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Article

Hydrodynamic Model Optimization for Marine Tourism Development Suitability in Vicinity of Poso Regency Coastal Area, Central Sulawesi, Indonesia

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Abstract: Poso regency, Central Sulawesi, Indonesia, has a coastal area that has marine tourism potential to be developed. It is expected that marine tourism can bring socio-economic impact to the community. This research was conducted with the objective of assessing the suitability of the area to be developed as a marine and coastal tourism site to provide benefits to the coastal community. Hydrodynamic model will be used in this research as coastal area mapping. As an approach, Analysis Hierarchy Process (AHP) is utilized whose parameters consist of depth, coast type, coast width, brightness, current speed, water base materials, observation of dangerous biota and availability of fresh water. Based on the overall mapping area of 98,644 ha, the research results show that the area that can be utilized is 7,979 ha with a very suitable category, while there is an area of 1,045 ha which can still be classified in the appropriate category.

Keywords: Hydrodynamic model, marine and coastal tourism, Analysis Hierarchy Process (AHP)

1. Introduction

Coastal areas are considered as essential from an environmental and economic standpoint [1]. These two standpoints have detrimental consequences to the coastal communities. Therefore, it is important to manage those environments' resources sustainably [2]. Typically, resources of a coastline destination play a significant role in luring investments and infrastructure related to tourism. This is because coastal areas typically have a variety of natural resources in addition to cultural treasures [3] According to Bob et al. (2018), coastal and marine tourism (CMT), which is a component of the ocean economy, has enormous development potential that can support sustainability and the creation of jobs [4].

Coastal tourism is an activity that involves visitors, locals, and the places they want to go, especially the coastal environment and its natural and cultural elements. [5]. Marine and coastal tourism are two of the oldest forms of travel and highly sought-after destinations for tourists [6]. Therefore, marine and coastal tourism is one of the largest and fastest-growing divisions of the tourism business. According to projections, 8.6 million people would be employed by marine and coastal tourism by 2030. Hence, it makes up 26 percent of the entire global ocean economy [7]. Sustainable development is impacted by coastal and maritime tourism in all its aspects. The natural ecosystems of coastal resorts are altered by poorly managed tourism activities in terms of their environmental impact. The demand on natural resources has grown dramatically because of widespread tourism. The coasts are overrun by mass tourism, which damages local ecosystems and has a negative impact on local species in coastal ecosystem. Additionally, induced land-use change contributes to coastal artificialization and transport-related air and noise pollution. Through the creation of negative externalities that are frequently uncompensated, this condition affects the welfare of residents and local communities [8].

Indonesia, as an archipelago country with 17,499 islands and a total coast length of almost 81,000 km, as well as the largest nation in the Indian Archipelago, is offering tremendous potential for coastal and marine tourism. The tourism industry has helped to enhance the country's overall Gross Domestic Product (GDP) since Indonesia is one of the most desirable tourism destinations from tourists around the world [9]. Development of the tourism industry in Indonesia has been planned to lessen poverty and protect the environment and natural resources [10]. The main challenge for the coastal planner in designing the development coastal tourism at remote area is a limited number of measurable data along with the capacity building of the people.

Poso regency's 4,013 km of coastline offers a lot of potential for marine ecotourism development (see Fig. 1). However, the local coastal communities are not utilizing optimally. If natural resource potential is explored to their its full potential, it can help to bring positive socio-economic impact to local communities. Most of the coastal communities in Indonesia coastal region live in poverty with a total per capita below World Bank norms. Hence, the tourist industry is one of the key areas where it is expected to make a significant contribution to the efforts to improve the existing economy in coastal community. It can be stated as well that coastal regions have a high economic value that includes both tangible and intangible economic benefits. Tangible benefits are typically categorized as utility benefits, whether they are used or not, whereas intangible benefits are more in the type of long-term ecosystem maintenance [11].

Poso District was chosen as a research field for this research because it has a lot of natural resources. On the contrary side, these natural resources are not currently being utilized to their full potential by the coastal community. This research will be conducted by building a hydrodynamic model to gather information such as water level conditions, current characteristics, wind speed, and tides to determine the oceanographic conditions in the Poso regency area. With the assistance of these data, it should be possible to decide what actions should be taken in the future to develop Poso coastal area in terms of tourism development, marine culture, and other areas. It is expected that this research will have significant contribution on the community in and its surrounding in Poso regency, particularly to the community in coastal area, by providing information, education, and applications for optimizing natural resources. Hence, this will have immense economic impact if the community is able to employ the coastal area potential. Unfortunately, an unstable environment is still susceptible to violence. This poses one of the largest threats to Poso regency's tourism industry [12].

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Figure 1. Research field area, coastal area in Poso regency in Central Sulawesi, Indonesia

2. Materials and Methods

To create this hydrodynamic model simulation, Poso Beach, which is in Poso regency, Central Sulawesi, Indonesia, was utilized as the setting point. The model will be run for 2 weeks. As the first step, it starts with preparing and determining observation points around the coastal area of Poso Regency. Secondly, the data needed for research is prepared from the *General Bathymetric Chart of the Ocean* (GEBCO) for bathymetry data, Copernicus for wind data and *International Hydrographic Organization* (IHO) for water level data. The hydrodynamic model will be then assessed for its validity and accuracy with Root Means Square Error (RMSE) method. It will be compared also with the data on land, air, and sea observations from Copernicus. The study used wind data, which is collected from the last ten years, from January 1, 2011, to March 31, 2021. The gathered wind data is then processed to create a wind rose diagram.

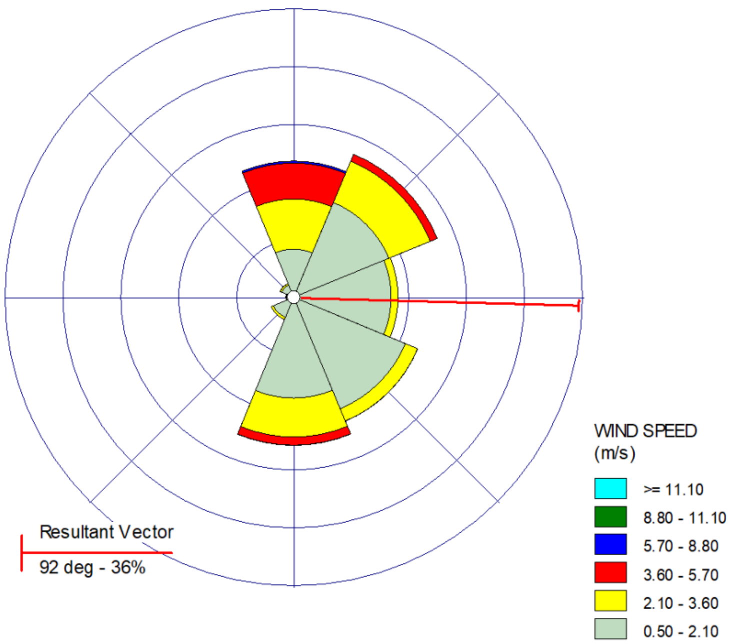

Figure 2. Wind Rose Diagram

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2.1. *Hydrodynamic Model using Delft3D*

The *Delft3D* model can simulate currents, waves, sediment movement, water quality, morphological development, and ecology in the modeled area while simulating the original circumstances in rivers, estuaries, and coastal areas. In practice, this application can be coupled with *ArcGIS* and needs several other supporting programs, such *MATLAB*. A hydrodynamic modeling program called *Deflt3D* uses numerical techniques to process input data. Astronomical equations (see equation) are used to drive the model by supplying details regarding its boundary conditions (the land border).

The general formula for the astronomical tide which driven the hydrodynamic numerical model is:

$$H(t) = Ao + \sum_{i=1}^{k} Ai\, Fi \cos(\omega it + (Vo + u)i - Gi)$$

H(t)	= Water level at time t
A0	= Mean water level over a certain period
k	= Number of relevant constituents
i	= Index of a constituent
A_i	= Local tidal amplitude of a constituent
F_i	= Nodal amplitude factor
ω_i	= Angular velocity
(Vo + u)	= Astronomical argument
G_i	= Improved kappa number (= local phase lag)

The primary data are bathymetry data from GEBCO Bathymetry Data or sounding data from Deeper Smart Sonar. This is to ensure the accuracy of the simulation results. It can serve as a basic reference to see the present and forecast the future dynamic movement of water.

The *Shallow Water Equation* (SWE) is calculated using the *Delft3D-Flow* software in *Delft3D* with two different variables, namely the velocity and the height variable. These variables are then projected onto a line with two directions—horizontal and vertical—or what the *Delft3D-Flow* application refers to as a grid. The Navier Stokes equation is used in the open source *Delft3D* software system's calculations. The Stokes-Navier formula will be described as following equation. [13].

$$\frac{\partial \rho}{\partial t} + \frac{\partial(\rho u)}{\rho x} + \frac{\partial(\rho v)}{\rho y} + \frac{\partial(\rho w)}{\rho z} = 0$$

x, y, z	= Coordinates
u, v, w	= Speed components
ϱ	= Density

2.2. *Root Mean Square Error* (RMSE)

When evaluating the performance of models in studies like meteorology, air pollution, and climate research, the root mean square error (RMSE) approach is frequently employed as a standard statistical metric. Numerous researchers in geosciences employ the RMSE approach as a common metric to evaluate the model's level of error [14]. Consequently, using the RMSE approach, the hydrodynamic model that results can be calculated using the RMSE formula.:

$$RMSE = \sqrt{\frac{\sum_{i=1}^{N}(Predicted_i - Actual_i)^2}{N}}$$

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$Predicted_i$ = Predicted value data
$Actual_i$ = Actual simulation
N = Number of data

RMSE has been used as a benchmark for assessing hydrodynamic model performance [15]. If the RMSE value is within or less than 0.1, the modeling has been done correctly and could be considered as accurate. On the other side, if the RMSE value is more than 0.1, the required data collecting phase to support the simulation must be repeated.
The validated hydrodynamic model can be used as supplement to the online collected data, as well as to be utilized for mapping the suitability of a coastal area. The suitability for tourism development is mapped with *ArcGIS* technology. Only the waterways surrounding the Poso regency area were used for the mapping.

Table 1. Marine Tourism Suitability Score Beach Category [18]

Parameter	Unit	Very suitable	Suitable	Unsuitable
Waterdepth	m	0 -3	>3-6	>6-10
Type of coast		White sand	White sand with coral	Black sand, coral and stiff
Wide of coast	m	>15	<10-15	3 - 9
Bed coast material		Sand	Sandy coral	Sandy mud
Current speed	m/s	0 – 0.17	0.17 – 0.34	0.34 – 0.51
Coastal slope	o	<10	10 -25	>25 – 45
Water clarity	%	>10	>5 – 10	3 – 5
Coastal closing area		Coconut tree, open area	Scrubb, lowland, savanna	High scrubb
Dangerous biota		No	Jellyfish, sea urchin	Nani's fur, stingray
Freshwater	Km	<0.5	>0.5 – 1	> 1 - 2

2.3 Analysis Hierarchy Process (AHP)
The Analysis Hierarchy Process (AHP) approach can be used to process a suitability mapping from each of the above suitability parameters. According to Fig. 3. [19], this strategy involves estimating values using an analytical framework. As illustrated in Fig.3., the suitability parameter data was divided into three categories: highly suitable, suitable, and unsuitable. Following reclassification, the data were compiled and once more evaluated against the preexisting parameters as shown in Fig. 3., resulting in the creation of the suitability map's result.

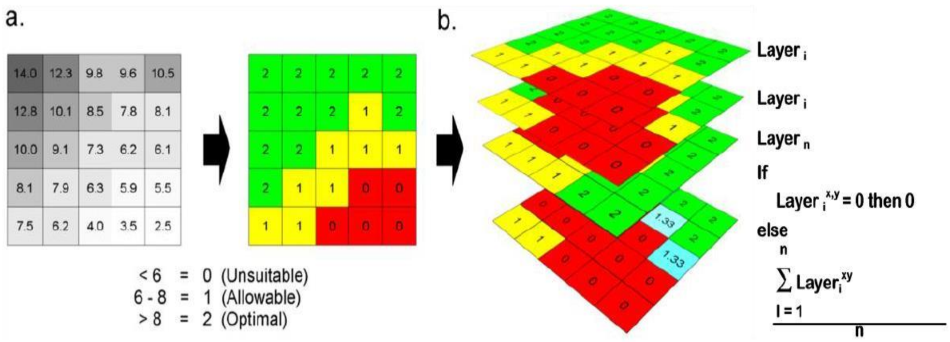

Figure 3. Value summation scheme:
a) Reclassification of Parameter Data
b) Estimation of Some Parameter Data for Final Results

3. Results

3.1. Model Simulation Using *Delft3D*

Square grid and bathymetry data from *GEBCO* was used for the hydrodynamic model simulation. The results from several generated simulations with different grid sizes and manning roughness are shown in Tab. 2.

Tabel. 2. *Delft3D* model simulation

No.	Model	Grid (meter)	Bathymetry	Manning Roughness	Time Step (Minutes)	Simulation Duration (Days)	Desc.
1	A	200	GEBCO	0,05	60	365	Failed
2	B	1200	GEBCO	0,05	60	365	Failed
3	C	1600	GEBCO	0,05	5 30 60	30	Failed
4	D	5550	GEBCO	0,05	5 30 60	14	Success
5	E	5550	GEBCO	0,05 0,033 0,025	5	14	Success

All model simulation experiments were successful with different manning roughness numbers in model E. Therefore, Model E is the model used for further research.

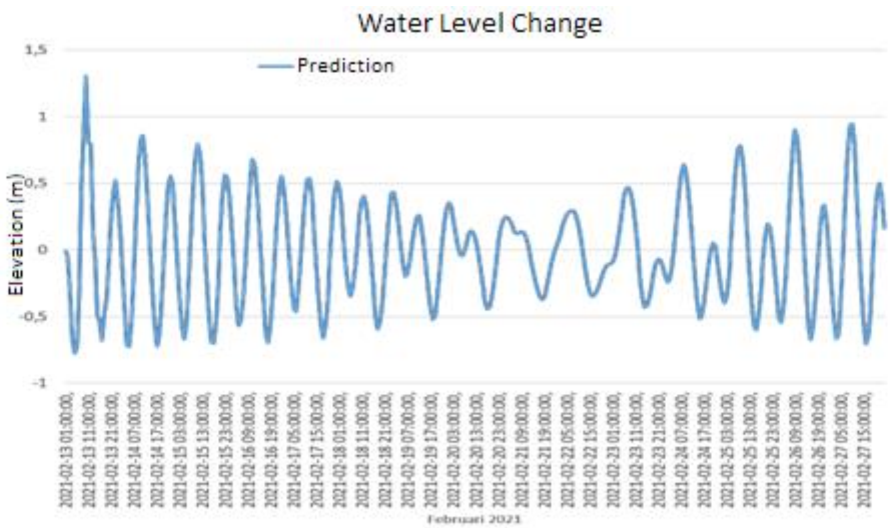

Figure 4. Hydrodynamics Model Results in the Form of Water Level Change Graph

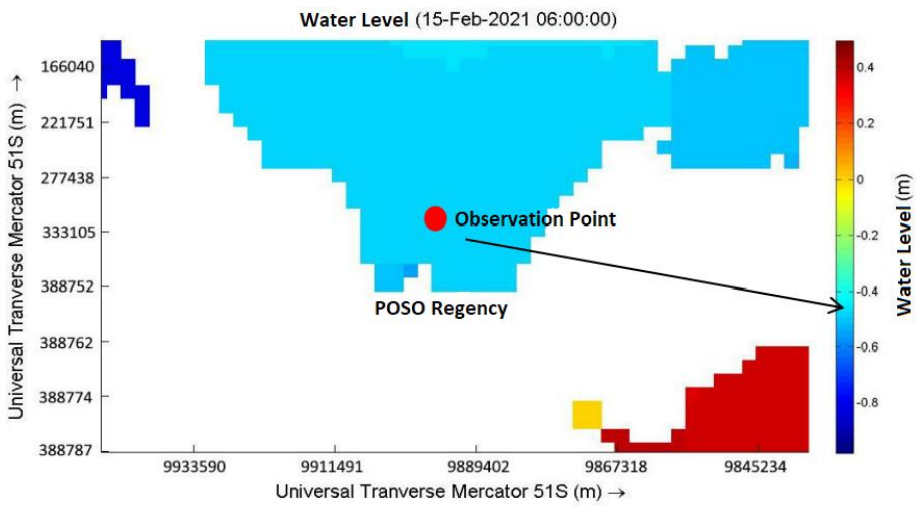

Figure 5.-Dimensional Simulation Results of Water Level Change (Elevation)

3.2. Validation and Verification of Simulated Hydrodynamic Model

The RMSE approach will be used to test and verify the model between the simulation results and the results of the measuring station (*Delft Dashboard*). Water level elevation data from the model will be used in the RMSE formula. The *IHO* monitoring station relates to the Poso station, which can be found in the Delft Dashboard program (see Tab. 3.).

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Table 3. Root Mean Square Error Calculation Data Model E Manning Roughness 0.05

POSO		Jumlah Data (n)=	360
Date and Time	***Predicted (m)***	***Actual (m)***	***(Predicted - Actual)^2***
2021-02-13 01:00:00,	-0,00660431	-0,266	0,067286124
2021-02-13 02:00:00,	-0,0402799	-0,42	0,144187354
2021-02-13 03:00:00,	-0,308369	-0,489	0,032627558
2021-02-13 04:00:00,	-0,667691	-0,446	0,049146899
2021-02-13 05:00:00,	-0,772871	-0,29	0,233164403
2021-02-13 06:00:00,	-0,727247	-0,051	0,457310005
2021-02-13 07:00:00,	-0,240389	0,221	0,212879809
2021-02-13 08:00:00,	0,439049	0,464	0,000622552
2021-02-13 09:00:00,	0,86659	0,623	0,059336088
2021-02-13 10:00:00,	1,30275	0,661	0,411843063
2021-02-13 11:00:00,	0,80441	0,57	0,054948048
2021-02-13 12:00:00,	0,796764	0,374	0,1787294
2021-02-13 13:00:00,	0,123352	0,12	1,12359E-05
2021-02-13 14:00:00,	-0,11178	-0,132	0,000408848
2021-02-27 19:00:00,	-0,127693	0,054	0,033012346
2021-02-27 20:00:00,	0,206054	0,22	0,000194491
2021-02-27 21:00:00,	0,430109	0,306	0,015403044
2021-02-27 22:00:00,	0,499308	0,285	0,045927919
2021-02-27 23:00:00,	0,401124	0,159	0,058624031
2021-02-28 00:00:00,	0,166415	-0,038	0,041785492
TOTAL (∑)			12,249
The Root Mean Square Error (RMSE)			0,184

Furthermore, this model will be used as supporting data for mapping the suitability of coastal area development in Poso regency with the *ArcGIS* application.

3.3. Coastal Area Development Mapping with ArcGIS

The suitability mapping of coastal marine tourism in this study will be based on the evaluation in depth, brightness, slope, current speed, and wave height as criteria in Tab. 1.

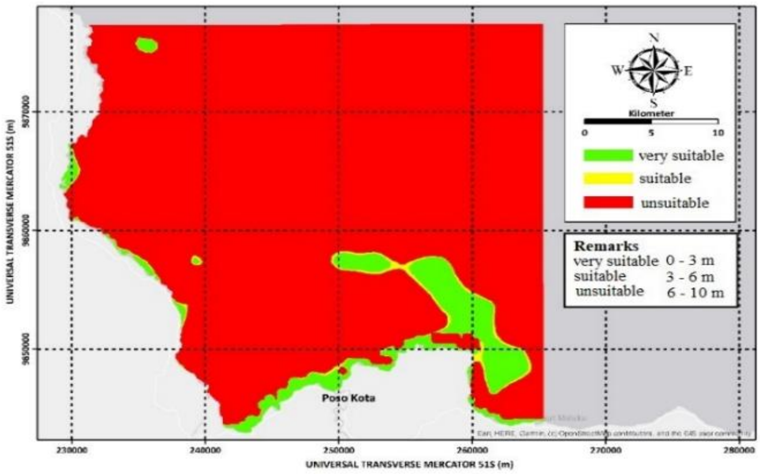

Figure 6. Beach Category for Marine Tourism Suitability Map Based on Depth

Depth mapping is shown in Fig. 6. There are more than 90% of areas at about 88,780 ha which are remarked as unsuitable, especially around the center of the map. These areas are unsuitable because the depth is around 6 to 10 meters, which is considered dangerous for tourism activity. However, it can be seen areas around the coast are remarked as very

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suitable since these areas have 0 to 3 meters depth. This is considered acceptable and safe for tourism activity.

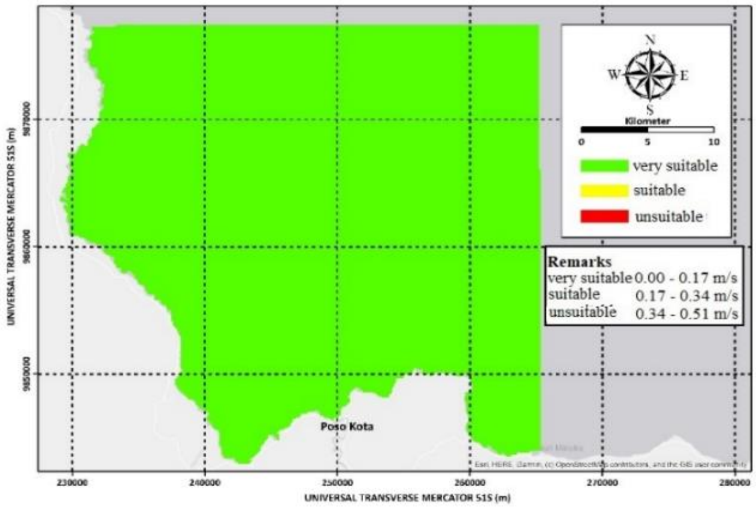

Figure 7. Coastal Area Category Marine Tourism Suitability Map based on Current Speed

Based on the current speed category, all areas on the suitability marking are marked green as shown in Fig. 7. as very suitable for marine tourism. It can be observed also that the current speed in this area can be considered low at about 0.17 m/s, which makes it suitable for tourism.

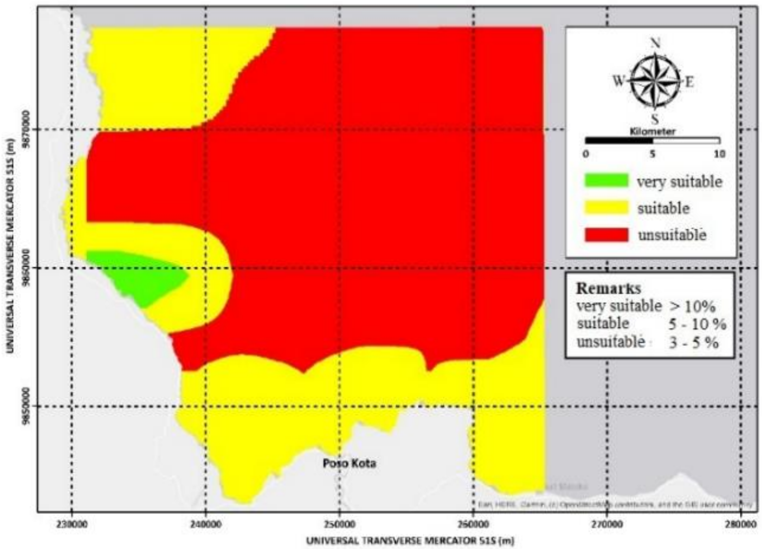

Figure 8. Beach Category Marine Tourism Suitability Map Based on Brightness

As shown in Fig. 8., about 70% of the mapped areas with 69,050 ha are remarked as unsuitable with red color. It indicates these areas have less than 5% water clarity with 4,952 ha which is both unpleasant and dangerous for marine tourism. There are only certain areas that are categorized as very suitable and suitable. These areas are shown in green color as a very suitable category and yellow color as suitable category.

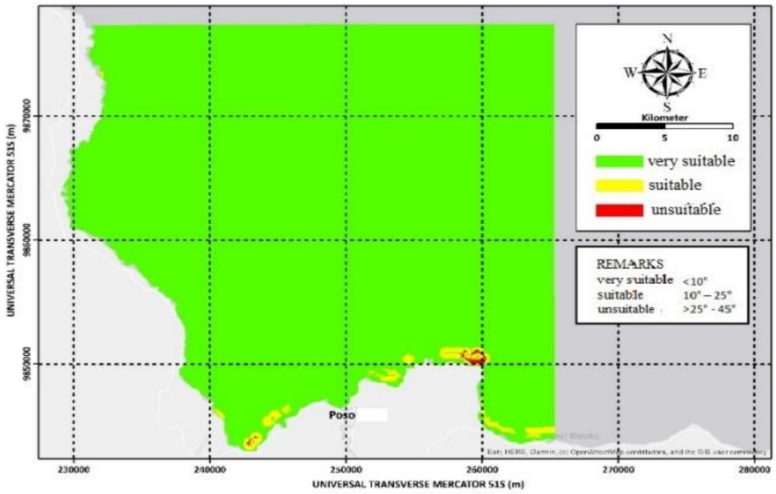

Figure 9. Beach Category Marine Tourism Suitability Map based on Slope

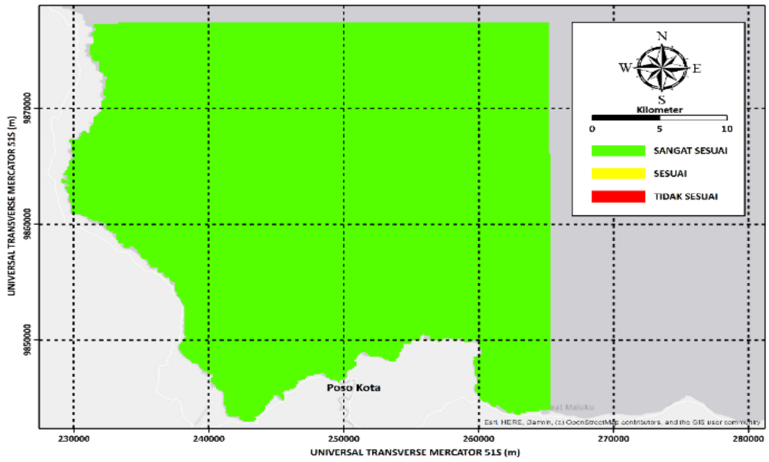

Figure 10. Beach Category Marine Tourism Suitability Map based on Wave Height

Based on slope category as displayed in Fig. 9., most of the mapped areas are marked as very suitable with less than 10° slopes. There are some small areas at 2 % of the total area, 1,972 ha with yellow color are considered as suitable. Like the slope category, it can be seen in Fig. 10, all mapped areas are considered very suitable for marine tourism.

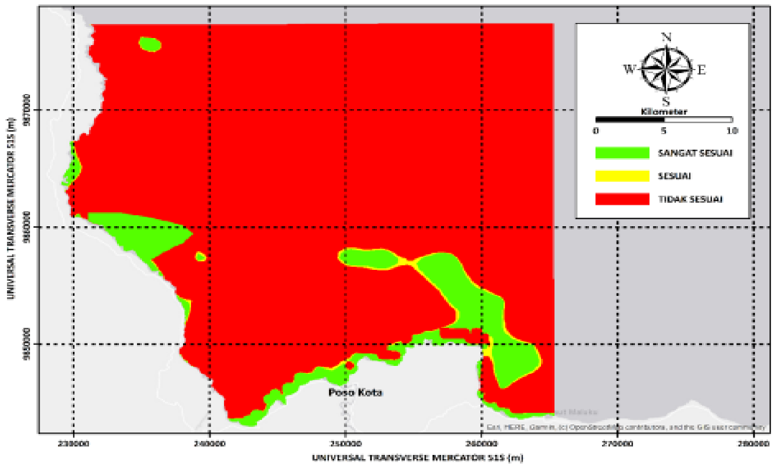

Figure 11. Result of Beach Maritime Tourism Suitability Map.

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The overall result, by using the AHP approach and considering the depth, current speed, brightness, slope, and wave height factor, indicates that most of the coastal areas in Poso regency are suitable for marine tourism. It can be seen from Fig. 11 those areas with 7,979 ha marked with green color are very suitable for marine tourism (in green color) while there is also 1,045 ha area marked in yellow color can be considered as suitable as well. Some coastal area and most of the open water area in red color are marked as unsuitable for marine tourism because it has depth more than 10 meters and low water clarity

4. Discussion

Data simulations were run from February 13 to 28, 2021, for a period of 2 weeks. Model A simulations were run with a 200-meter grid, manning roughness of 0.05, and a time step of 60 minutes. The simulation failed because the grid was unstable. In model B, the grid was improved by increasing the grid size to 1200 meters and orthogonalizing the grid. However, model B still experienced errors. The grid was then improved again in model C by increasing the grid size and using a time step of 5, 30 and 60 minutes. It turned out that model C still has errors. Manning roughness cannot be larger because the largest manning roughness limit is 0.05. Model D is created with 5550 grid and 0.05 as manning roughness value. It turned out to be successful with 3 different time steps.

Model E is created with the same grid as model D, but with 3 different manning roughness. With this modification based on the model D, all parameters in Model E were successfully simulated. Model E with a manning roughness number of 0.05 has an RMSE value close to 0.1, namely 0.184. It can be concluded that model E is accurate enough to describe the original condition of the waters in Poso District. The simulated hydrodynamic data from model E can be applied in Analysis Hierarchy Process (AHP) to determine the suitability of the areas which can be developed as marine tourism.

The AHP mapping result shows that Poso regency coastal area has suitable depth for marine tourism activity with less than 3 meters of depth. Compared to Pantar Strait area which has depth of 1.1 – 2.6 meters [21], Poso regency coastal areas are more suitable for swimming and bathing. Based on current speed, with maximum current speed 0.17m/s, it is remarked as very suitable [22]. In the water clarity category, the AHP mapping showed many varieties of remarks along the area. Even though it shows lower water clarity compared to other coastal areas [21], it was still remarked as very suitable. The coastal area in Poso regency is considered as flat beach which has less than 10^0 of slope. This will be as advantage in the safety and convenience factor in marine tourism [23]

5. Conclusions

The results of the beach category marine tourism suitability map based on the mapped region with a total area of 98,466 ha has revealed that 7,979 ha is very suitable, while 1,045 ha is suitable for marine tourism development. However, important information, such mapping of substrates and of dangerous animals, cannot be acquired using internet stations. However, to meet all these requirements, it needs to retrieve either regional data provided by the local government or live data. Only four out of ten suitability factors—depth, brightness, slope, and current speed—are included while mapping the suitability of coastal marine tourism in this study. Hence, it is expected that this research will be as base information to be developed further for more accurate suitability mapping for determining the appropriate coastal marine tourism.

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