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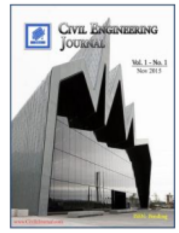

Utilization of Hydrodynamic Models in Decision Support System for the Future Development in Remote Area at Coastal Zone Central Sulawesi Indonesia

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Abstract

The archipelago nation of Indonesia boasts a wealth of marine resources. Yet, one issue brought on by marine development, such as Poso Regency, is a lack of measurement data. Despite being close to the coast, local villages in this regency are still unable to fully utilize its maritime resources. Thus, it is intended that by creating the methodology for hydrodynamic models for decision support system in the waters or coastal regions of Poso Regency. This decision support system can serve as serve as the foundation for instruction, knowledge, and application in developing coastal areas. Then it can advance the economy of the surrounding community. This research project is still underway due to the comprehensive aspect. The initial investigation of the potential area are about 98.466 ha shows that the model fulfills the accuracy within the range of root mean sqaure error of roughly 0.184 after calibration and verification have been completed. The outcome of hydrodynamic model simulation can be used as fundamental information for maritime development at this site, such as tourism, agriculture, or development in other areas. The research's findings demonstrate the suitable area for floating net cage grouper, seaweed cultivation, and marine tourism area are 6.163 ha, 91.001 ha, and 9.024 ha, respectively. It is hoped that this result can help develop the economic problem in Poso Regency and for future area development.

Keywords: Hydrodynamic Model, Poso, Coastal Potential, Cultivation, Tourism

1. Introduction

Urban coast can contribute to the city's identity, improve the area's visual appeal, and improve residents' quality of life in general when it is in a good condition [1] [2]. Indonesia has already been referred to be a maritime countries due to its 5.8 million km² of sea, of which 0.7 million km² are territorial waters, 2.3 million km² are made up of sea islands [3]. One of the benefit of having water resources are besides having natural resources, it can also support aquatic ecosystem as well as being an important component in economic development [4] [5] [6]. Decision support system is one of the method to support the economic development problem [7] [8] [9]. Poso Regency is one of the area in Central Sulawesi that is located on a coastal area (see fig 1. Poso Regency, Central Sulawesi, Indonesia). Being an area that is located on a coastal area, there should be a lot of possible maritime activities. But in reality, the local community have not optimally utilized the use of the natural resources. As a result people in Indonesia especially those on the coastal area still lives below the line poverty with total per capita income that is still far below World

Bank standard [10]. There are activities, especially on the coastal areas, to raise the economic gain such as seaweed cultivation, floating net cage grouper, and tourism.

Figure 1. Poso Regency, Central Sulawesi, Indonesia. Research work location

Researches has been conducted about the development of the Coastal Zone. Zeichen, et. al. (2022) made a research about geospatial analysis for fish farming across Tyrrhenian coast which is located on Tuscay, central Italy. This study shows that aquaculture activities needs more development to determine the zone the area for aquaculture suitable areas [11]. Sarker, et. Al (2021) explained about the study of seaweed distribution in Bangladesh for ecological and economic value by using Generalized Additive Model [12]. Atzori, et. al. made a research about impacts of climate change on tourism destination on Florida. This research explained about tourist preference on condition factors such as environmental attributes and weather conditions [13]. Garbossa, et. al. (2021) made a research about the seaweed dispersion on a different environmental condition in Brazil by using the hydrodynamic model. The result shows that there are variances of seaweed branches that ranges from 2 ha – 6 ha based on the parameters of the simulation [14]. Spencer, et. al. (2022) explained about the tourism industry that is located on Carribean where it is potentially threatened by the climate change which is caused by sea level rise. These results on economic loss from the tourism aspect which is needed to protect the future of Carribean economics as well as the tourism sectors [15].

This research objective is to maximize the potential natural resources that have not been maximized by the local community. This research is located on Poso Regency, Central Sulawesi and utilizing the hydrodynamic model to find out the oceanographic condition such as wind speed, current speed, water level, and tides. The data that are obtained from the models will be expected to be a reference in the future to determine what activities that can be done to advance the coastal area in terms of mane cultivation such as seaweed, floating net cage grouper and marine tourism. By conducting this research, it is also expected to be able to bring positive impacts such as information, education, and applications for the community around Poso Regency, especially the coastal area in maximizing the natural resources that have potential to be utilized.

2. Material and Methods

Hydrodynamic model will be used for the simulation on this research. The location will be located in Poso Regency, Central Sulawesi, Indonesia. Data such as bathymetry data, wind speed data, and water level is needed for the simulation to start. Delft3D is an application that is used to simulate the hydrodynamic model. The validity and verification of the data is then compared by using the Root Mean Square Error (RMSE) method. The result of the model can be used to help the decision support system in Poso, a rural area, raising the economics gain.

2.1 Data

Data that are used to simulate the model are bathymetry data, wind speed data, and water level data. The water level data are obtained from International Hydrographic Organization (IHO). The Bathymetry data are obtained from the General Bathymetric Chart of the Ocean (GEBCO). Bathymetry is the study of the water depth where the information obtained can be helpful on seafloor morphology as well as other sea activities [16] [17].

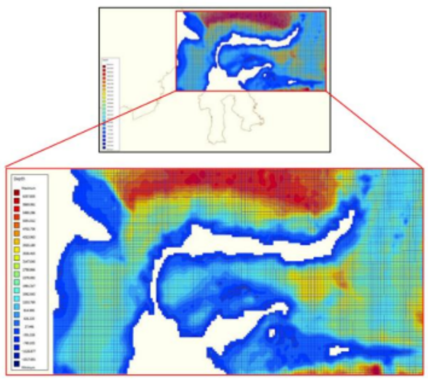

Figure 2. Bathymetry

The wind speed data for the simulation are obtained from Copernicus. Copernicus is a program that provides data to observe the land, air, and sea condition on Earth. The wind data that are collected are from the last ten years, ranges from January 1 2011 to March 31 2021. The amount of data obtained are around 89000 data with the measuring every hour at a height of 10 meters due to the altitude of the wind speed is considered stable. The wind data are then processed on a table and converted into a wind rose diagram.

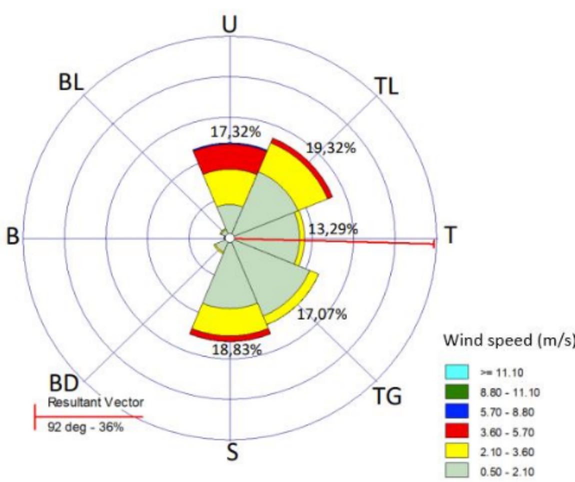

Figure 3. Wind Rose Diagram

2.2. Delft3D for Hydrodynamic Modelling

Deltf3D is a 3D modelling application that is used to simulate hydrodynamic movements of bodies of water such as water qualities, currents, morphology, and sediment transport for estuarine, fluvial, and coastal environments [18]. This application need other software to operate such as MATLAB and ArcGIS. Delft3D are divided into two main software which are Delft3D-Flow and Delft3D Wave. Delft3D-Flow calculates the flow that are unsteady and phenomena that brought by the meteorological stress and tidal on a curved boundary fitted grid [19]. Delft3D-Flow is also used to determine the Shallow Water Equation (SWE) which is also known as the current water equation which is calculated using velocity and height variable. To get the result of the currents and tides from the model, Navier Stokes equation are used on Deltf3D calculation. The Stoke Navier Stokes equation are as following [20].

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

x,y,z = Coordinate

u,v,w = Speed

ρ = Density

Delft3D-Wave is used to simulate the wind-generated waves in coastal water that changes over time. The wave module computes wave generation by wind, wind field, wave propagation, non-linear wave-wave interaction, and finite depth [21] [22]. The software can also be used not only for shallow type of water but can also used for medium and deep type bodies of water.

Primary data is needed to compare the results from the hydrodynamic model simulation that uses secondary data. The bathymetry data using the Deeper Smart Sonar is one of the primary data that is needed. This primary data can be used as the base reference to predict the upcoming future water movement in the particular areas.

2.3. Root Mean Square Error (RMSE)

Root Mean Square Error (RMSE) is a standard for measuring errors a modeling studies in predicting quantitative data such as meteorology, climate research, and air quality [23] [24]. RMSE method are used as a standard statistic by researchers to assess how much error the model prodeuced in geoscience activities [25] [26]. As a result, the hydrodynamic model that is produced using the RMSE method can be estimated using the RMSE formula:

$$RMSE = \sqrt{\frac{\Sigma(X-Y)}{n}}$$

X = Predicted Value

Y = Observation Value

n = Number of Data

To evaluate the result of the models, RMSE have certain parameters. The modeling can be marked as done and can be regarded as accurate if the RMSE number is within or less than 0.1. On the other hand, the necessary data collection step to enable the simulation must be redone if the RMSE value is more than 0.1. The data then can be used for online access for future study and development of the coastal areas. ArcGIS software is utilized for the suitability map on seaweed cultivation, floating net cage grouper, and tourism development.

Table 1. Floating Net Cage Grouper Fish Cultivation Suitability Table [27]

PARAMETER	UNIT	VERY SUITABLE	SUITABLE	NOT SUITABLE
Physical Parameter				
Minimum Water Depth	m	> 8	> 6	< 6
Maximum Depth (Anchor)	m	< 20	< 25	> 25
Maximum Wave Height	m	< 0.6	< 1	> 1
Wind Speed	m/s	< 10	< 15	> 15
Current Speed	m/s	< 0.6	< 1	> 1
Water Quality				
Water Temperature	°C	27 - 31	20 - 35	< 20 & > 35
Salinity	ppm	26 - 31	15 - 35	< 15 & > 35
Dissolved Oxygen	mgO_2/l	> 5	> 4	< 4
Water pH	-log(H+)	7.8 - 8.5	6 - 8.5	< 6 & > 8.5
Water Clarity	m	> 5	> 2	< 2

Table 2. Seaweed Cultivation Suitability Table [28]

PARAMETER	UNIT	VERY SUITABLE	SUITABLE	NOT SUITABLE
Water Depth	m	> 2 (low tide)		< 2
Current Speed	m/s	0.2 - 0.4	0.1 < x < 0.2	< 0.1 & > 0.4
Water Temperature	°C	32 -26	26 - 20	< 20 & > 32
Salinity	mg/l	35 - 32	32 -28	< 28 & > 35
Dissolved Oxygen	mgO_2/l	8 - 3	3 -1	< 1

Table 3. Marine Tourism Suitability Table For Beach Category [29]

PARAMETER	UNIT	VERY SUITABLE	SUITABLE	NOT SUITABLE
Water Depth	m	0 - 3	> 3 - 6	> 6 -10
Type of Coast		White Sand	White Sand, Less Coral	Black Sand, Coral, Steep
Coast width	m	> 15	< 10 - 15	3 - <10
Water Base Material		Sand	Sandy Coral	Muddy Sand
Current Speed	m/s	0 - 0.17	0.17 - 0.34	0.34 - 0.51
Coast Slope	°	< 10	10 - 25	> 25 - 45
Water Clarity	%	> 10	> 5 - 10	3 - 5
Coast Land Closure		Coconut, Open Field	Shrubs, Low, Savannah	Tall Bush
Dangerous Biota		None	Jellyfish and Sea Urchins	Sea Urchins and Stingrays
Fresh Water Availability	km	< 0.5	> 0.5 - 1	> 1 -2

2.4. Analysis Hierarchy Process (AHP)

Based on the suitability parameters, suitability mapping area can be processed by using the Analysis Hierarchy Process (AHP) method for each development sector. Analytic Hierarchy Process is a decision making process which consists of identifying and categorizing decision objectives, criteria, and constraints into a hierarchy and evaluating comparisons between elements across all level of hierarchy [30]. This method is done by estimating the value using an analytic framework (see figure 4 Summation Value Scheme) [31]. parameter data are then classified into 3 classes which are very suitable, suitable, and not suitable. Re-classification are summed and reanalyzed against the previous parameter and the final suitability map are formed.

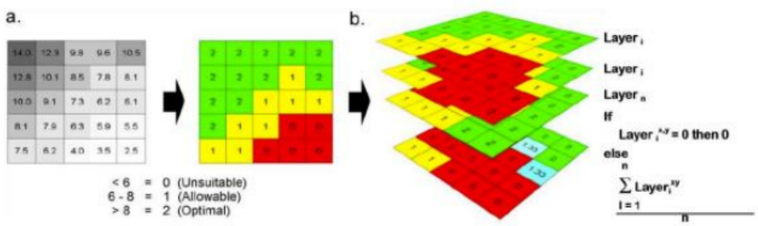

Figure 4. Summation Value Scheme

3. Results

3.1. Delft3D For Model Simulation

Parameter data such as land boundary, grid, bathymetry, manning roughness, and time step are used in making the model simulation. Using the trial & error method, this data will eventually be evaluated for compatibility between the simulation mode and the actual condition in the area. The result of multiple trials of the hydrodynamic model simulation, which was done by using a square grid and bathymetry data provided form GEBCO are shown in the figure below.

Table 4. Simulation Model Using Delft3D-Flow

No.	Model	Grid (meter)	Bathymetry	Manning Roughness	Time Step	Simulation Duration	Description
1	A	200	GEBCO	0.05	60 minutes	365 days	Fail
2	B	1200	GEBCO	0.05	60 minutes	365 days	Fail
3	C	1600	GEBCO	0.05	5 minutes	30 days	Fail
					30 minutes		
					60 minutes		
4	D	5550	GEBCO	0.05	5 minutes	14 days	Success
					30 minutes		
					60 minutes		
5	E	5550	GEBCO	0.05	5 minutes	14 days	Success
				0.033			
				0.025			

Based on table 4 above, error simulation occurred on model A through C. The reasoning for the error are because of the small grid as well as the long simulation duration. On the other hand, model D shows a success result with the grid presented on table 4. Model E uses the same grid and duration of the simulation but with variations of manning roughness and 5 minutes time step. Because the result shows success, model E is used for further researches.

The result for water level in 2D in Poso Regency, research location, are shown in figure 5 and figure 6. The exact time from the simulation taken are on the 15^{th} of February 2021 at 00:00:00. The elevation of water level on that particular time are 0.45 m. The observation points shows that from that time ahead, the water level will be decreasing and increasing in elevations, which affects the direction of the current as it shown in figure 7.

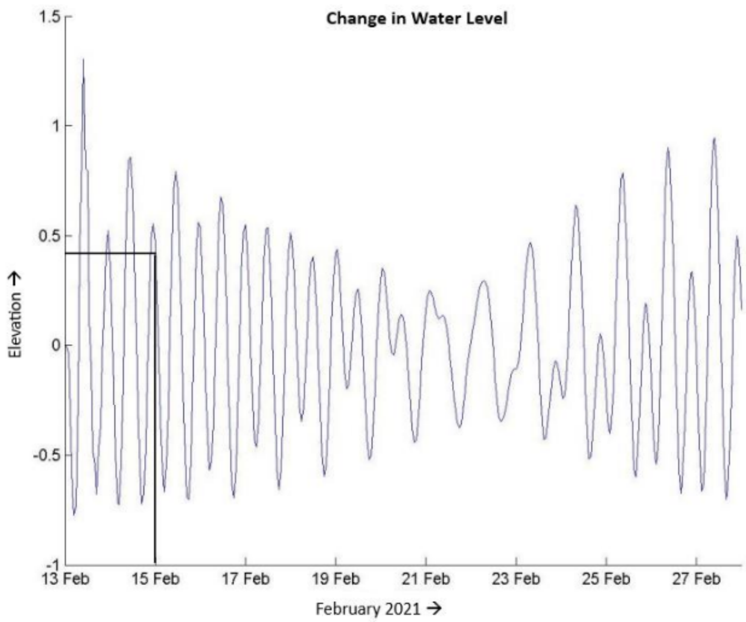

Figure 5. Hydrodynamic Model Results Shown in Water Level Changes Graphics

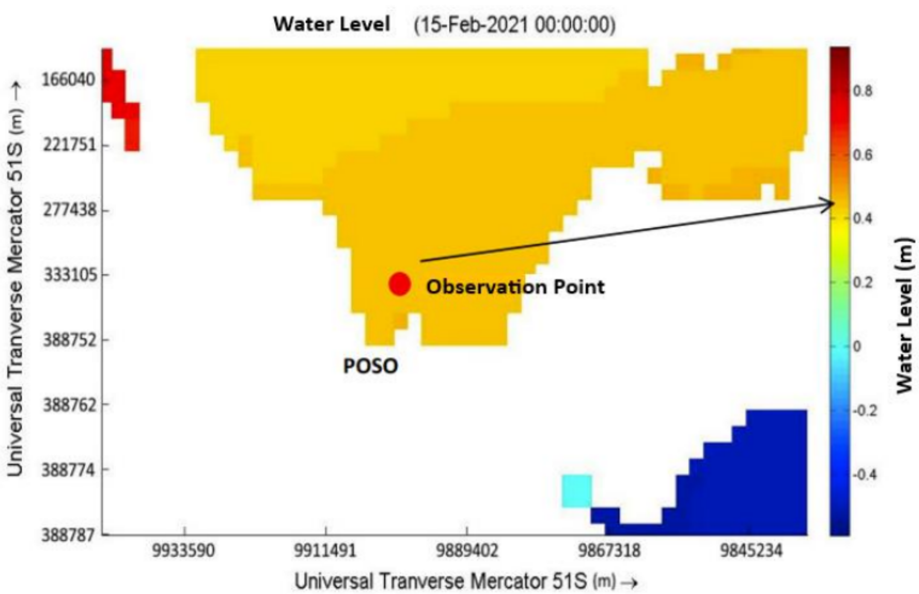

Figure 6. 2D Simulation Result on Water Level Changes (Elevation)

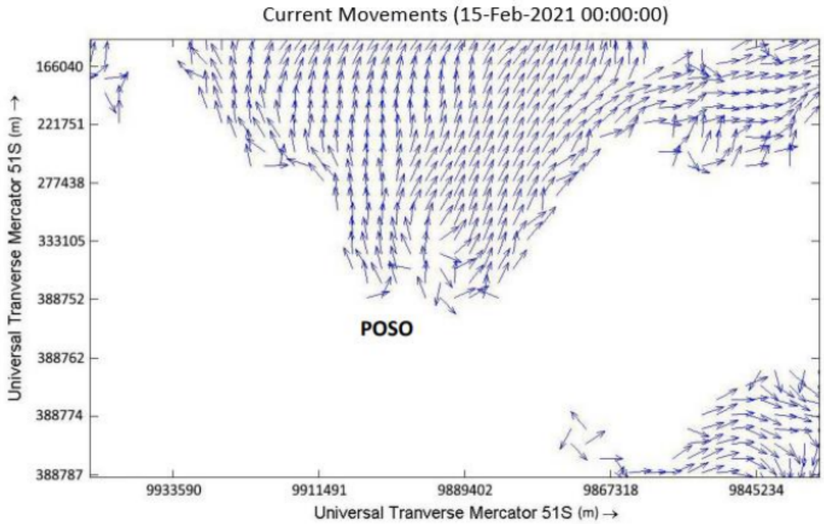

Figure 7. Simulation Results of Current Movements on Low Tides

Figure 7 shows that the currents are moving away from the coast due to a condition where the water will soon experience low tide condition in the future. The current speed at the observation point every hour can be seen in figure 8 below.

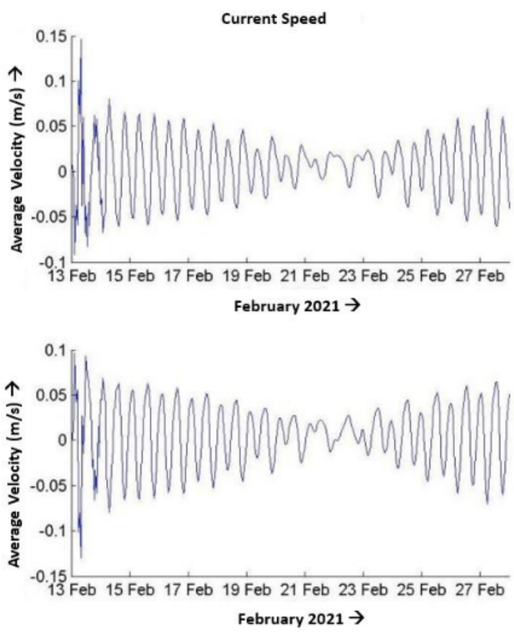

Figure 8. Current Speed on Observation Point

The hydrodynamic model simulation also shows the wave simulation on 2D format, which is the wave heights that is shown on figure 9. The wave heights around the observation point are around 0.1 – 0.2 meter based on the color indicator on the right side of the figure. The model is then undergo the validation and verification process through the RMSE method.

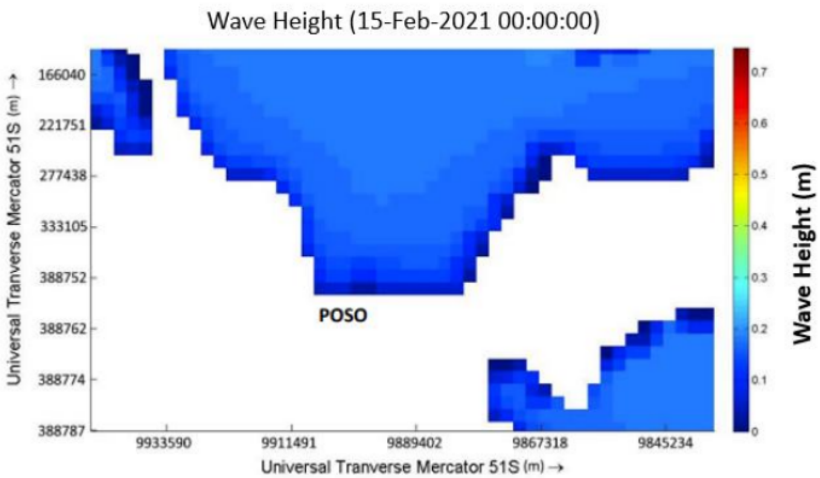

Figure 9. Wave Height

3.2. Verification and Validation Using RMSE

To validate and verify the model between the station measurements and the results the simulation results using the Delft Dashboard software, Root Mean Square Error (RMSE) method can be used. The water level elevation data is entered into the RMSE formula. From several model simulation, model E is used for further investigation. Three manning roughness results from model E will shows three different RMSE values. Station data for the research location, Poso Regency, are taken from Delft Dashboard software which are related to the International Hydrographic Organization (IHO). RMSE for model E is shown on table 5.

Table 4. RMSE value Model E Summary

No	Manning roughness	RMSE Value
1	0.025	0.296
2	0.033	0.186
3	0.05	0.184

Based on the result of the simulation with three different manning roughness, 0.05 have the lowest RMSE value 0.184 which shows that the results of 0.05 manning roughness have the lowest error and the most similar to the field condition. The data comparison of the water level condition between the station data and simulation can be shown on figure 10.

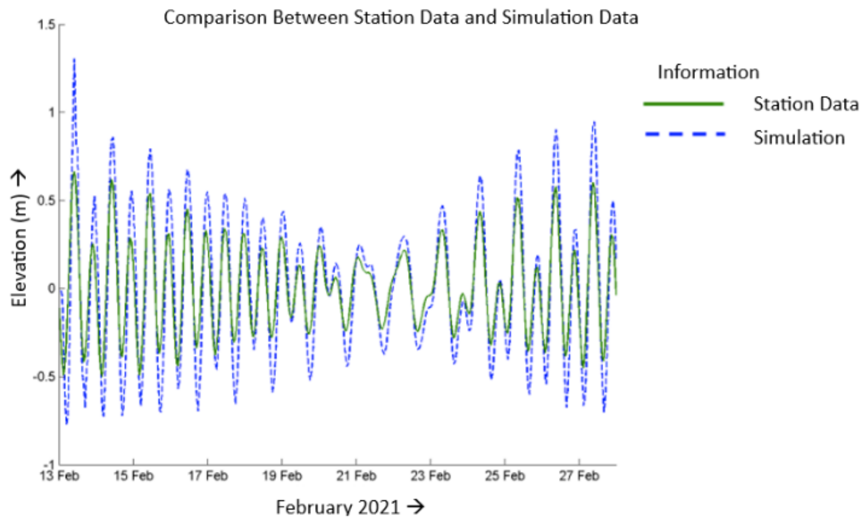

Figure 10. Comparison Water Elevation Between Station Data and Simulation Data

Model E with manning roughness 0.05 will be selected for further investi2tion because the RMSE value in this model is the highest between the three model that closes to 0.01 and it is good enough to describes the field condition of the water in Poso Regency. By using the ArcGIS application, the model will be used to map the suitability level on a coastal area on Poso Regency.

3.3. Coastal Area Mapping Development

Hydrodynamic model that have already validated with RMSE can be used as a support to complement the online 5ta retrieved ad used as suitability mappng data for the coastal area.ArcGIS software is used to process the mapping for the development of floating net cage grouper, seaweed cultivation, and marine tourism. Mapping is done only on the area of Poso Regency.

3.3.1 Floating Net Cage Grouper Suitability Mapping

The floating net cage grouper suitability mapping results are based on table 1, parameters of the floating net cage grouper fish cultivation. Based on the water depth as shown on figure 11, most of the area are indicated red which shows that it is not suitable for grouper farming.

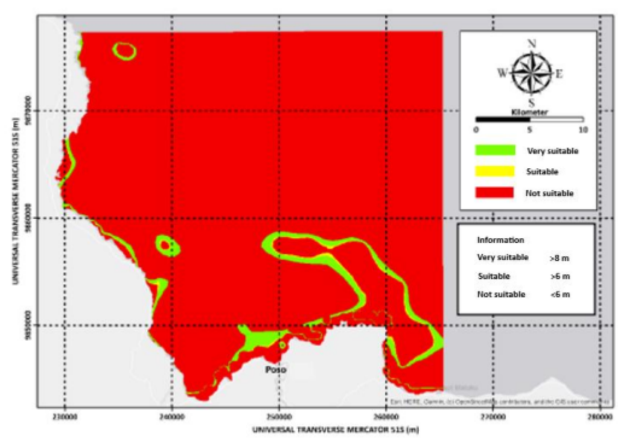

Figure 11. Floating Net Cage Grouper Suitability Map According to Minimum Water Depth

Based on the wave heights, all of the area are suitable for grouper farming which can be shown on figure 12 below.

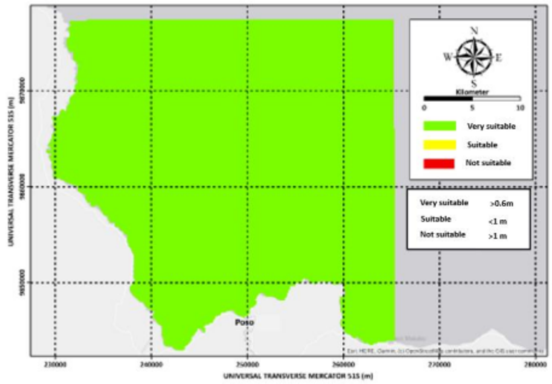

Figure 12. Floating Net Cage Grouper Suitability Map According to Wave Height

Based on the current speed, all of the area are suitable for grouper farming which can be shown on figure 13 below.

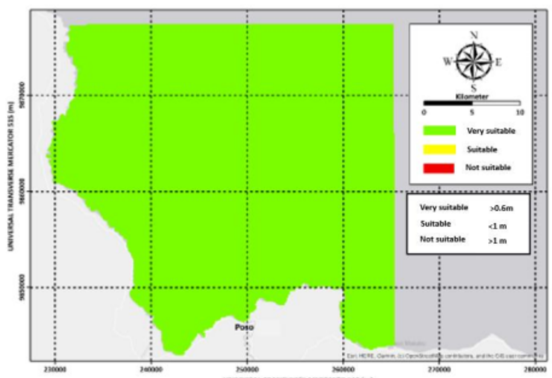

Figure 13. Floating Net Cage Grouper Suitability Map According to Current Speed

Based on the wind speed, all of the area are suitable for grouper farming which can be shown on figure 14 below.

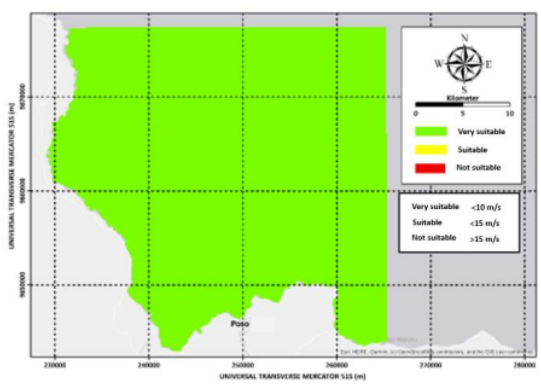

Figure 14. Floating Net Cage Grouper Suitability Map According to Wind Speed

Based on the water quality, all of the area are suitable for grouper farming which can be shown on figure 15 below.

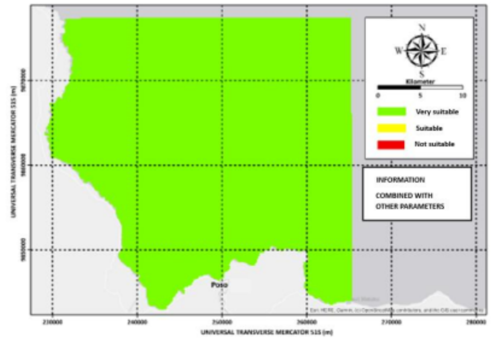

Figure 14. Floating Net Cage Grouper Suitability Map According to Water Quality

3.3.2 Seaweed Cultivation Suitability Mapping

The seaweed cultivation suitability mapping results are based on table 2, which are specified in SNI 7579.2:2010 to regulate the cultivation of Cottoni seaweed (*Euchema Cottoni)* using the long-line method. Based on the water depth as shown on figure 15, most of the area suitable for seaweed cultivation.

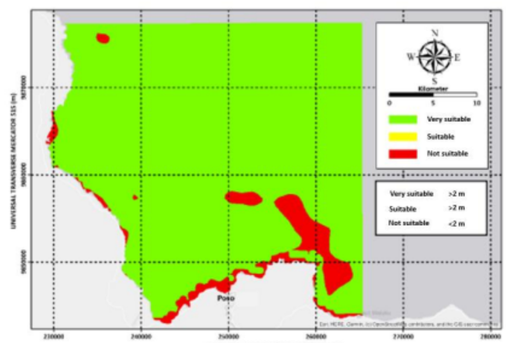

Figure 15. Cottoni Seaweed Cultivation Suitability Map According to Water Quality

Based on the current speed, most of the area are not suitable for seaweed cultivation and some area are suitable which can be shown on figure 16 below.

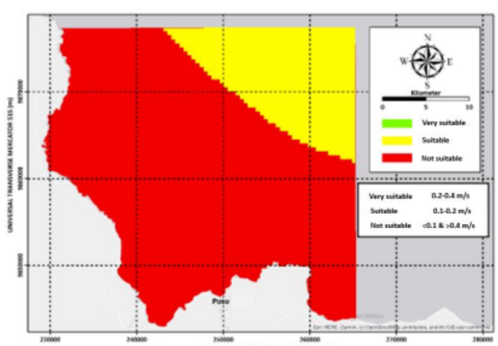

Figure 16. Cottoni Seaweed Cultivation Suitability Map According to Current Speed

Based on the water temperature, all of the area are suitable for seaweed cultivation which can be shown on figure 17 below.

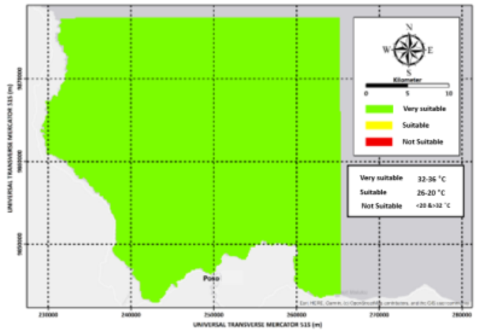

Figure 17. Cottoni Seaweed Cultivation Suitability Map According to Water Temperature

Based on the water quality, all of the area are suitable for seaweed cultivation which can be shown on figure 18 below.

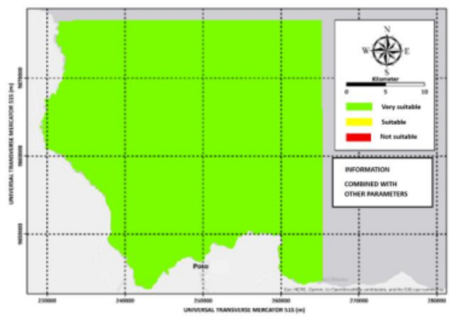

Figure 18. Cottoni Seaweed Cultivation Suitability Map According to Water Quality

3.3.3 Marine Tourism Suitability Mapping

The marine tourism suitability mapping results are based on table 3, however some data, such as substrate mapping and mapping of dangerous animals, cannot be accessed through online stations. Because data provided by Indonesia governments or direct data collection is required to meet all of these standards. Mapping of the coastal marine tourism on this study only covers depth, clarity, and current velocity which only covers 4 out of 10 parameters. Because of that, the maximum final result for the coastal marine tourism has yet to achieved the actual condition. Based on the water depth as shown on figure 19, most of the center area are not suitable for marine tourism while some of the are near the coastal area are very suitable for the marine tourism.

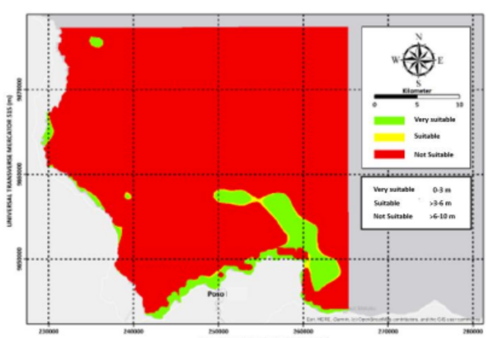

Figure 19. Marine Tourism Suitability Map According to Water Depth

Based on the current speed, all of the area are very suitable for marine tourism which can be shown on figure 20 below.

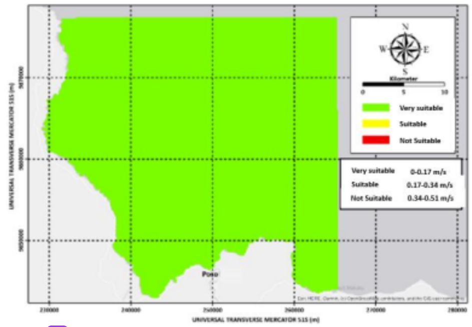

Figure 20. Marine Tourism Suitability Map According to Current Speed

Based on the water clarity, some of the area are not suitable and some of the area near the coastal area are suitable for marine tourism which can be shown on figure 21 below.

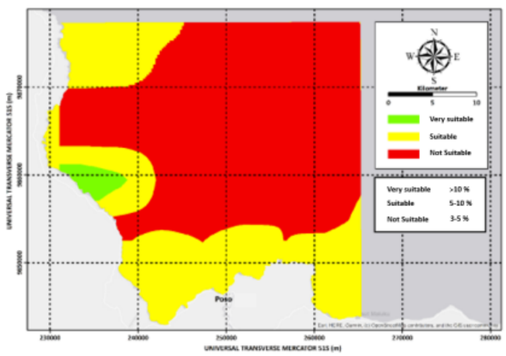

Figure 21. Marine Tourism Suitability Map According to Water Clarity

Based on the coast slope, almost all of the area are very suitable, some area are suitable, and small area are not suitable for marine tourism which can be shown on figure 22 below.

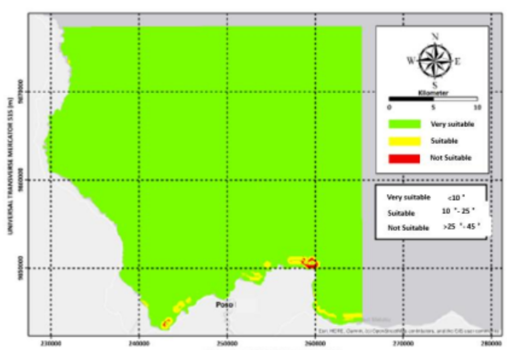

Figure 22. Marine Tourism Suitability Map According to Coastal Slope

3.3.4 Suitability Mapping Results

Based on all parameters that have been mapped according to each sector, value estimation is then carried out to produce the suitability map of the floating net cage grouper shown on figure 23, seaweed cultivation shown on figure 24, and marine tourism shown on figure 25.

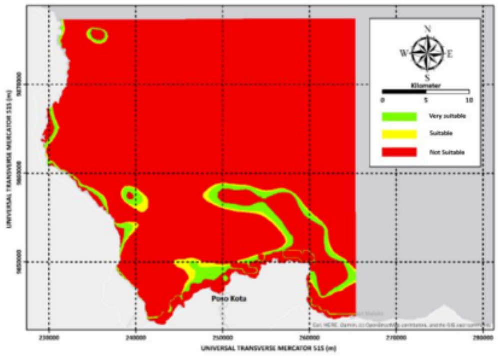

Figure 23. Floating Net Cage Grouper Suitability Map

The final result of the floating net cage grouper map based on the total area are 98466 ha, which 4161 ha shows a very suitable area and 2002 ha shows a suitable area.

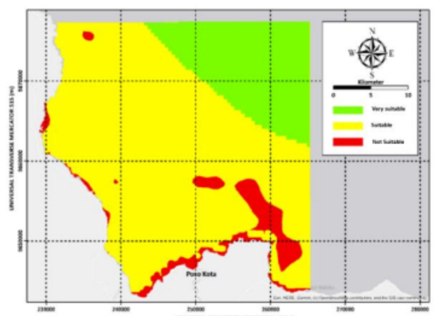

Figure 24. Seaweed Cultivation Suitability Map

The final result of the Cottoni seaweed cultivation map based on the total area are 98466 ha, which 20685 ha shows a very suitable area and 70316 ha shows a suitable area.

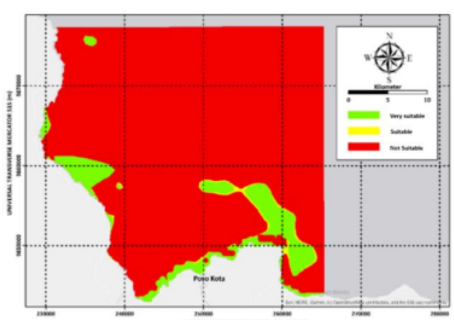

Figure 25. Marine Tourism Suitability Map

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The final result of the marine tourism map based on the total area are 98466 ha, which 7979 ha shows a very suitable area and 1045 ha shows a suitable area. However, the final result of the suitability map are not optimal because several variables are not fulfilled.

4. Disscussion

Suitability map for each content, which are floating net cage grouper, seaweed cultivation, and marine tourism,, may vary based on each parameters required. The use of hydrodynamic model may help the coastal area water simulation to help areas which are having a lot of potential but are yet to be developed. Parameters such as grid sizes and time step taken are important to determine the accuracy of the model. Model E is used because the grid size and time step are rather good and shows no error when it is simulated by using 3 different manning roughness. The simulation data are then applied to ArcGIS software for the AHP processes to determine the suitability map for each sectors.

Based on the results from the AHP processes for each sectors, results may vary due to the differences of seasons, locations, and conditions. The average temperature of seaweed cultivation on Brazil was around 22.17˚C on a growing region and 17.11˚C on a coldest month [7], while the results on Poso region's average temperature 32 – 36˚C which based on the parameter, Poso has better area to cultivate Cottoni seaweed. The researches in Florida shows that it is important for beach size, water clarity, and types of sand for a coastal area to be suitable for a marine tourism spot [6]. Wave height on Italy ranges around 0.01 – 0.4 m [4], which are relatively similar to the condition in Poso Regency to cultivate fishes. The result shows that different location have different conditions for each cultivation sectors. Areas that are located on tropical area have different parameters such as wind speed, water temperature, and area size that areas that are located on sub-tropical areas.

5. Conclusion

The usage of hydrodynamic model simulation can be a method that are used to determine developing area, especially the coastal area. The result of the suitability mapping shows that there are a total of 98466 ha area that are available for development in Poso Regency. 6163 ha of areas are suitable for floating net cage grouper, 91001 ha area are available for seaweed cultivation, and 9024 ha area are available for marine tourism. However, the marine tourism suitability map needs more data such as substrate mapping and mapping of dangerous animals are not available. Data are needed to be research further to get more accurate of suitability mapping. Primary data gathering by the local government is one of the solution for data gathering. This research uses only 4 out of 10 factors which are current speed, coastal slope, water clarity, and water depth to determine the suitability map. As a result, it is anticipated that this research will serve as the starting point for the development of more precise suitability mapping for choosing the right coastal marine tourism on Poso Regency.

6. Acknowledgements

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7. Conflicts of Interest

The authors declare no conflict of interest.

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