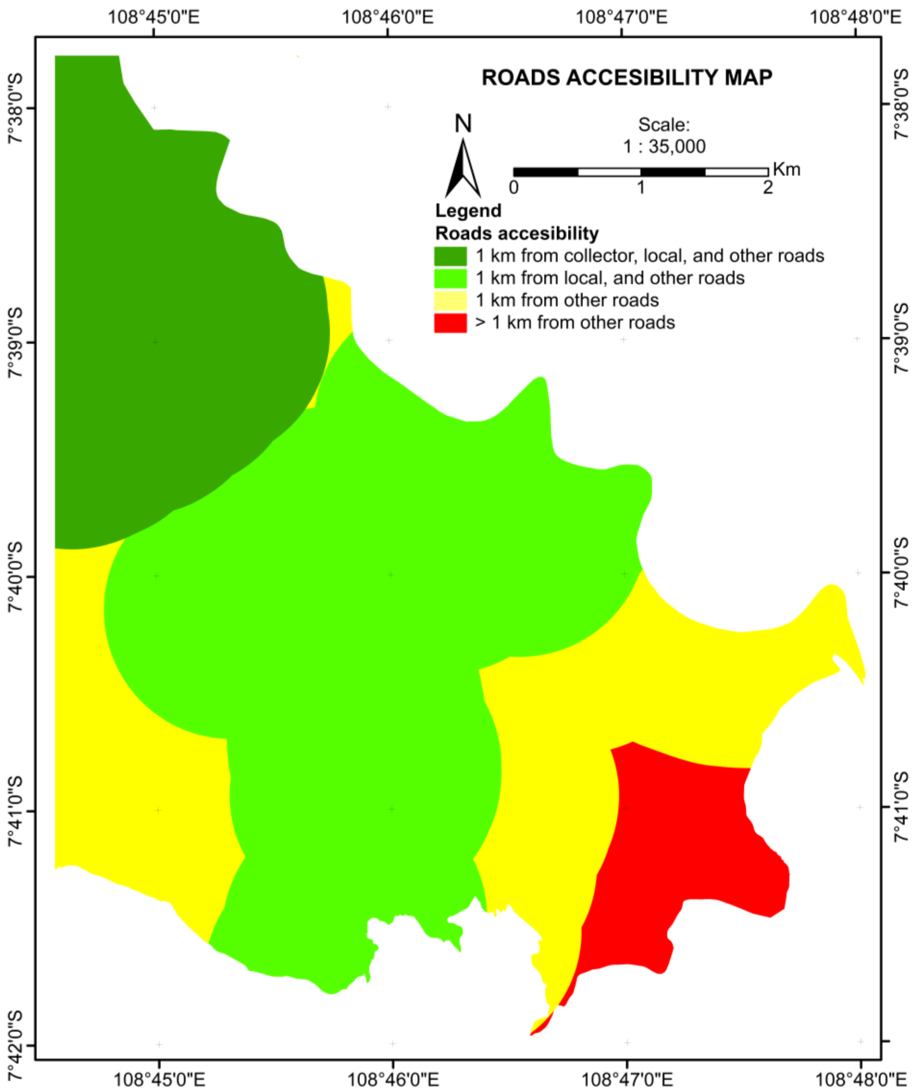
Meanwhile, the road accessibility parameter is derived from road data that is buffered on the class of collector roads, local roads and other roads with a width of 1 km. The classification results are grouped into 4 classes, namely 1 km from collector roads, 1 km from local roads, 1 km from other roads and > 1 km from all types of roads, where the road accessibility class of 1 km from collector roads is the most potential [29], [37]. The results of the road accessibility analysis show that the class 1 km from other roads is the most dominant class in the study area. (Figure 3) shows the results of the six-parameters processing and analysis for site selection of potential IWT locations in the research locus. Meanwhile, the road accessibility parameter is derived from road data that is buffered on the class of collector roads, local roads and other roads with a width of 1 km. The classification results are grouped into 4 classes, namely 1 km from collector roads, 1 km from local roads, 1 km from other roads and > 1 km from all types of roads, where the road accessibility class of 1 km from collector roads is the most potential [29], [37]. The results of the road accessibility analysis show that the class 1 km from other roads is the most dominant class in the study area. (Figure 3) shows the results of the six-parameters processing and analysis for site selection of potential IWT locations in the research locus [29], [37].

2.3.3. Map Overlays

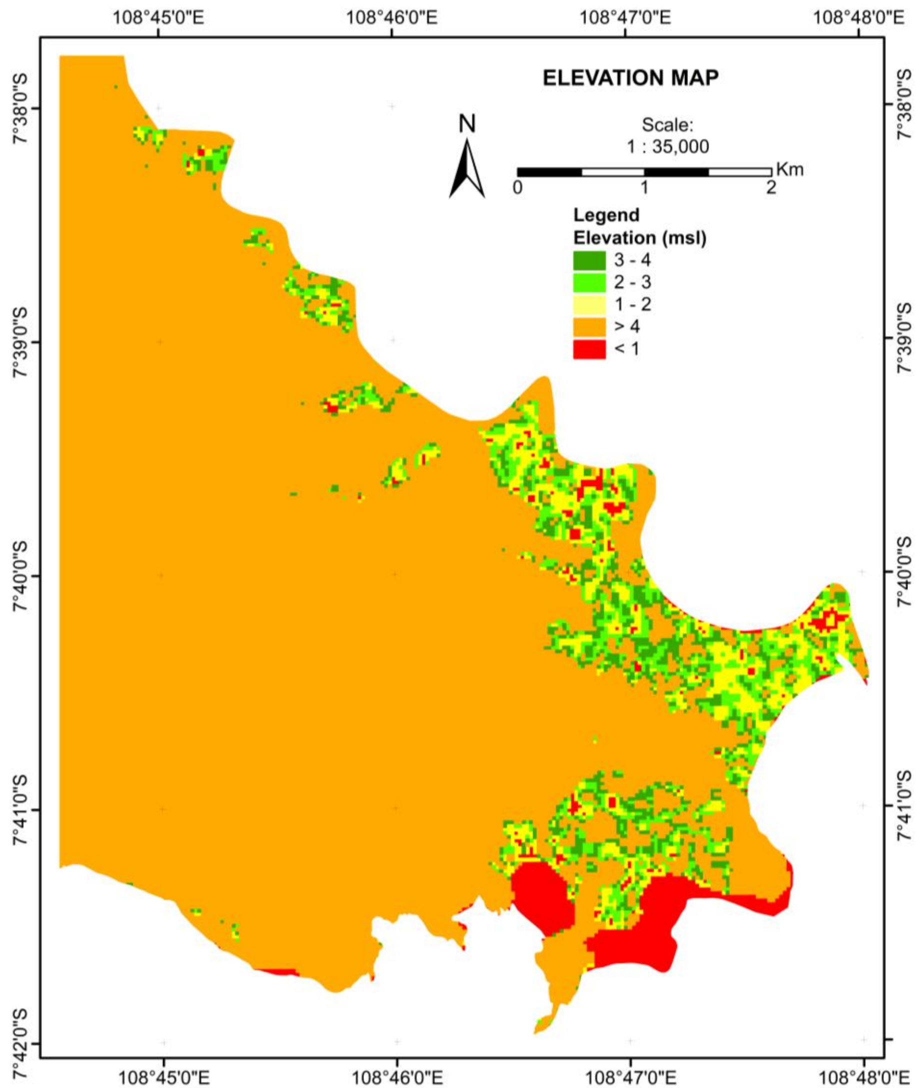
An overlay is performed on these six parameters to obtain the land suitability for the IWT location. The overlay score is obtained by summing each parameter. The elevation and altitude parameters are scored from 1 to 5 classes, while the landslide risk, flood risk, land use, and road accessibility parameters are scored from 1 to 4 classes. The elevation and altitude parameters have higher scores than the others as they are the dominant factors in determining the potential IWT locations.

The overlay results using the intersect method show a final score range between 7 and 20, based on a minimum-maximum score range of 6 to 26. Land suitability classes are determined using a quartile division, where the final scores are ranked from minimum to maximum values and then divided into three classes, each with an equal number of entries [51], [52]. The IWT location's land suitability classes are categorized into suitable, moderately suitable, and not suitable, with score ranges of 6–11, 11–13, and 13–20, respectively.

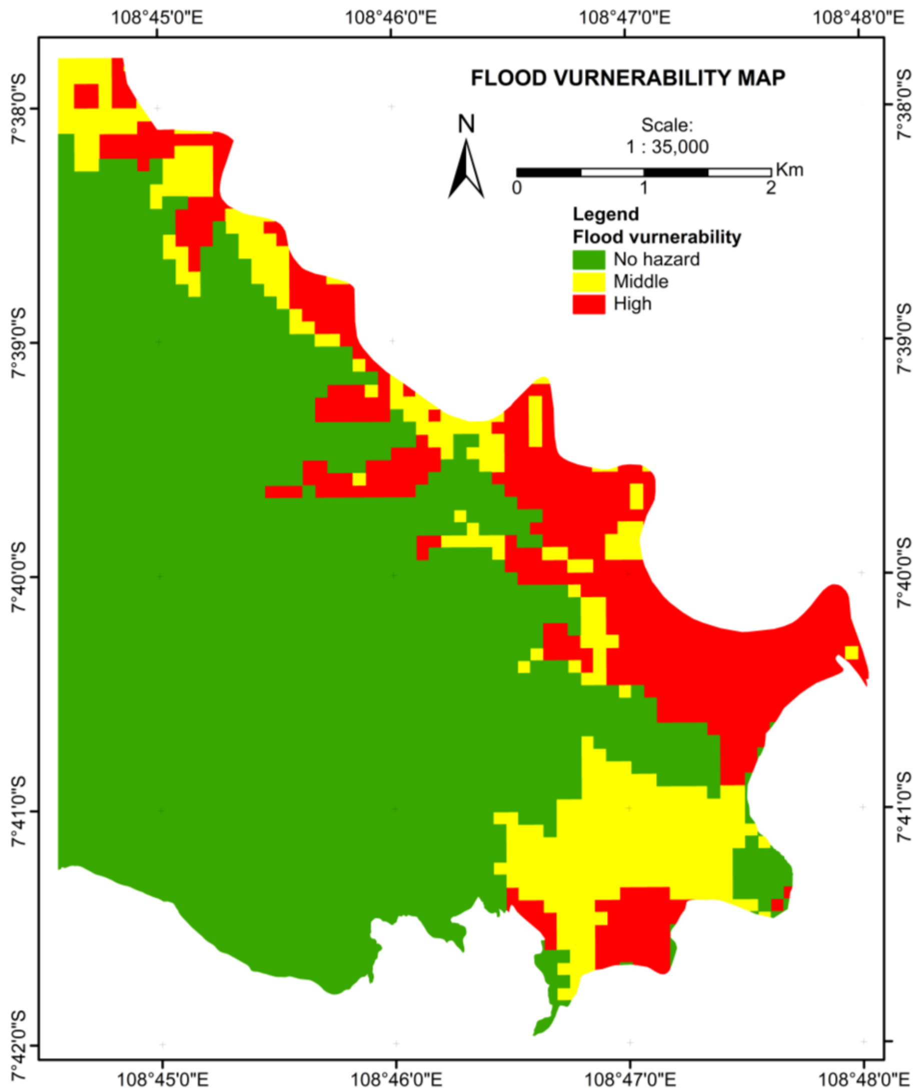
The land suitability results indicate that the 'suitable' class covers the largest area, accounting for 36.68% of the total region, followed by the 'not suitable' and 'moderately suitable' classes, which cover almost equal areas of 31.68% and 31.63%, respectively. Although the classification used a quartile system dividing the data into three equally sized groups, the 'suitable' class has a larger coverage than the others due to the varying sizes of each polygon. As a result, polygons with larger areas accumulate more coverage in the cumulative calculation. The land suitability for the IWT location is illustrated in (Figure 4), where green represents the suitable class, yellow represents the moderately suitable class, and red represents the unsuitable class.


ROADS ACCESIBILITY MAP
N
Scale:
1 : 35,000
Km
0
1
2
Legend
Roads accesibility
1 km from collector, local, and other roads
1 km from local, and other roads
1 km from other roads
> 1 km from other roads
108°45'0"E
108°46'0"E
108°47'0"E
108°48'0"E
7°38'0"S
7°39'0"S
7°40'0"S
7°41'0"S
7°42'0"S

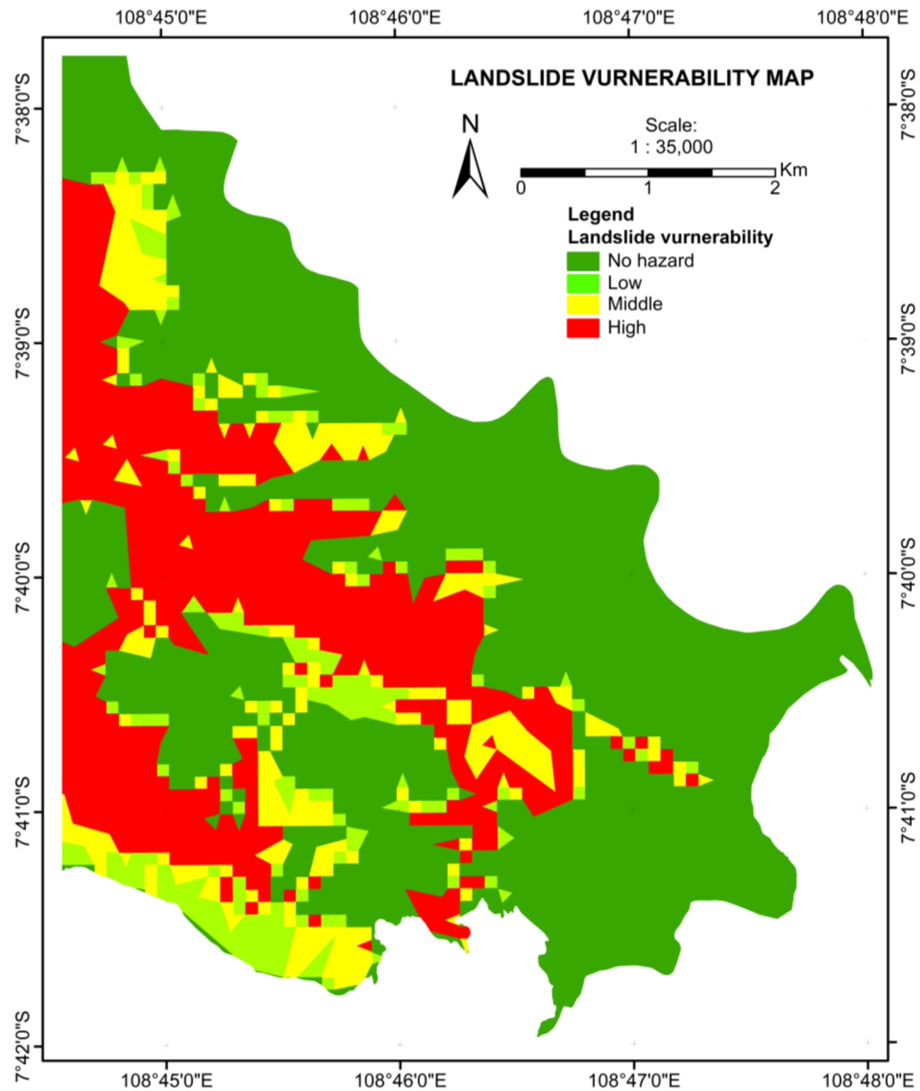
(a)


ELEVATION MAP
N
Scale:
1 : 35,000
Km
0
1
2
Legend
Elevation (msl)
3 - 4
2 - 3
1 - 2
> 4
< 1
108°45'0"E
108°46'0"E
108°47'0"E
108°48'0"E
7°38'0"S
7°39'0"S
7°40'0"S
7°41'0"S
7°42'0"S

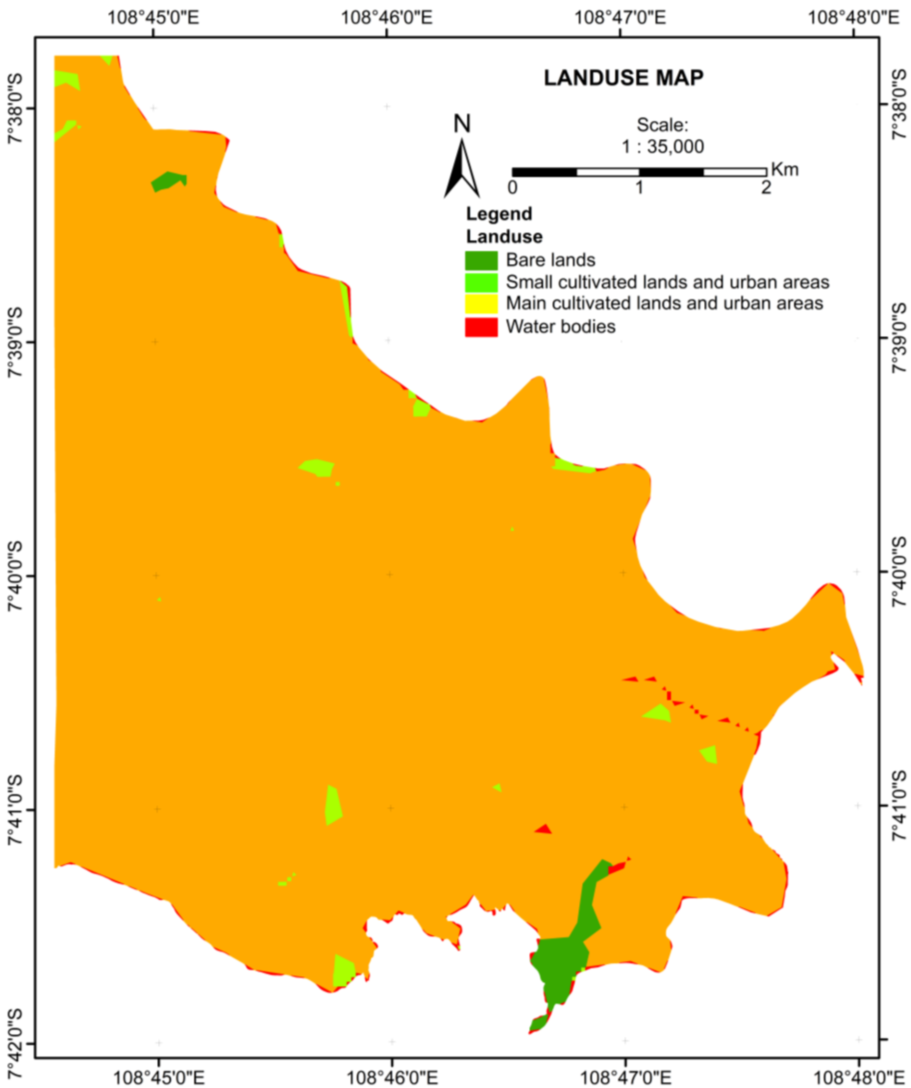
(b)


FLOOD VURNERABILITY MAP
N
Scale:
1 : 35,000
0 1 2 Km
Legend
Flood vurnerability
No hazard
Middle
High
108°45'0"E
108°46'0"E
108°47'0"E
108°48'0"E
7°38'0"S
7°39'0"S
7°40'0"S
7°41'0"S
7°42'0"S

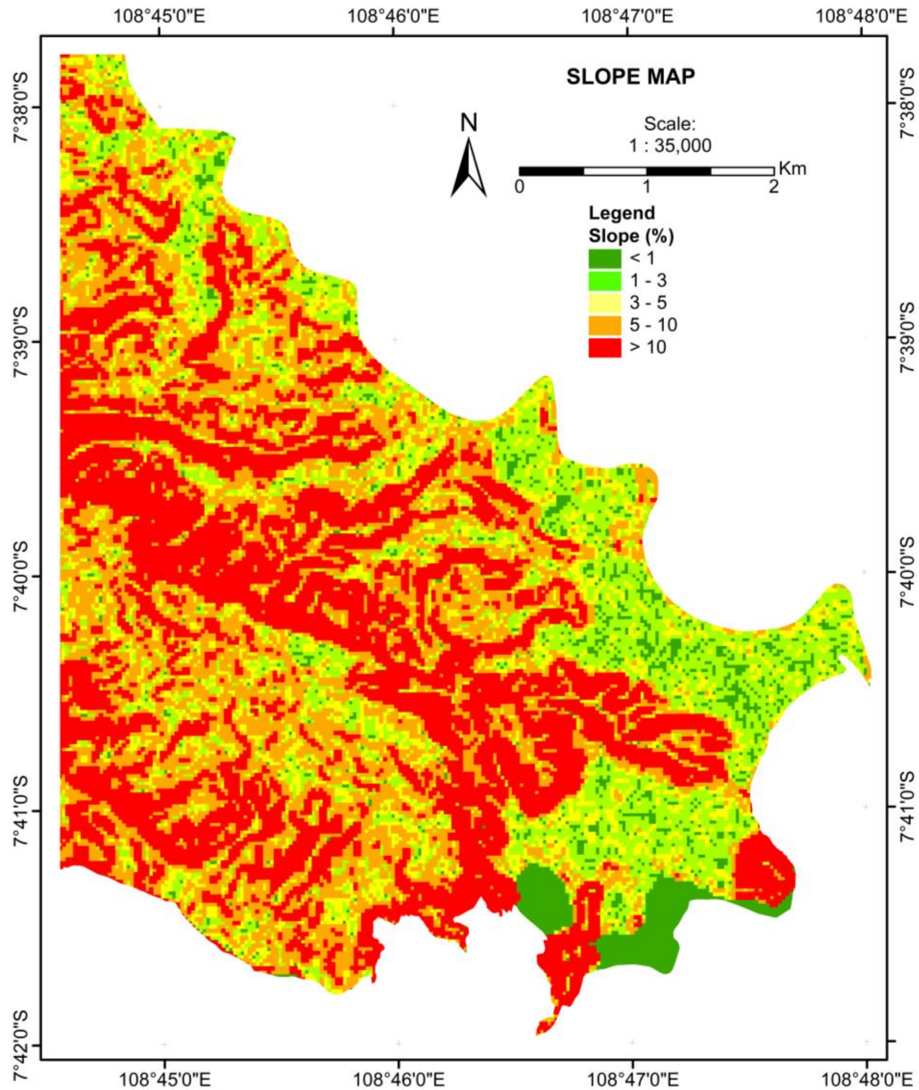
(c)


LANDSLIDE VURNERABILITY MAP
N
Scale:
1 : 35,000
0 1 2 Km
Legend
Landslide vurnerability
No hazard
Low
Middle
High
108°45'0"E
108°46'0"E
108°47'0"E
108°48'0"E
7°38'0"S
7°39'0"S
7°40'0"S
7°41'0"S
7°42'0"S

(d)



(e)



(f)

Figure 3. Site Selection Parameters consist of (a) road accessibility, (b) elevation, (c) flood vulnerability, (d) landslide vulnerability, (3) land use, and (f) slope. Those colors which are described by dark green, light green, yellow, orange as well as red represent their score namely very high (5), high (4), medium (3), low (2), very low (1), respectively

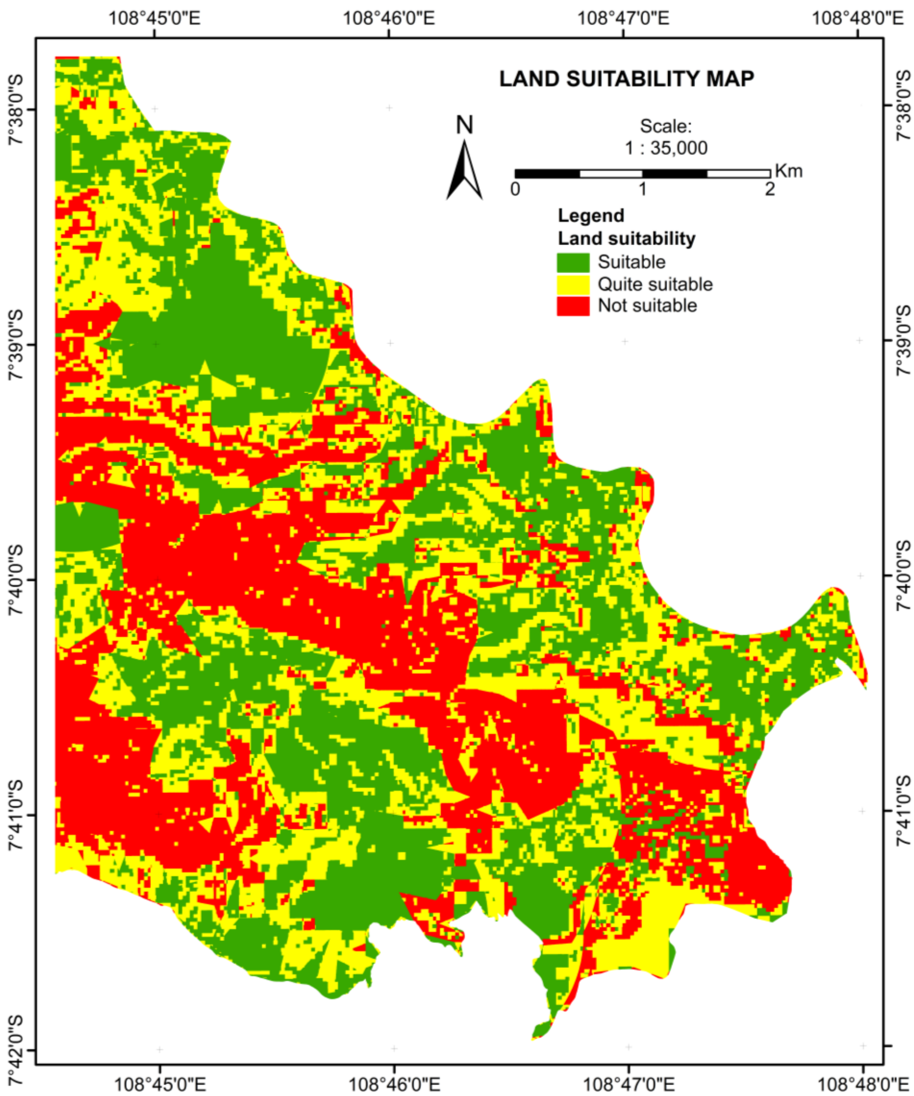


Figure 4. Land Suitability of Inland Water Transport Based on Site Selection Parameters

2.4. Parameter Weighting Calculation Analysis

The third step weighted parameters using The Decision-Making Trial and Evaluation Laboratory (DEMATEL) method. The DEMATEL method was developed by Battelle Memorial Institute, Geneva between 1972 and 1979 [52], [53]. The DEMATEL method is based on matrix theory, an extension of the analytic hierarchy process (AHP) method [54]. The DEMATEL method is a method to analyze and establish causal relationships between parameters [13], [51], [52]. The DEMATEL method process is outlined in 7 steps, among others.

1. **Stage 1.** Gathering Expert Opinions

The experts collected consisted of 6 (six) experts in shipping, port, and policy who were asked to determine the value of the influence of the level of importance between one parameter and another in determining the location of the Inland Water Transportation (IWT) crossing pier.

In conducting the assessment, a five-level comparison scale was used, namely 0 (no influence), 1 (low influence), 2 (moderate influence), 3 (high influence), and 4 (very high influence). Then, the measurement of the relationship between parameters using this scale is carried out in the form of an $n \ x \ n$ pairwise comparison matrix, as in Equation (1).

$$X^k = [x_{ij}^k] \quad (1)$$

Where k is the total number of experts.

2. **Stage 2.** Determine the Average Matrix Z.

All the results of the expert's assessment were calculated as the average matrix $Z = [z_{ij}]$ as in Equation (2).

$$Z_{ij} = \frac{1}{m} \sum_{i=1}^{m} x_{ij}^k \quad (2)$$

3. **Stage 3.** Determine the Initial Normalized Direct Relationship Matrix Y.

The normalized initial direct relationship matrix $Y =$

$[y_{ij}]$ is obtained using Equations (3) to (4). Each element of the matrix Y lies between [0,1].

$$Y = \lambda * Z \quad (3)$$

$$[y_{ij}]_{nxn} = \lambda \ [z_{ij}]_{nxn} \quad (4)$$

$$\lambda = Min \ \left[\frac{1}{\max 1 \le i \le n \ \sum_{i=1}^{n}[z_{ij}]}, \frac{1}{\max 1 \le i \le n \ \sum_{i=1}^{n}[z_{ij}]}\right] \quad (5)$$

Equation (6) is Markov chain Theory Y^m.

$$\lim_{m \to \infty} Y^m = [0]_{nxn} \quad (6)$$

4. **Stage 4.** Drive the Total Relation Matrix T.

The overall relation matrix T is attained by Equation (7), where I represents the identity matrix.

$$T = Y \ (1 - Y)^{-1} \quad (7)$$

5. **Stage 5.** Compute the Sum of the Rows and Columns of matrix T.

The number of D rows and the number of R columns of the total relation matrix can be obtained using Equations (8), (9), and (10).

$$T = [t_{ij}] \ (i, j = 1, 2, \ldots, n) \quad (8)$$

$$D = (D_i)\left(\sum_{j=1}^{n} t_{ij}\right) \quad (9)$$

$$R = (R_i)\left(\sum_{i=1}^{n} t_{ij}\right) \quad (10)$$

6. **Stage 6.** Set a Threshold Value (p) and Determine the Weights of Parameters that Contain Influence.

A value of threshold (p) is established in the T matrix to obtain the total correlation. Equation (11) generates the weight vector $w = (w1, w2, \ldots, wn)$ for the evaluation criteria.

$$w = \frac{\sqrt{(r_j + d_j)^2 + (r_j + d_j)^2}}{\sum_{j=1}^{N}\sqrt{(r_j + d_j)^2 + (r_j - d_j)^2}} \quad (11)$$

2.5. Ranked Assessments

In this method, each alternative location is subjected to ranking analysis. The ranking analysis will use the DEMATEL-MARCOS and DEMATEL-RAM methods. The following are the steps of these methods.

2.5.1. Measurement Alternative and Ranking According to Compromise Solution (MARCOS) Method

The MARCOS method was developed by Stević et al. in 2020 [54], [55], [56], [57], [58], and has been acknowledged for its robustness and stability in multi-criteria decision-making (MCDM) analysis [57], [58], [59]. MARCOS compares alternatives with both the ideal (best case) and anti ideal (worst case) solutions, which helps ensure a balanced evaluation of alternatives. The steps of the MARCOS method are as follows [57], [58], [59], [60]:

1. **Stage 1.** Establish the initial decision matrix. The decision matrix X is created where each element x_{ij} represents the performance of alternative I with respect to criterion j:

$$X = \begin{bmatrix} X_{11} & \cdots & X_{1n} \\ \vdots & \ddots & \vdots \\ X_{m1} & \cdots & X_{mn} \end{bmatrix} \quad (12)$$

2. **Stage 2.** Determine the ideal and anti-ideal solution. The ideal solution x_{gj} is the best value for each criterion, and the anti ideal solution x_{agj} is the worst value:

$$x_{gj} = \begin{cases} j \in benefit \ \Rightarrow \ \max_j \ x_{ij} \\ \{ \ j \in cost \ \Rightarrow \ \min_j \ x_{ij} \end{cases} \quad (13)$$

$$x_{agj} = \begin{cases} j \in benefit \ \Rightarrow \ \min_j \ x_{ij} \\ \{ \ j \in cost \ \Rightarrow \ \max_j \ x_{ij} \end{cases} \quad (14)$$

3. **Stage 3.** Normalization. The decision matrix is normalized by comparing each alternative to the ideal and anti ideal solutions. For benefit criteria, the normalization is calculated as:

$$n_{ij} = \begin{cases} j \in benefit \ \Rightarrow \ \frac{x_{ij}}{x_{gj}} \\ \{ \ j \in cost \ \Rightarrow \ \frac{x_{gj}}{x_{ij}} \end{cases} \quad (15)$$

4. **Stage 4.** Weighted normalized values. The normalized values are then multiplied by their respective criterion weights w_j to obtain the weighted normalized values:

$$v_{ij} = w_j \ n_{ij} \quad (16)$$

5. **Stage 5.** Total weighted normalized value. The total weighted normalized value for each alternative is calculated by summing across all criteria:

$$S_i = \sum_{j=1}^{n} v_{ij} \quad (17)$$

6. **Stage 6.** Utility degree regarding to ideal solution and anti-ideal solution. The total weighted normalized value for the ideal solution S_g and for the anti ideal solution S_{ag} are calculated similarly:

$$S_g = \sum_{j=1}^{n} v_{gj}, \ S_{ag} = \sum_{j=1}^{n} v_{agj} \quad (18)$$

The utility degree of each alternative is determined by comparing it to the anti ideal and ideal solutions:

$$K_i^- = \frac{S_i}{S_{ag}}, \ K_i^+ = \frac{S_i}{S_g} \quad (19)$$

7. **Stage 7.** Final ranking. The alternatives are ranked based on the utility function values:

$$f(K_i) = \frac{K_i^+ + K_i^-}{1 + \frac{1 - f(K_i^+)}{f(K_i^+)} + \frac{1 - f(K_i^-)}{f(K_i^-)}} \quad (20)$$

The alternative with the highest utility value is considered the best choice.

2.5.2. Root Assessment Method (RAM) Method

The RAM (Root Assessment Method) is a new method introduced by Alieza Sotoudeh – Anvari in Moon in September, 2023 [33]. It is particularly advantageous in MCDM as it provides a balance between benefit and cost criteria, ensuring that both are considered fairly in the decision-making process.

The steps involved in the RAM method are as follows:

1. **Stage 1.** Establish the initial decision matrix. As in MARCOS, the decision matrix X is created to represent the performance of alternatives across all criteria.
2. **Stage 2.** Normalize the decision matrix. The decision matrix is normalized to ensure that all criteria are comparable. Normalization is done using the following formula:

$$r_{ij} = \frac{x_{ij}}{\sum_{i=1}^{n} x_{ij}} \quad (j = 1,2, \dots, n) \qquad (21)$$

where rij is a normalized rating of the alternative i about the parameter j, and xij denotes the rating of the alternative i about the parameter j.

3. **Stage 3.** Weighted normalized decision matrix. After normalization, each criterion is weighted according to its importance:

$$y_{ij} = r_{ij} w_j \quad (i = 1,2, \dots, m; \ j = 1,2, \dots n) \qquad (22)$$

4. **Stage 4.** Sum of weighted normalized value. The total score for each alternative is calculated by summing the weighted normalized values across all criteria:

$$S_i = \sum_{j=1}^{n} y_{ij} \qquad (23)$$

5. **Stage 5.** Benefit and cost criteria. To ensure that both benefit and cost criteria are appropriately balanced, the RAM method calculates separate sums for benefit and cost criteria:

$$S_{+i} = \sum_{j=1}^{n} y_{+ij} \, (benefit), S_{-i} = \sum_{j=1}^{n} y_{-ij} \ \ (cost) \qquad (24)$$

6. **Stage 6.** Final ranking. The overall score for each alternative is determined using the root formula, which balances the benefit and cost values:

$$RI_i = \sqrt[2+S_{-1}]{2 + S_{+1}} \qquad (25)$$

The alternative with the highest RI_i value is ranked first.

By incorporating both benefit and cost considerations, the RAM method provides a comprehensive evaluation of alternatives, ensuring that decisions are made based on the overall impact of all criteria.

2.6. Evaluation of Ranking Result

Different decision-ranking methods often produce varying levels of similarity in the rankings of alternatives within a decision matrix. To systematically evaluate the consistency and agreement between these methods, we employed Kendall's Tau and Spearman Rank Correlation in this study. These two non-parametric measures assessed the correlation between the rankings produced by the two decision-making approaches, RAM and MARCOS. A strong correlation coefficient between these ranking scores provides valuable confirmation of agreement and serves as a global method for comparing decision outcomes in practical applications [61].

Kendall's Tau is a non-parametric statistic that measures the strength and direction of the association between two ranked variables, particularly when the data do not meet the assumptions required for parametric tests, such as normality or linearity. It evaluates the correspondence between two rankings by considering the number of concordant and discordant pairs; a pair of observations is considered concordant if the rank order is the same in both sets and discordant if the order differs.

Spearman's Rank Correlation Coefficient is another non-parametric measure that assesses the strength and direction of the association between two ranked variables. Both Kendall's Tau and Spearman's Rank Correlation were selected for their robustness in handling non-parametric data and their effectiveness in measuring associations between ranked datasets. These methods are particularly suitable in decision-making contexts where data are ordinal and the primary focus is on the agreement between different ranking methodologies.

3. Result and Discussion

3.1. Parameter Weights Determination

Following the procedure of the DEMATEL method, seven experts prepared a questionnaire based on the identified parameters for pairwise comparison to assess the direct relationship between parameters (Table 2).

Table 2. Profile of Experts

Experts	Degree	Field	Yrs Exp.
1	Master of Geoinformation Science and Earth Observation	Remote Sensing and Geographic Information Science for Natural Resources Management	>15
2	Doctor of Marine Technology	Maritime expert	>30
3	Master of Science	Marine Technology	>13
4	Master of Marine Technology	Marine Remote Sensing and GIS	>10
5	Master of Science	Capture Fisheries	>10
6	PhD, Department of Environmental Science	Environmental expert	>20
7	Master of Marine Environmental	Applied Oceanography	>15

The experts evaluated the relationship between the parameters using a five-point Likert scale. Each expert's evaluation results were used to form a matrix using Equation (1). Next, the average of the Z matrix was calculated using Equation (2). The DEMATEL method at this stage is used to obtain the respective weights of each parameter that affects the selection of IWT dock locations. The weighting results, which determine the relationship between parameters, are presented in (Table 3). The $Ri + Ci$ values correspond to factors that indicate the dimensions' significance level. This significance level is also presented with the calculated Wi value, which shows that the most important parameters are Conformity of the location with the Provincial and or District Spatial Plan (P22), Road Accessibility (P6), Land cost (P17), Land use (P5), Road accessibility based on road width (P10). In addition, the $Ri - Ci$ Value is used to determine the effect status of these dimensions. A positive value of $(D - R)$ is part of the causal group, affecting parameters. Meanwhile, a negative value of $(D - R)$ is part of the affected group, meaning other parameters affect the parameter. Based on the results of (Table 3) row 3, parameters that affect other parameters include Elevation (P1), Degree of slope (P2), Landslide risk (P3), Flood risk (P4), Road Accessibility (P6), Depth of water (P7), Sediment condition of the Waters (P8), River Width (P9).

Table 3. Level in Interdependence Between Parameters in IWT Berth Site Selection

Parameters	$D + R$	$D - R$	Weight
P1	7,041	1,114	0,043
P2	7,032	1,271	0,043
P3	7,777	0,949	0,048
P4	7,706	1,04	0,047
P5	8,713	-0,136	0,053
P6	9,21	0,15	0,056
P7	6,112	0,254	0,037
P8	5,812	0,363	0,036
P9	6,297	0,639	0,039
P10	8,095	-0,1	0,05
P11	7,549	-0,139	0,046
P12	7,691	-0,327	0,047
P13	6,598	-0,392	0,04
P14	6,959	-0,234	0,043
P15	5,95	-0,331	0,036
P16	6,074	-0,269	0,037
P17	8,823	-1,232	0,054
P18	7,748	-0,847	0,047
P19	7,935	-0,927	0,049
P20	6,918	-0,157	0,042
P21	7,974	-0,454	0,049
P22	9,411	-0,237	0,058

3.2. Determination of Potential IWT Berth Locations

The IWT locations in Pangandaran include three existing berths: Kalipucang, Pamotan, and Majingklak. Presently, Kalipucang and Majingklak berths remain active, while Pamotan is not operational. Initial analysis indicates that these three berths are not classified as potential locations. However, in the following analysis phase, these berths (Kalipucang, Pamotan, and Majingklak) will serve as alternative sites for IWT berths in a ranking evaluation. (Table 4) provides the coordinates and status of these existing IWT berths.

Table 4. Existing IWT Berths

Existing IWT Berth	Kalipucang	Pamotan	Majingklak
X	108.754525	108.770187	108.800347
Y	-7.639560	-7.654739	-7.674550
Sub-District	Kalipucang	Pamotan	Pamotan
Status	Active	Inactive	Active

Potential locations for the Pangandaran IWT berth were selected through geospatial analysis of the land suitability map, focusing on areas near the riverbank. (Figure 5) displays six potential IWT locations alongside three existing berths, further evaluated and ranked using the MARCOS and RAM methods.

Table 5 shows the coordinates and administrative locations of potential IWTs in the study area. IWT – 1 and IWT – 2 are adjacent to the existing Kalipucang IWT, while IWT – 4 is adjacent to the existing Pamotan IWT. Regarding accessibility, IWT – 1, IWT – 4, and IWT – 6 are located close to the existing road, which has the advantage of being the preferred candidate location for the IWT. Whereas IWT – 2, IWT – 3, and IWT – 5 are a little far from the existing road, additional costs are needed for road construction to facilitate accessibility to the selected IWT location.

3.3. Ranking of Alternative IWT Berth Locations

In this stage, the six potential locations analyzed in section 3.2 and the three existing dock locations are ranked based on the parameters in (Table 1). The total number of alternative locations analyzed for ranking was 9 locations. The parameter values for each potential IWT berth location were determined based on field data, and the results, forming a decision matrix, are shown in Equation (26).

3.3.1. MARCOS Method Ranking Results

After constructing the decision matrix in Equation (26), further analysis was conducted using Equations 12 through 20. The results in Table 6 present the ranking of berth locations based on the MARCOS method. The ranking order generated by this method is as follows: IWT – 6 > IWT – 1 > IWT – 4 > Kalipucang berth > IWT – 2 > IWT – 3 > Majingklak berth > Pamotan berth > IWT – 5.

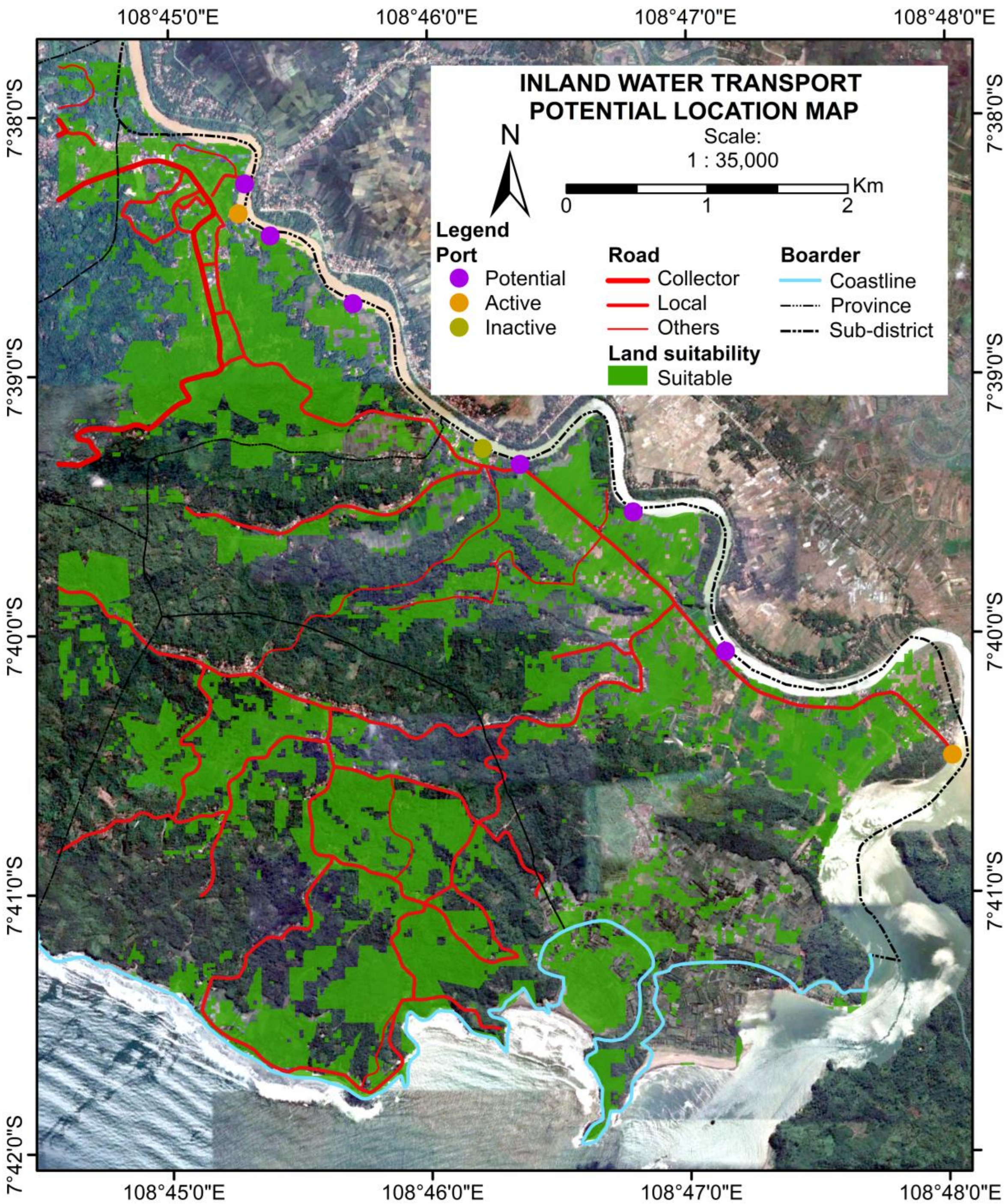


Figure 5. IWT Potential Location in Pangandaran

Table 5. Coordinates of IWT Potential Location

ID	X	Y	Sub-district	District	Region
IWT-1	108.754685	-7.637612	Kalipucang	Kalipucang	Pangandaran
IWT-2	108.761692	-7.645697	Kalipucang	Kalipucang	Pangandaran
IWT-3	108.774089	-7.655918	Pamotan	Kalipucang	Pangandaran
IWT-4	108.776784	-7.653976	Pamotan	Kalipucang	Pangandaran
IWT-5	108.780287	-7.658989	Pamotan	Kalipucang	Pangandaran
IWT-6	108.785408	-7.668065	Pamotan	Kalipucang	Pangandaran

$$X = \begin{bmatrix} 3 & 4 & 4 & 1 & 1 & 4 & 3,9 & 23,5 & 86 & 2,8 & 45 & 36 & 46,4 & 16,9 & 3 & 2 & 500 & 2 & 63 & 2 & 2 & 1 \\ 0 & 5 & 4 & 2 & 1 & 4 & 3,5 & 23,9 & 76,6 & 2,3 & 178 & 35,7 & 46,6 & 16,6 & 3 & 2 & 500 & 2 & 61 & 2 & 2 & 1 \\ 0 & 4 & 4 & 1 & 1 & 4 & 3,0 & 15,7 & 118,52 & 2,4 & 620 & 37,5 & 46,8 & 18,4 & 2 & 2 & 400 & 3 & 60 & 2 & 2 & 1 \\ 0 & 4 & 4 & 2 & 1 & 3 & 4,5 & 14,5 & 63,22 & 4 & 28 & 37,9 & 50,2 & 18,8 & 2 & 1 & 750 & 4 & 55 & 2 & 2 & 1 \\ 1 & 3 & 4 & 1 & 2 & 3 & 5,2 & 23,0 & 73 & 2,5 & 247 & 40,9 & 51,3 & 21,8 & 2 & 2 & 500 & 2 & 51 & 2 & 1 & 1 \\ 3 & 4 & 4 & 1 & 1 & 2 & 4,3 & 28,4 & 93,81 & 4 & 20 & 38,2 & 52 & 19,1 & 2 & 2 & 700 & 4 & 46 & 3 & 2 & 1 \\ 0 & 3 & 4 & 1 & 1 & 4 & 4,2 & 24,3 & 94 & 2,52 & 94 & 35,9 & 46,5 & 16,8 & 3 & 2 & 500 & 2 & 62 & 2 & 2 & 2 \\ 0 & 2 & 4 & 2 & 1 & 3 & 4,5 & 20,3 & 93 & 3,42 & 92 & 37,6 & 49,9 & 18,5 & 2 & 2 & 750 & 3 & 57 & 2 & 2 & 1 \\ 0 & 2 & 4 & 1 & 0 & 2 & 3,5 & 29,8 & 191 & 5,55 & 130 & 40,2 & 54 & 21,1 & 2 & 2 & 700 & 3 & 40 & 3 & 2 & 2 \end{bmatrix} \quad (26)$$

Table 6. Ranking Results of Berth Location Selection Using the MARCOS Method

AI	Si	$Ki-$	$Ki+$	$f(K-)$	$f(K+)$	$f(Ki)$	Rank
Anti-ideal (AAI)	0,4919						
IWT-1	0,74982	1,524333	0,74982	0,329714	0,670286	0,64518	2
IWT-2	0,716206	1,456	0,716206	0,329714	0,670286	0,616258	5
IWT-3	0,702148	1,427419	0,702148	0,329714	0,670286	0,604161	6
IWT-4	0,726434	1,476792	0,726434	0,329714	0,670286	0,625058	3
IWT-5	0,664968	1,351835	0,664968	0,329714	0,670286	0,57217	9
IWT-6	0,771634	1,568679	0,771634	0,329714	0,670286	0,66395	1
Kalipucang Berth	0,717834	1,459308	0,717834	0,329714	0,670286	0,617658	4
Pamotan Berth	0,683761	1,39004	0,683761	0,329714	0,670286	0,58834	8
Majingklak Berth	0,689896	1,402511	0,689896	0,329714	0,670286	0,593619	7
Ideal (AI)	1						

The MARCOS method produces a clear ranking by balancing the benefits and costs of each alternative. It is notable that IWT-6 is consistently ranked highest due to its optimal balance of accessibility, land use, and alignment with spatial planning. The method also indicates that IWT-5 and Pamotan Berth rank lower due to less favorable scores on road connectivity and land cost.

3.3.2. RAM Method Ranking Results

In addition to the MARCOS results, the RAM was applied to verify and enhance the robustness of the ranking outcomes. The RAM results are displayed in Table 7, showing a similar top rank for IWT-6 and IWT-1, while IWT-5 again ranks lower. Despite slight differences in the ranks of other locations (IWT-3 and Majingklak Berth), both methods align in highlighting IWT-6 as the most suitable location for the inland waterway berth.

This consistency demonstrates the reliability of the decision -making process. RAM's advantage lies in its ability to emphasize a clear trade-off between benefit and cost factors, reaffirming the robustness of the top-ranked locations identified by MARCOS.

Based on the IWT berth site selection result in (Table 8), the ranking of the RAM and MARCOS methods differs for Alternatives IWT – 3, IWT – 5, and Majingklak Berth. However, both methods have the same result for rank 1, namely IWT – 6. To evaluate the consistency and agreement between the two methods, we employed Kendall's Tau and Spearman Rank Correlation in this study shown in (Table 8).

Kendall's Tau coefficient of 0.778 indicates a high positive correlation between the two ranking methods, MARCOS and RAM. With a $p-value$ of 0.0024, much smaller than the significance level of 0.05, this correlation is statistically significant, suggesting a strong level of agreement between the two methods. Similarly, Spearman's coefficient of 0.883 reflects an extremely high positive correlation, further supported by a p-value of 0.0016. This small $p-value$ confirms that the correlation is statistically significant, reinforcing that both methods produce highly consistent rankings.

Overall, both Kendall's Tau and Spearman's rank correlation coefficients demonstrate a very high level of agreement between the MARCOS and RAM ranking methods. The statistically significant $p-values$ confirm that this agreement is robust and unlikely to have occurred by random chance, indicating that both methods can be reliably used to achieve comparable ranking results in decision-making contexts.

Table 7. Ranking Results of Berth Location Selection Using the RAM Method

Alternatives	S_{+1}	S_{-1}	$\sqrt[2+S_1]{2+S_{+1}}$	Normalization results of RI_i	Rank
IWT – 1	0,087775	0,030392	1,436975	0,946846	2
IWT – 2	0,073017	0,034382	1,430955	0,392782	5
IWT – 3	0,069363	0,046515	1,426688	0	9
IWT – 4	0,072845	0,031109	1,431723	0,463459	3
IWT – 5	0,073769	0,037893	1,430327	0,334927	7
IWT – 6	0,090857	0,03221	1,437552	1	1
Kalipucang Port	0,073412	0,03196	1,431701	0,461401	4
Pamotan Port	0,070723	0,034226	1,430216	0,324742	8
Majingklak Port	0,073238	0,036313	1,430544	0,354925	6

Table 8. Ranking Results of Berth Location Selection Using the RAM Method

	MARCOS – RAM
Kendall's Tau	
τ	0.778
$p-value$	0.0024
Spearman Rank	
r_s	0.883
$p-value$	0.0016

4. Conclusions

The development of inland waterway transportation (IWT) faces the challenge that passengers prefer longer inland routes. Therefore, the selection of the right IWT berth site is very important. Unlike coastal ports, IWT locations require different parameters for optimal site selection. This research introduces a four-step process that includes: parameter definition, GIS analysis, parameter weighting, and final site selection to identify suitable IWT berth sites.

The results show that alignment with the Provincial or District Spatial Plan is the main factor in the selection of IWT berth sites, followed by road accessibility, land cost, land use, and road width. In addition, specific parameters such as elevation, slope, risk of landslides and flooding, water depth, sediment conditions, and river width also have a significant influence on site feasibility. Based on the ranking, IWT - 6, IWT - 1, and IWT - 4 emerged as the most feasible locations due to their good road connectivity.

This study has limitations as it was only conducted in Pangandaran Regency, so future follow-up research is recommended to expand coverage to other regions in Indonesia. Methodological considerations related to replicability have also been included in the conclusions, with an emphasis on the potential for future research that could improve and refine the methods used in this study. Further developments could explore more comprehensive weighting methods or expand the use of spatial data to optimise IWT berth site selection in different regions.

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