Microplastics model distribution in Semarang Waters

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Abstract

The microplastics distribution in Semarang waters is simulated using a two-dimensional coastal model where the microplastics distribution is coupled with the transport equation. The source of the microplastics itself came from the West Banjir Kanal and the East Banjir Kanal river already studied in the previous studies. Semarang Waters also have potential on the fishing ground where this location is vulnerable with this microplastics distribution.

This study is to determine the pattern of current distribution of microplastics pollution with a mathematical model approach on the waters of Semarang Waters. The microplastics pollution distribution that already overlays with the fishing ground area in Semarang Waters shows few places that already contaminated by microplastics. Therefore, we have to increase awareness through education at the public, private and Government sectors that will go a long way in reducing the entry of microplastics into the environment.

Keywords: Microplastics distribution, Two-dimensional coastal model, Fishing ground, Semarang waters.

Introduction

With the increasing reliance on plastics as an everyday needs and rapid increase in their production and subsequent disposal, the environmental implication of plastics is growing concern[16]. Plastic pollution is one of the biggest issues in Indonesian rivers and coastal seas. Indonesia is the second-largest source of plastic waste dumped into the sea worldwide[10]. Part of this waste originates from urbanized deltas where it is transported by rivers to the coastal seas (Figure 1). About 10 percent of all newly manufactured plastics will be discharged through rivers and end to the sea[23]. There are two main rivers (West Banjirkanal dan East Banjirkanal) that flow in the city of Semarang Indonesia. They become the transportation line of almost all kinds of waste (including plastics waste) from the mainland activities to the sea waters.

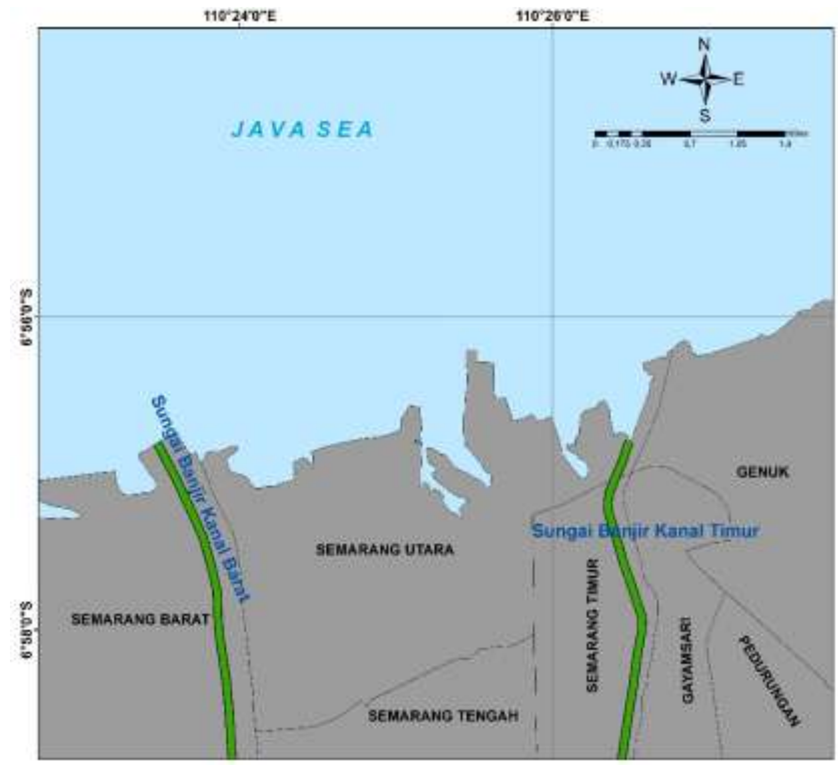

Figure 1: The imagery of the study area around Semarang Waters focuses on West Banjir Kanal, East Banjir Kanal, Semarang, Jawa Tengah

The impact of the amount of plastic waste in the aquatic environment will cause many problems such as pollution of the soil, reducing the aesthetic value (beauty), and the cleanliness of the waters. The decreasing of water quality in the environment has implications of causing various diseases, decreasing biota populations, reducing the productivity of captured fish and even lots of dead fish[5].

Plastic waste reaches the environment; exposure to ultraviolet (UV) radiation causes the photo-oxidation of plastic making it fragile[11]. There are also other environmental factors such as wind, wave, wave action, and abrasion which degrade plastic fragments into macro- (≥ 25 mm), meso- (< 25 mm-5mm), micro- (<5 mm-1µm) plastics size ranges and further nano-plastics (<1 mm) particles respectively[4,12].

The origin of meso-, micro- and nano-plastics in the ocean is attributed to either product that incorporates such particles (such as cosmetics, sandblasting media, virgin pellets) or to the weathering degradation of larger plastics debris in the marine environment[19].

Microplastics were first described as microscopic particles in the region of 20 µm diameter[20]. In this study, microplastics refer to items <5 mm in size using the criteria by US National Oceanic and Atmospheric Administration (NOAA)[1]. Microplastics are divided into primary and secondary microplastics. Primary microplastic is widely used as abrasive and cosmetic. Secondary microplastic is formed from macroplastic by the influence of physical force and photochemical oxidation[7].

Once in the sea, microplastics are transported around the globe by ocean currents where they persist and accumulate[1]. Because of their persistent nature, plastics can be transported and distributed over long distances depending on local winds, ocean currents and geography of the coast line[2.6.9].

Microplastics are suspended in the water column, surface waters, coastal waters, estuaries, rivers, beaches, and deep-sea sediments[16]. Normally, microplastics float at the sea surface because they are less dense than seawater. However, the buoyancy and specific gravity of plastics may change during any time at sea due to weathering and biofouling which results in their distribution across the sea surface, the deeper water column, the seabed, beaches, and even sea ice[2.3].

The polymer plastic particles specified are plastic particles retained in a 0.3 mm filter called a microplastic. The microplastic content in the water column in these waters varies. In Semarang Waters area, the concentration of the microplastic in surface water (0,2D) ranged from 0,0096 - 0,1094 gr/lt while in-depth 0.8D ranged from 0,0014 - 0,04 gr/lt.[24] Based on the fishing ground zone set out in RZWP3K, Semarang has potential fishing ground areas in both the west and east seasons. This study aims to predict the extent of microplastic distribution that occurs in Semarang waters including the fishing ground area.

Material and Methods

The research method is quantitative. Quantitative Method is a systematic, planned method ranging from data collection to data analysis in the form of numbers[22]. The data used in the study consisted of primary data and secondary data. Primary data is in the form of data speed and direction of the flow at one observation station. Field current data will be used to test the accuracy of the model. Water flow data throughout the year is generated from 2-dimensional mathematical modeling. Secondary data consists of wind data for 10 years (2004-2014) with hourly recording obtained from the Meteorology and Climatology Geophysics Agency (BMKG) Semarang, tidal data obtained from the Geospatial Information Agency (BIG), coordinate data and bathymetry of Semarang waters obtained from Center for Hydrographic and Oceanographic Indonesian Navy (PUSHIDROSAL).

The research flowchart illustrates implementation of research presented in the form of the following fishbone diagram.

Current Measurement and Analysis: The accuracy of measurement module is 0.01 cm/s with a maximum column depth of 12m measurement, a maximum of 10 cells can be measured and a minimum layer thickness of 0.8 m with a maximum speed that can be recorded as 6 m/s. This equipment is included with measurements in the dynamic column.

Data recording of the speed and direction of the field current are needed to verify the accuracy of the model. Method is used to determine the sample if the data source is very broad and the sampling is based on a predetermined area[14]. Determination of the flow measurement point is carried out in a safe area and not in a lot of shipping activities.

Field flow data analysis is presented in graphical form so that it is easy to describe. The graphs to be used are time series, current rose and scatter plot graphs (Figure 3 and 4)[21]. The current rose will present the speed of the dominant current, while the scatter plot will present the current data into the U and V components of the current so that the direction of the dominant current will be known. Current data processing is done with the 2 D Numerical Model. Tidal observations are processed using the admiralty method.

The analysis will produce tidal components that will become variables in the mathematical modeling of the current. Besides, the tidal type classification in the waters[18] will be obtained.

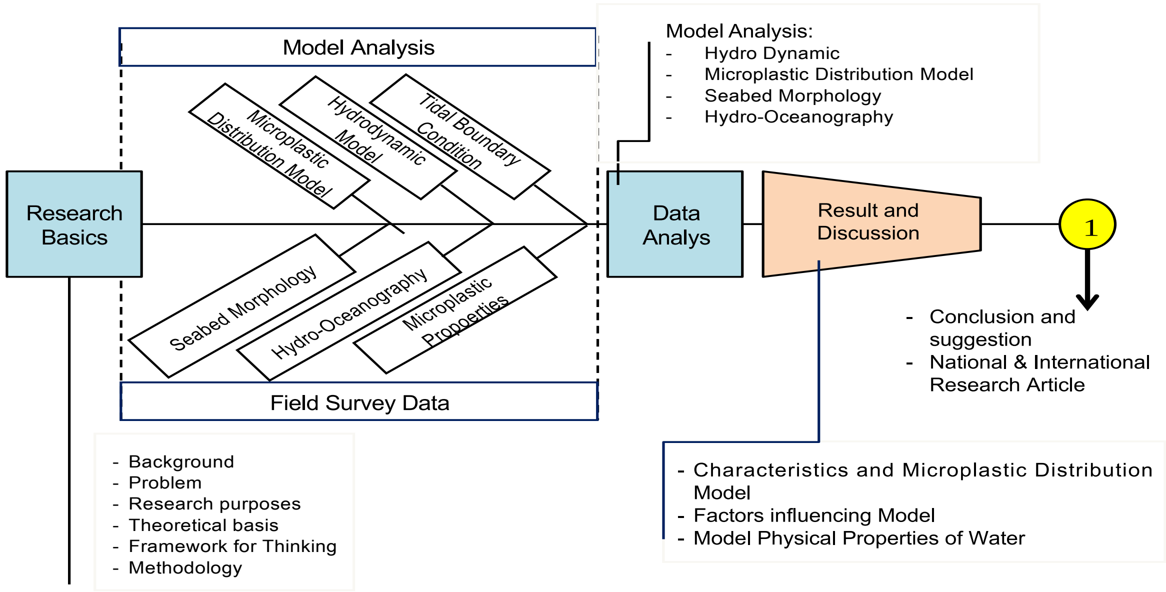

Figure 2: Flow Chart of Research In Fishbond Forms

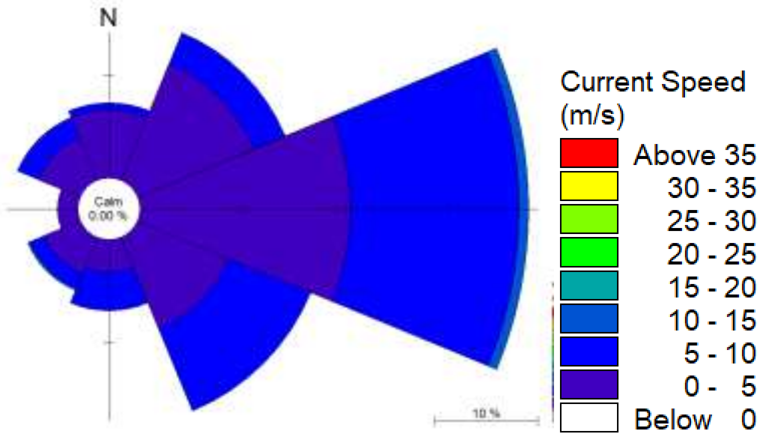

Figure 3: Current rose average measurement of ADCP deployments in Semarang Bay Waters

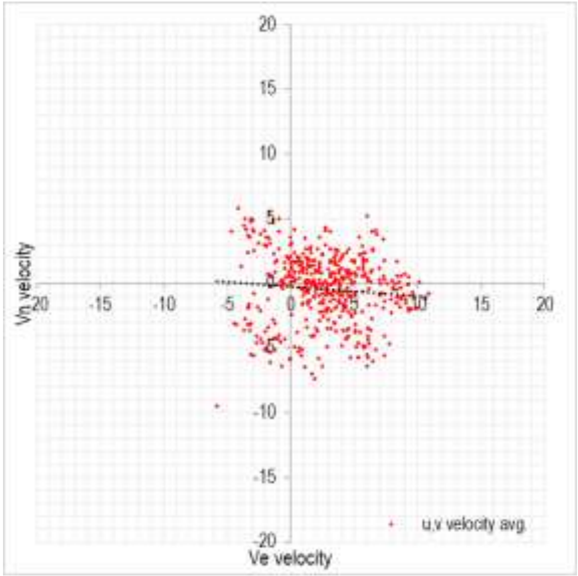

Figure 4: Scatter Plot average measurement of ADCP deployments in Semarang Bay Waters

Mathematic Two-Dimensional Model

Hydrodynamic Models: The basic flow equation used is a two-dimensional flow equation at the average depth (depth-averaged) for sub-critical flow conditions. Flow conditions occur in very wide rivers, so the variation in velocity to depth is relatively small. Gravity acceleration is more dominant than vertical flow acceleration so that the flow equation can be approximated by the shallow water equation.

The average velocity component of depth in horizontal coordinates x and y is defined as follows[13]:

$$U = \frac{1}{H}\int_{zb}^{zb+H} u\, dz \quad (1)$$

$$V = \frac{1}{H}\int_{zb}^{zb+H} v\, dz \quad (2)$$

where H = depth; u = horizontal speed x direction; Z_b = riverbed elevation; v = horizontal speed y direction and $(z_b + H)$ = water level elevation.

The continuity equation for averaged continuity equation can be written as:

$$\frac{\partial H}{\partial t} + \frac{\partial}{\partial x}(HU) + \frac{\partial}{\partial y}(HV) = 0 \quad (3)$$

The momentum equation in the x-axis and y-axis direction for the two-dimensional flow of the average depth can be written as:

$$\frac{\partial}{\partial t}(HU) + \frac{\partial}{\partial x}(\beta_{xx}HUU) + \frac{\partial}{\partial y}(\beta x_y HUV) + gH\frac{\partial Z_b}{\partial x} + \frac{1}{2}g\frac{\partial H^2}{\partial x} + \frac{1}{\rho}\left[\tau_{bx} - \tau_{sx} - \frac{\partial}{\partial x}(H\tau_{xx}) - \frac{\partial}{\partial y}(H\tau_{xy})\right] = 0 \quad (4)$$

For x-axis direction:

$$\frac{\partial}{\partial t}(HV) + \frac{\partial}{\partial x}(\beta_{xy}HVU) + \frac{\partial}{\partial y}(\beta_{yy}HVV) + gH\frac{\partial Z_b}{\partial y} + \frac{1}{2}g\frac{\partial H^2}{\partial y} + \frac{1}{\rho}\left[\tau_{by} - \tau_{sy} - \frac{\partial}{\partial x}(H\tau_{yx}) - \frac{\partial}{\partial y}(H\tau_{yy})\right] = 0 \quad (5)$$

for flow along the y-axis; with $\beta xx, \beta xy, \beta yy$ momentum correction coefficient; g = acceleration due to gravity; ρ = water mass meeting; τ_{bx}, τ_{by} = basic shear stress; τ_{sx}, τ_{sy} = surface shear stress; $\tau_{xx}, \tau_{xy}, \tau_{yy}$ = shear stress due to turbulence (e.g. τ_{xy} is the shear stress in the x-axis acting on the perpendicular plane of the y-axis).

The shear stress component on the basis in the x and y-axis direction is calculated as follows:

$$\tau_{bx} = \rho c_f U\sqrt{U^2+V^2}\left[1 + \left(\frac{\partial z_B}{\partial x}\right)^2 + \left(\frac{\partial z_B}{\partial y}\right)^2\right]^{1/2} \quad (6)$$

$$\tau_{by} = \rho c_f V\sqrt{U^2+V^2}\left[1 + \left(\frac{\partial z_B}{\partial x}\right)^2 + \left(\frac{\partial z_B}{\partial y}\right)^2\right]^{1/2} \quad (7)$$

where c_f is the basic friction coefficient that can be calculated as:

$$c_f = \frac{g}{C^2} = \frac{gn^2}{\lambda^2 H^{1/3}} \quad (8)$$

where C = Chezy coefficient; n = Manning's roughness coefficient; dan λ = 1,486 when using British units and 1.0 when using international units (SI).

Simplifying the calculation, the eddy value of the average kinematic viscosity of depth is considered isotropic (it is assumed that the value $\nu_{xx} = \nu_{XY} = \nu_{yx} = \nu_{yy}$) and eddy isotropic viscosity is denoted by the value (0,3 ± 0,6 U_*H).

Particle Tracking Models (case: microplastic): The transportation equation used is formulated as follows[21]:

$$\frac{\partial C}{\partial t} + u\frac{\partial C}{\partial x} + v\frac{\partial C}{\partial y} = \frac{\partial}{\partial x}\left(D_x\frac{\partial C}{\partial x}\right) + \frac{\partial}{\partial y}\left(D_y\frac{\partial C}{\partial y}\right) + \alpha_1 C + \alpha_2 \quad (9)$$

where *C* = microplastic concentration, kg/m^3; *t* = time, detik; *u* = direction velocity flow x, m/d; *v* = direction velocity flow y, m/d; D_x = the direction coefficient of dispersion x, m^2 /d; D_y = the direction coefficient of dispersion y, m^2/d; α_1 =source term coefficient (erosion-deposition), 1/sec; α_2 = balanced concentration of source terms (erosion-deposition), kg/m^3/d = - $\alpha_1 C_{eq}$.

The type of plastic waste used is microplastic where microplastic concentrations have been analyzed in previous studies using microplastic analysis in water samples according to NOAA Standards [17].

Model Scenario: Hydrodynamics and the microplastic dispersion model are simulated by inserting force-generating tidal and wind. The simulation was performed under various scenarios with tidal conditions shown in table 2.

Domain Area: The input for the model is bathymetry and coastline data. The model domain (Figure 6) is divided into land and water boundary condition. The model process begins with dividing the domain area continued with input parameter value, time control and running the model. The hydrodynamics model process is shown in table 3.

Model Validation: The validation in this model used the RMS (Root Mean Square) method where RMS is a non-dimensional value to indicate a match for two kinds of data. The set values of model are defined by b_1, b_2,..., b_n while the measurement is defined by a_1, a_2,..., a_n, so we have [8]:

$$X_{rms} = \left(\frac{\sqrt{\Delta x_1^2 + \Delta x_2^2 + \cdots + \Delta x_n^2}}{n}\right) \text{where } \Delta x_n = b_n - a_n \quad (10)$$

Table 1
Configurations of ADCP deployments in Semarang Bay Waters. Its configuration used for these measurements is not appropriate to quantify turbulence, but a representative current trace over several days highlights its significance.

Configuration	Station measurement set
Deployments dates	9/05 – 12/05 2019
Duration (days)	3
Deployment depth (m)	12 meters
Vertical bin size (m)	1.2 meters
Layers (m)	10 layers
Ensambles interval (s)	600s – 3600s
Blank distance (m)	0.8 meters

Table 2
Time scenario of simulation in Semarang Bay Waters.

S.N.	Elevation Level	Lunar Condition	Date
1	Ebb to Flood	Spring	12/05/2019 19:00
2	High Flood	Spring	12/05/2019 23:50
3	Flood to Ebb	Spring	13/05/2019 04:30
4	Low Ebb	Spring	13/05/2019 08:00

Table 3
Source of microplastic as a pollutant in Semarang Bay Waters.

Source	Longitude	Latitude	Depth (m)	Microplastic	Number of Particle
Banjir Kanal Barat	110.39775°	-6.95423°	-2	Polymer	400
Banjir Kanal Timur	110.44192°	-6.94777°	-2	Polymer	400
Semarang Port	110.420476°	-6.947611°	-2	Polymer	400

Results and Discussion

Particle Tracking Simulation Result: Modeling simulation results for currents which include the speed and direction of the current are shown in fig. 9. Validation results are displayed in fig. 7. Fig. 8 displayed on tidal elevation and visual scatter. Model validation uses flow measurement data that has been carried out in Semarang waters. The validation results of 2D flexible mesh numerical modeling show the calculation of the Root Mean Square (RMS) and obtained a large value of the model error against the value for each component of the current, u-velocity 0.0001 m/s v-velocity 0.0001 m/s, and water elevation of 0.002 m. The tolerance limit for water level is 0,1 meter while the speeds to within 0.2 m/s show that the model can be accepted with a small error tolerance.[8]

The results of modeling carried out using 2D flexible mesh numerical modeling are shown in figure 7. Spring conditions at elevation are shown in table 2. When elevation is receding towards the tide to the southeast with a speed of 0.1 m/s to 0.2 m/s, the current is directed towards the northeast direction with variations in the speed of 0.09 m/s - 0.15 m/s. Currents at the highest tide conditions have a westward motion pattern with velocity variations of 0.05 m/s - 0.1 m/s. Currents at low tide to high tide conditions in figure 9 show the movement of currents westward with a higher variation in the velocity of 0.1 m/s - 0.2 m/s. When the elevation shows the lowest ebb, the current moves towards the west with relatively low-speed variations ranging between 0.01 m/s - 0.05 m/s.

The results of modeling figure 10 are particle tracking simulations displayed in 4 conditions with time intervals at low tide, high tide, low tide, and low tide. The current movement in May as shown in figure 7 shows the dominant current movement towards the west with a variation in the velocity of 0.04 m/s to 0.2 m/s.

The current is external energy that transports several suspended materials including microplastic particles with a variety of concentrations. This process then becomes an advection force for several concentrations of non-conservative pollutants such as microplastic. Figure 8 shows particles and microplastic concentrations moving westward.

Based on the results at low tide toward the particle tides originating from the west canal, floods move further towards the northwest due to Slamming discharge from the west canal flood. Meanwhile, the source of the east canal flood moves towards the northwest with a slightly lower transport speed. Concentrations around the port are relatively higher due to the relatively low current speed around the waters of the Port of Semarang.

Table 4
Source of microplastic as a pollutant in Semarang Bay Waters.

Parameter	**Description**
File Specification	Particle Tracking
Hydrodynamic Simulation period	Scenario: 07 May 2019 – 15 May 2019
Mesh and Bathymetry	Semarang Bay mesh 14879 node
Particle Simulation period	Scenario: 07 May 2019 06:00 – 15 May 2019 08:00
No. Timestep	1200
HD: Solution technique	High order, fast algorithm The Minimum time step 0.01 s Maximum time step 600 s CFL 0.8
HD: Flood and dry	Active
HD: Initial Surface Level	0.3 m
HD: Wind	Varying in time, constant in domain Ogimet_wind (file)
HD: Wind friction	Constant :0.0025
HD: Eddy viscosity	Smagorinsky formulation 0.22
HD: Bed Resistance	Manning number. Constant value 28 $m^{1/3}/s$
HD: Source	• Banjir Kanal Barat debits on May: 1273.872 – 1748.88 m^3/s • Banjir Kanal Timur debits on May: 50 – 368.3 m^3/s
PT: Hydrodynamics	Decoupled result: Hydrodinamic_Semarang_Bay
PT: Number of Classes	1 (Microplastic_polymer)
PT: Number of Source	3 source Flux : Constant 100 Ug/sec
PT: Decay	No (Non-conservative particle)
PT: Settling	No (Non- swimming style)
PT: Dispersion	Scaled eddy viscosity formulations
PT: Drift Profile	Use raw data from hydrodynamics
PT: Result	The Total mass, Patikel on Z- coordinate
CPU Simulation Time	12 hr 35 Min with 3,6 GHz PC, 32 GB RAM

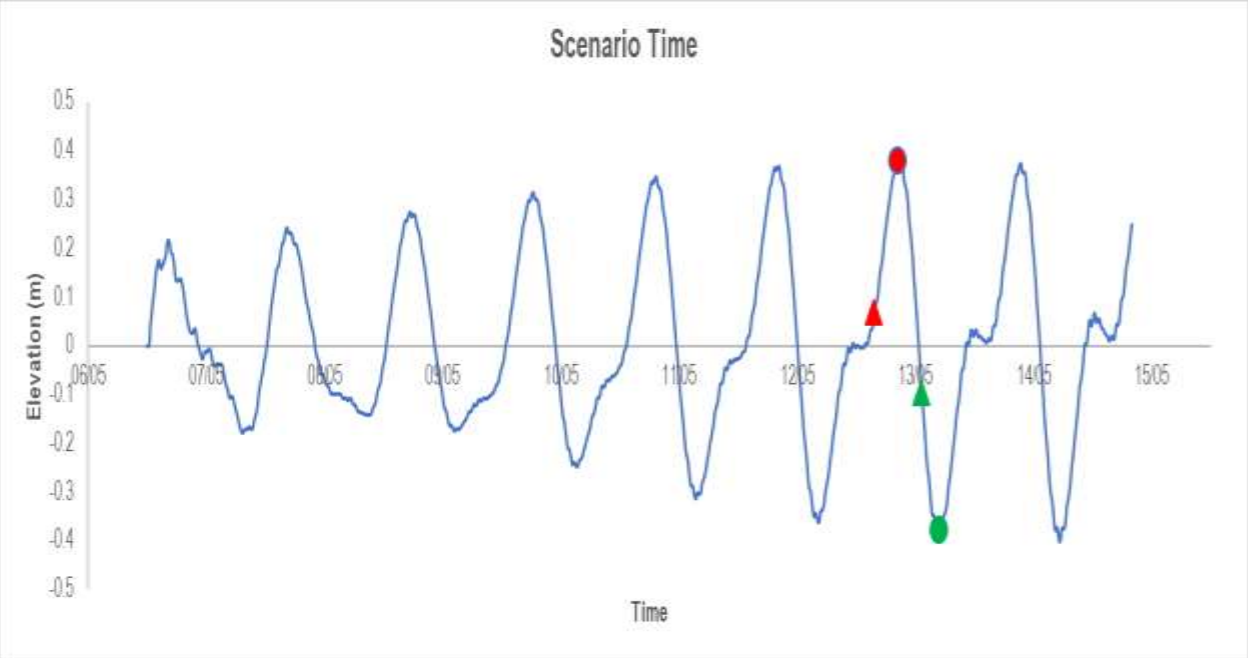

Figure 5: Scenario time for simulation result around Semarang Waters, focus on Banjir Kanal Barat, Banjir Kanal Timur, Semarang, Jawa Tengah

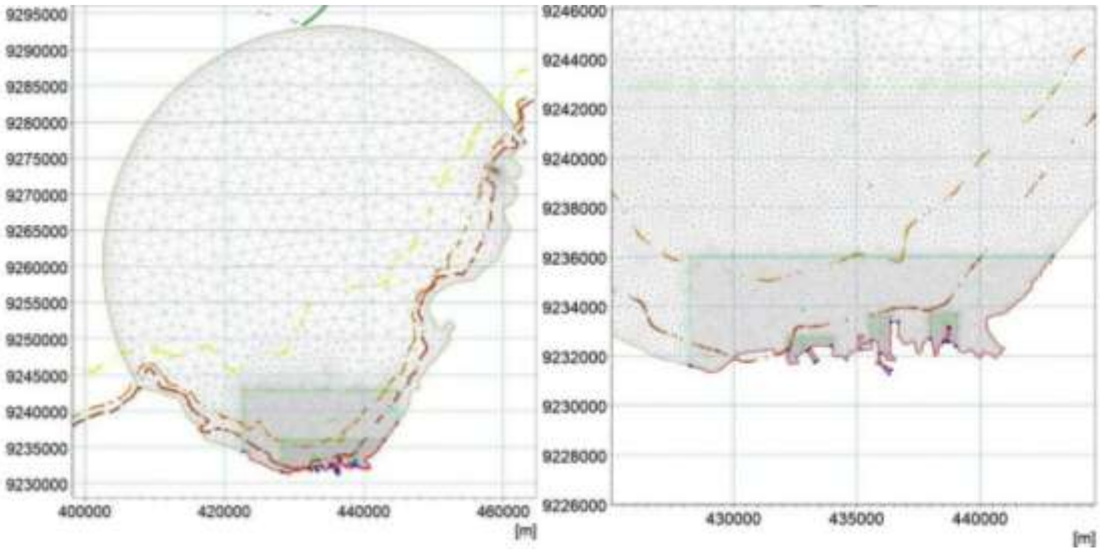

Figure 6: Domain Model in Semarang Waters.

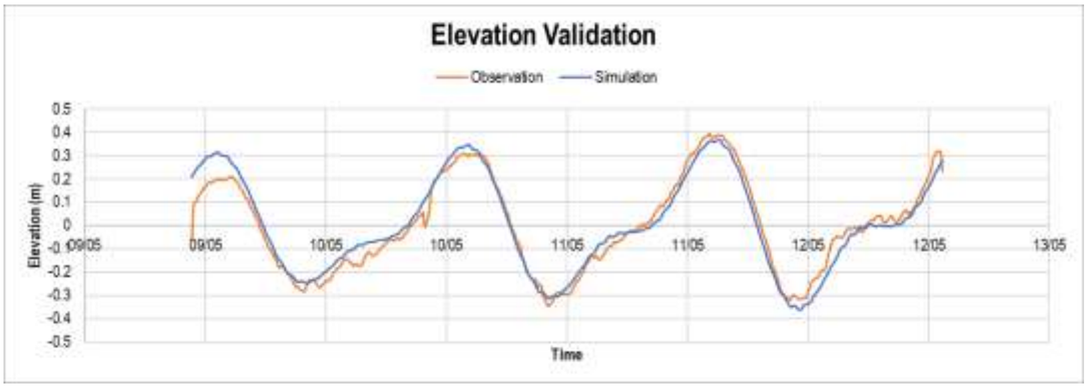

Figure 7: Comparison between observation with simulation on (a) Elevation level

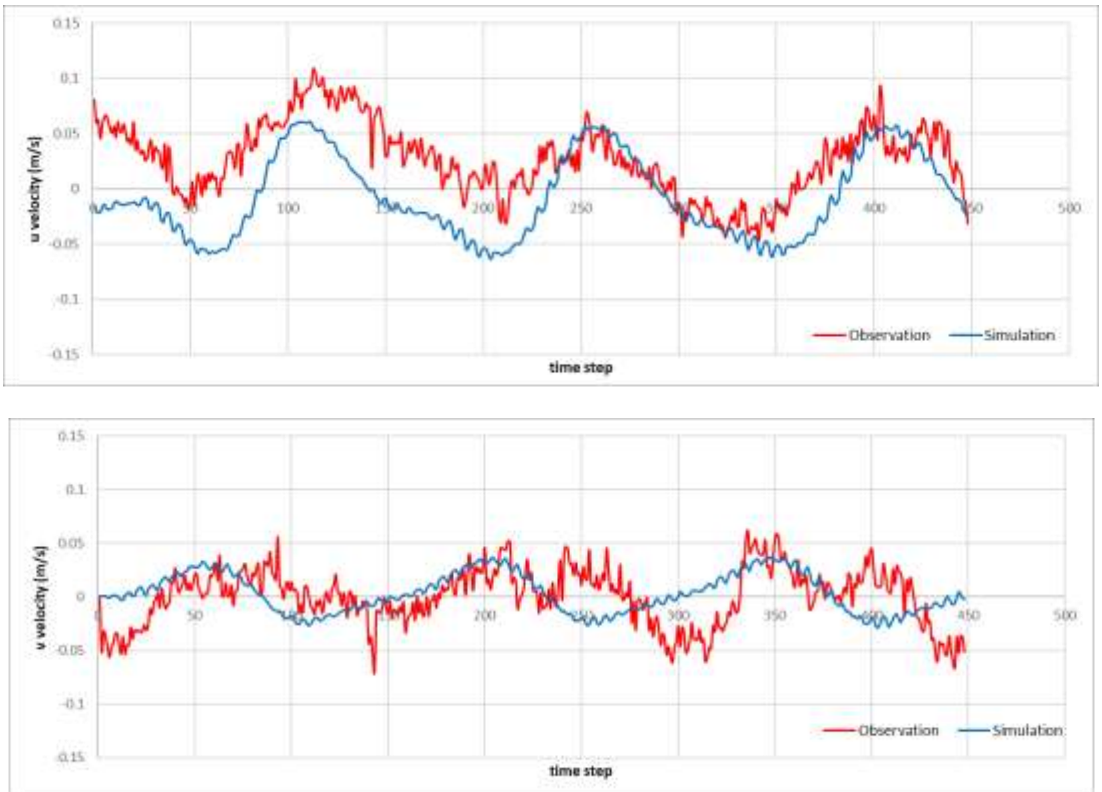

Figure 8: Comparison between observation with simulation on (a) u- velocity, and (b) v – velocity

The results of microplastic pollutant contamination have been compared with the results of the spatial fishing ground area of fishermen around the waters of Semarang. Figure 10 shows that the fishing ground areas are exposed to microplastic concentrations. Concentrations in each area varied between 0.003 gr/lt - 0.15gr/lt. This concentration is higher in areas close to the source allowing indications of catches of Semarang coastal fishermen exposed to this pollutant.

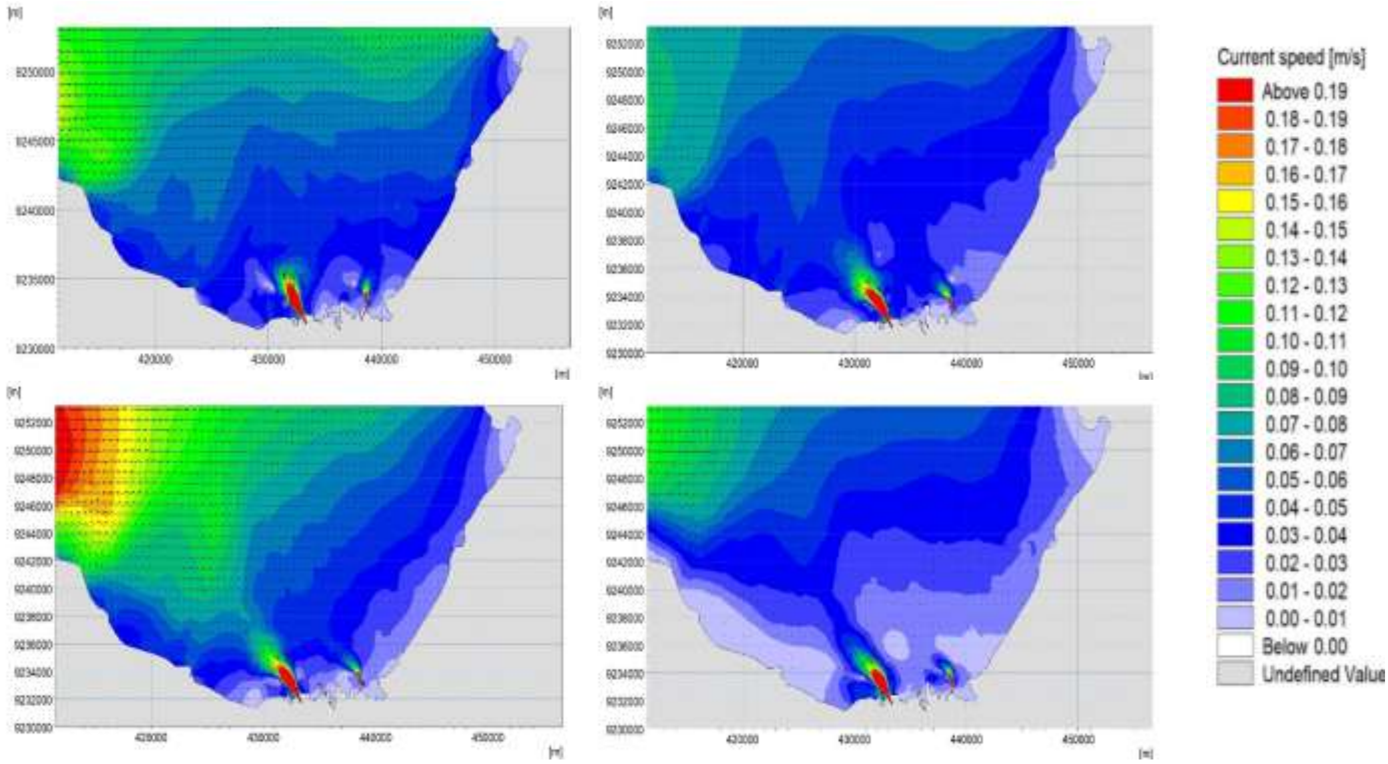

Figure 9: Current patterns of Semarang Bay waters, in full moon conditions with elevation variations; top left down: low tide towards high tide, high tide, high tide toward low tide and low tide

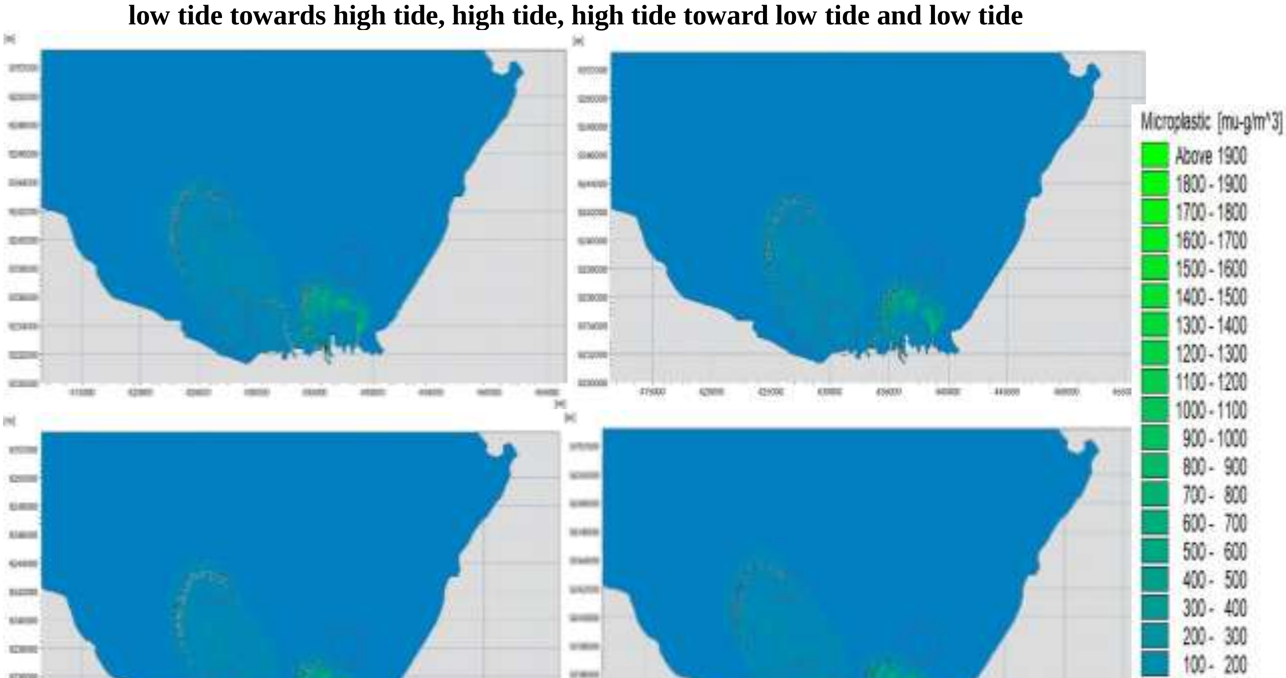

Figure 10: The distribution pattern of concentrations and microplastic particles is compared with the fishing ground (black circle) under various conditions of water elevation in full moon conditions, with variations in elevation; top left down: low tide towards high tide, high tide, high tide toward low tide and low tide

Particle Tracking Simulation Result on Monsoon: The simulation results on the microplastic concentration scenario are also carried out in several months which is the highest condition of each season. Indonesia has 4 seasons, each of which is the west season (January), Transition Season 1 (May), East Season (July) and Transition Season 2 (October). West season is shown in figure 11, there are 4 fishing ground locations which are the main fishing ground areas along the northern coast of Semarang. These four areas are aimed at exposure to microplastic concentrations with intervals of 0.004 gr/lt to 0.02gr/lt. The location close to the coast has a high concentration of exposure which is 0.02gr/lt.

Transition Season 1 shown in figure 12 shows that there are indications of fishing ground areas for fishermen with contaminated microplastic concentrations. Concentrations in each area varied between 0.003 gr/lt - 0.15gr/lt. This concentration is higher in areas close to the source allowing indications of catches of Semarang coastal fishermen exposed to this pollutant. The East season shown in figure 13 shows the season with the wind moving from the east, heading west. This greatly affects the distribution pattern of microplastic contamination concentrations. The fishing ground area in this condition has 7 large areas, 6 of which are indicated by microplastic contamination with concentrations ranging from 0.0001 gr/lt to 0.07gr/lt.

Season 2 shown in figure 14 shows the distribution along the tidal elevation in the full moon (spring). Wind conditions are a driving factor showing the distribution of microplastic concentrations moving east and north. Transition season condition 2 has 4 fishing ground areas, 3 of which are exposed to microplastic contamination concentrations at intervals of 0,0009 gr/lt to 0.0569gr/lt. Pollution concentrations with a high category can be found in fishing ground areas close to the coast.

The four-season model results are a representation of the contamination of microplastic concentrations. Some fishing ground areas display the season showing indications of being not polluted. Most fishing ground areas show exposure to contamination concentrations ranging from 0.00001 gr/lt to 0.15gr/lt.

Conclusion

Based on the results of the research, it can be concluded that most of the microplastic distribution in the West Banjir Kanal is wider but relatively of smaller concentration than the East Banjir Kanal area because the discharge is higher in West Banjir Kanal. In each Monsoon Season the fishing ground area, especially in the West banjir kanal, is indicated exposed by microplastic and some in East Banjir Kanal.

The predicted fishing ground of Semarang is exposed to concentrations of microplastic pollutants with concentrations of 0.003 gr/ lt to 0.15gr/lt, where the highest value is located in areas close to the coast.

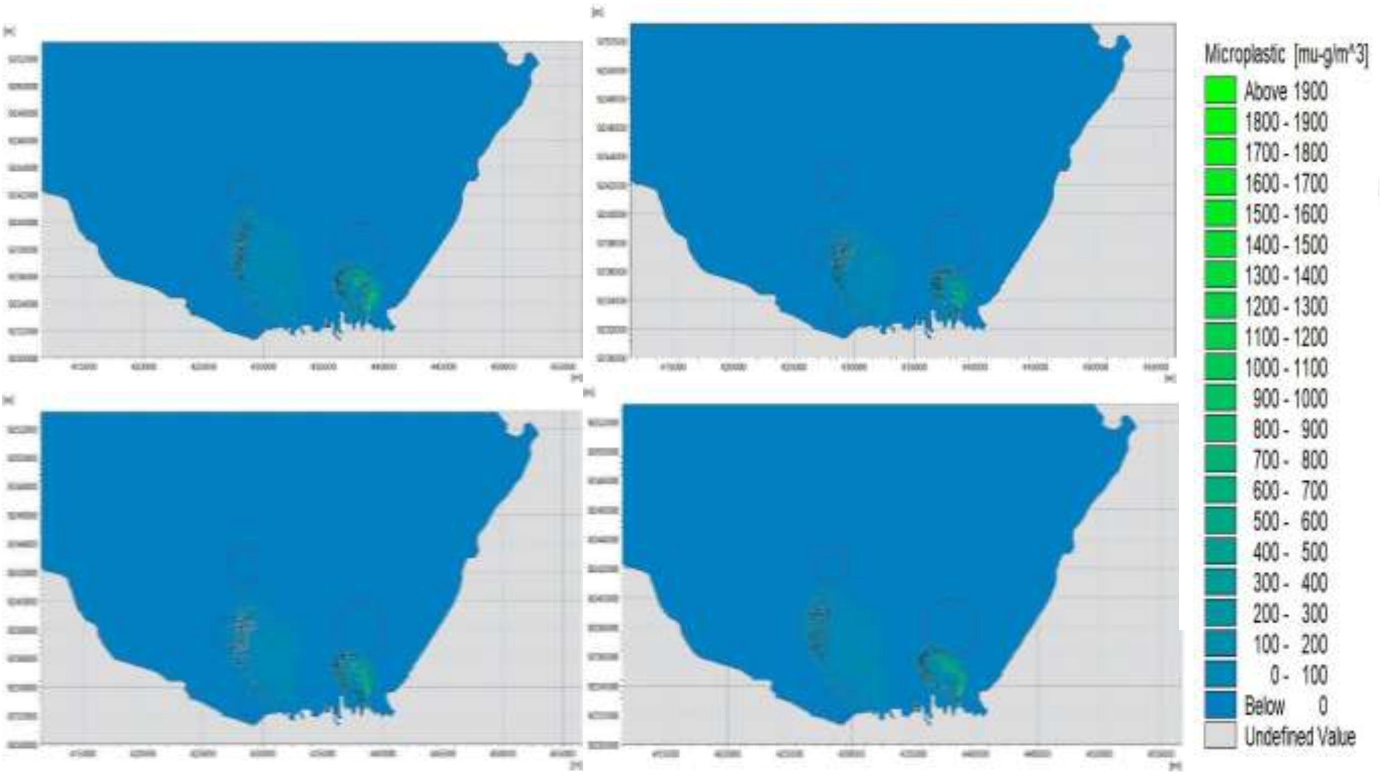

Figure 11: The distribution pattern of microplastic concentrations is compared with the fishing ground (black circle) in some water elevation conditions in the full season of the West Season, with variations in elevation; top left down: low tide towards high tide, high tide, high tide toward low tide and low tide

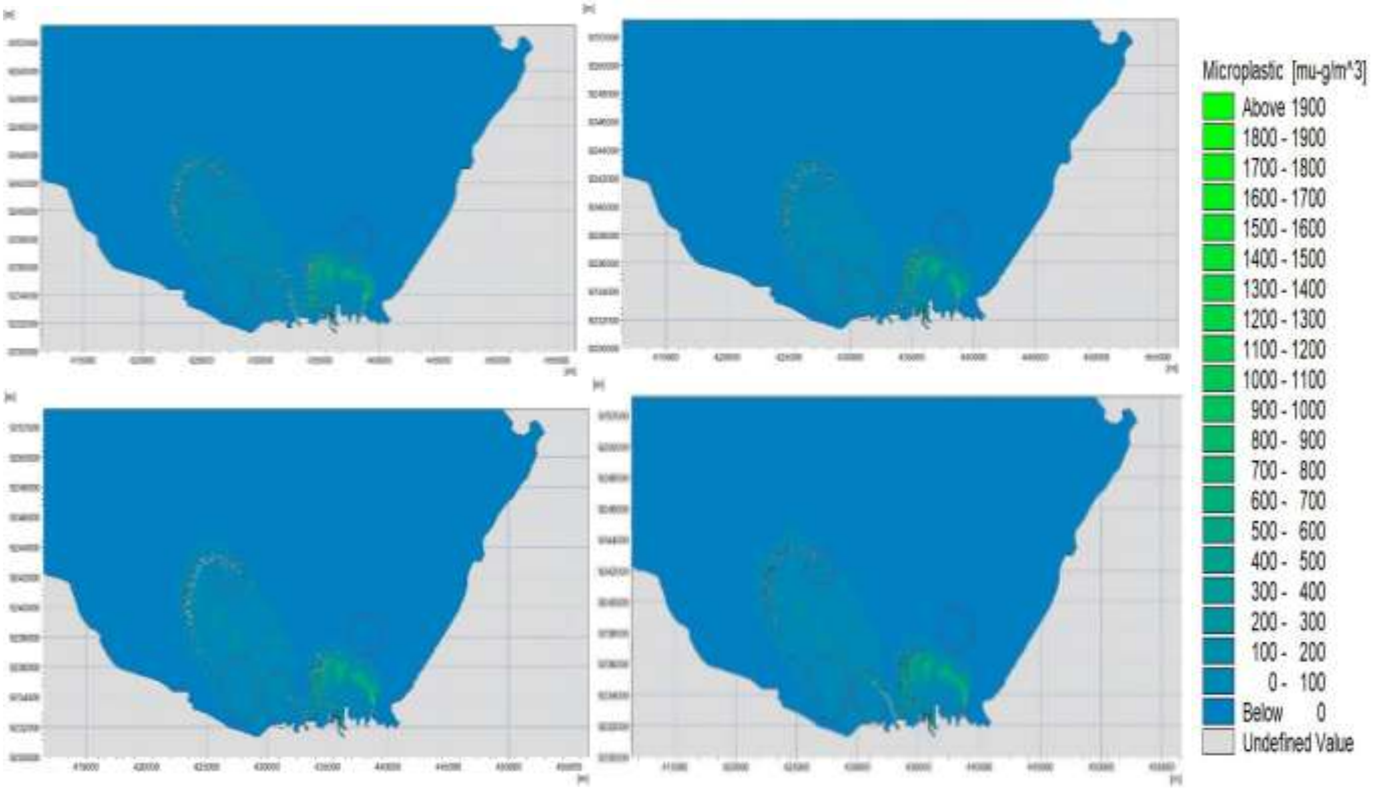

Figure 12: The distribution pattern of microplastic concentrations is compared with the fishing ground (black circle) in some water elevation conditions in the full moon conditions (spring) Transition Season 1, with variations in elevation; top left down: low tide towards high tide, high tide, high tide toward low tide and low tide

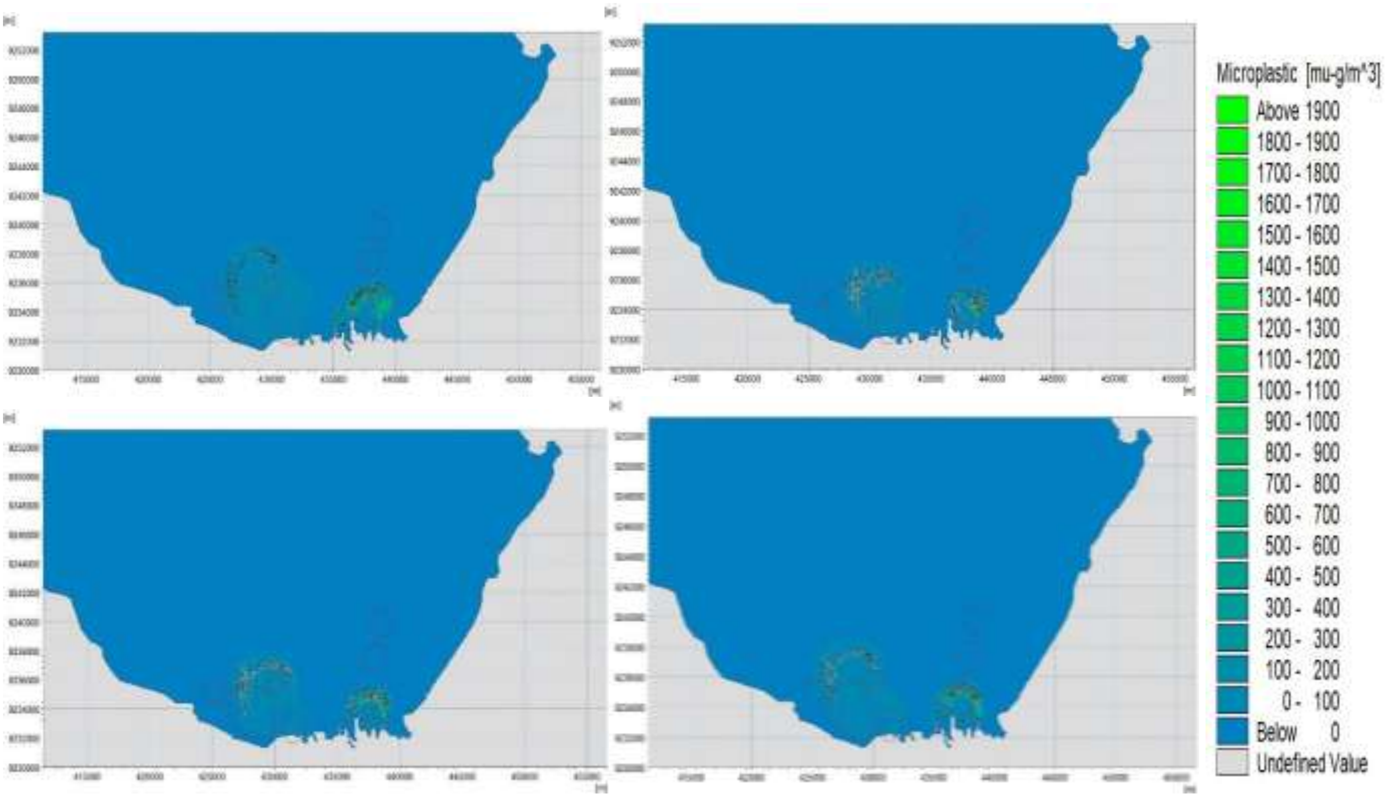

Figure 13: The distribution pattern of microplastic concentrations is compared with the fishing ground (black circle) under several conditions of water elevation in the condition of the full moon (spring) of the East Season, with variations in elevation; top left down: low tide towards high tide, high tide, high tide toward low tide and low tide

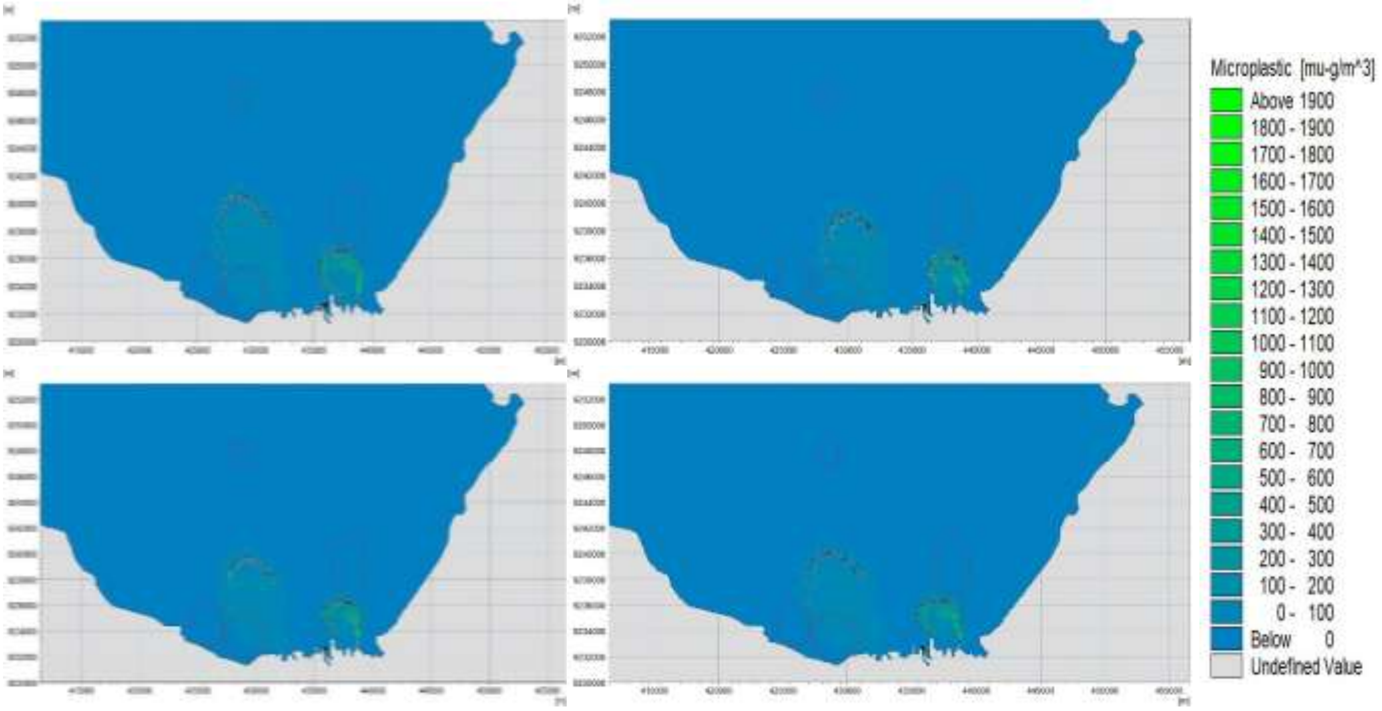

Figure 14: The distribution pattern of microplastic concentrations is compared with the fishing ground (black circle) in several water elevation conditions in the full moon conditions (Spring) Transition Season 2, with variations in elevation; top left down: low tide towards high tide, high tide, high tide toward low tide and low tide

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