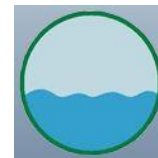




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Particle tracking simulation of marine debris using Lagrangian discrete and mesh spatial discretization in Banda Aceh waters

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ABSTRACT

Ocean dynamics has a direct impact on the distribution of objects or dissolved particles such as marine debris. Hydrodynamic studies are currently an important tool to identify the potential pollution in the region. Data were collected from March to September 2019 in the northern waters of Banda Aceh. Wind data were obtained using AWS and bathymetry data were collected using the single beam echosounder. The results showed that the wind direction on the coast of Banda Aceh City was dominant towards the Northwest and Northeast with a maximum speed of 9 m/s. Wind direction will highly influence the sea surface currents dynamics that lead to longshore currents and radiation currents occur in coastal areas.

Introduction

Ocean dynamics have an extensive scope, ranging in size from millimeters to thousands of kilometers. The dynamics and movement of water masses directly impact the distribution of mass and dissolved or suspended particles in the water column, such as plankton, sediment, nutrients, heat, salinity, and even marine debris (Rizal *et al.*, 2010; Supiyati *et al.*, 2011; Setiawan *et al.*, 2018; Setiawan *et al.*, 2019).

The conditions and dynamics of a very complex coastal area require calculations that are more than just a simple numerical scheme (Zhang *et al.*, 2013; Kline *et al.*, 2014; Brand *et al.*, 2020). Spatial discretization equations are used to calculate the dynamics of continuity based on geometric space (mesh) and Lagrangian equations in determining the numerical scheme. The Lagrangian method uses the virtual movement of particles that follow the mass transport of water (Bennett, 2006; Amemou *et al.*, 2020), hence the method were then used to describe the mass transport pattern of water formed in an area (Mancho *et al.*, 2006; Bettencourt *et al.*, 2012; Van-Sebille *et al.*, 2018).

Model discretization is a process of transforming a continuous (infinite) model into a discrete (finite) model. The discretization process is carried out by derivating partial differential equations into finite difference equations. Discrete computations can be performed using the Mike21 software (Warren and Bach, 1992) a comprehensive modeling software to simulate hydraulic patterns in the coastal, estuary, or marine areas. The advantage of this software is that it creates a two-dimensional model that is easier to calculate, especially for applications in sea-level areas.

The condition of the Banda Aceh waters which are adjacent to the Indian Ocean, the Malacca Strait and the Andaman Sea makes this water area very dynamic. (Rizal *et al.*, 2012; Ondara and Dhiauddin, 2020). As a city located at the northern tip of Sumatra Island, Banda Aceh has a strategic position contributing to the increasing ship traffic activity (Figure 1). Other impacts arising from anthropogenic activities are the presence of waste and sewage generated from human activities (Anderson *et al.*, 2014). The waste disposals are mainly carried from the river flows into the coastal water environment

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and carried to the sea (Eerkes-Medrano *et al.*, 2015; Hermabessiere *et al.*, 2017). The sewage that flows into the sea influenced the simulation of hydrodynamic conditions making it essential to understand the distribution patterns and tracing of waste trails through particle tracking simulations in Banda Aceh waters. The results of this study can be used as a basis for policymaking in the development of regional potential and mitigation of marine debris pollution in the waters of Banda Aceh City.

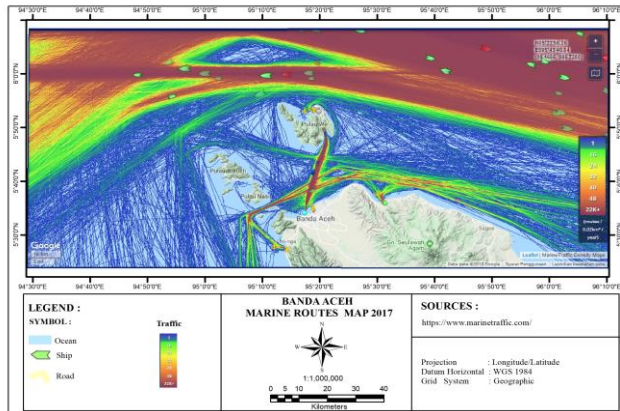


Figure 1. Ship tracking activity in Aceh waters.

Materials and Methods

Research location

The research was conducted in Banda Aceh waters from March to September 2019. Wind data collection (speed and direction) was measured using an Automatic Weather Station (AWS) installed at an altitude of 6 meters at coordinates 756649.00 E; 617512.00 N. AWS recording data was collected in April 2019 and June-September 2019.

Data setup

Bathymetry data were measured using a single beam dual frequency echo sounder conducted along the coastal area of Banda Aceh City. Bathymetric map data layout combined with the Dishidros bathymetry data to obtain a wider depth coverage area. The tidal data was collected from the forecasting data using the least square method from January to September 2019. The tidal data produced the tide and ebb values of the full moon and tides types. The currents characteristics were obtained using a 3D model using the flexible mesh method to determine the currents and waves patterns for each tide condition.

Marine debris particle tracking simulation used hydrodynamic data obtained from currents and waves modeling (raw data derived from hydrodynamics). Particles input for the simulation were classified into 6 different classes based on the mass, which are 0.01 μg ; 0.01 mg, 0.1 mg; 1 gram; 100

grams and 500 grams. The selection of the mass size was based on the marine debris findings, which were found when collecting data on the debris mass along the coastal area. The parameters used in the particle tracking simulation are shown in Table 1. The initial condition of the particles (source initial condition) was collected in 4 different locations (Figure 2). Each of these locations is located, namely: first at 95.2388 E, 5,592 N; second at 95.2830 E, 5.6628 N; third at 95.3796 E, 5.6515 N and; fourth at 95.3122 E, 5.5846 N.

Table 1. Marine debris simulation parameters.

Variable	item
Time simulation	01/01/2019 00.00.00 – 06/05/2019 00.00.00
Timestep	3600 s
Flood and dry	Drying depth : 0,005 m Flooding depth : 0,05 m Wetting depth : 0,1 m
Density	Barotropic
Eddy viscosity	Smagorinsky formulation 0,28
Bed resistance	Manning number 32 $\text{m}^{1/3}/\text{s}$
Shallow water eq	High order time integration High order space discretization
Settling particle	Include flocculation 0,1 m/s

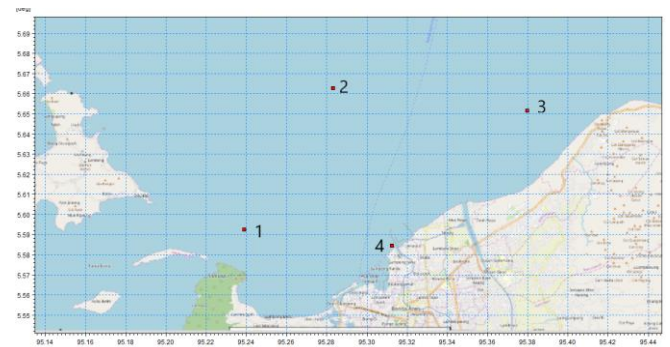


Figure 2. Marine debris initial location in particle tracking simulation.

The location selection was based on selecting the primary source of debris in 4 different directions to determine the sources of debris in the coastal areas. In each initial condition, there were 6 different debris classifications to determine the distribution of each class measured for marine debris collection. The output of this simulation is the final location and depth of the particles

Results

Wind

Wind speed and direction measurements were collected in July-September 2019 with a time step of every 30 minutes. This measurement was carried out to determine the dominant wind direction in the coastal area of Banda Aceh City because the surface

wind is one of the factors that mainly influence the direction of the water waves.

The measurement results showed different wind directions in April and June-September (Figure 3). In April, the dominant wind direction was towards the northwest, while in June-September 2019, it was towards the northeast. The data obtained in April showed the wind speed ranging from 0 m/s - 6.4 m/s. From the wind rose chart, it can be seen that the dominant wind was towards the Southwest with dominant speed ranging from 0-2 m/s. From June to September 2019, wind speed ranging from 0 m/s to 9.1 m/s. Figure 3 shows that the dominant wind direction is towards the northeast with a dominant speed ranging from 2-4 m/s.

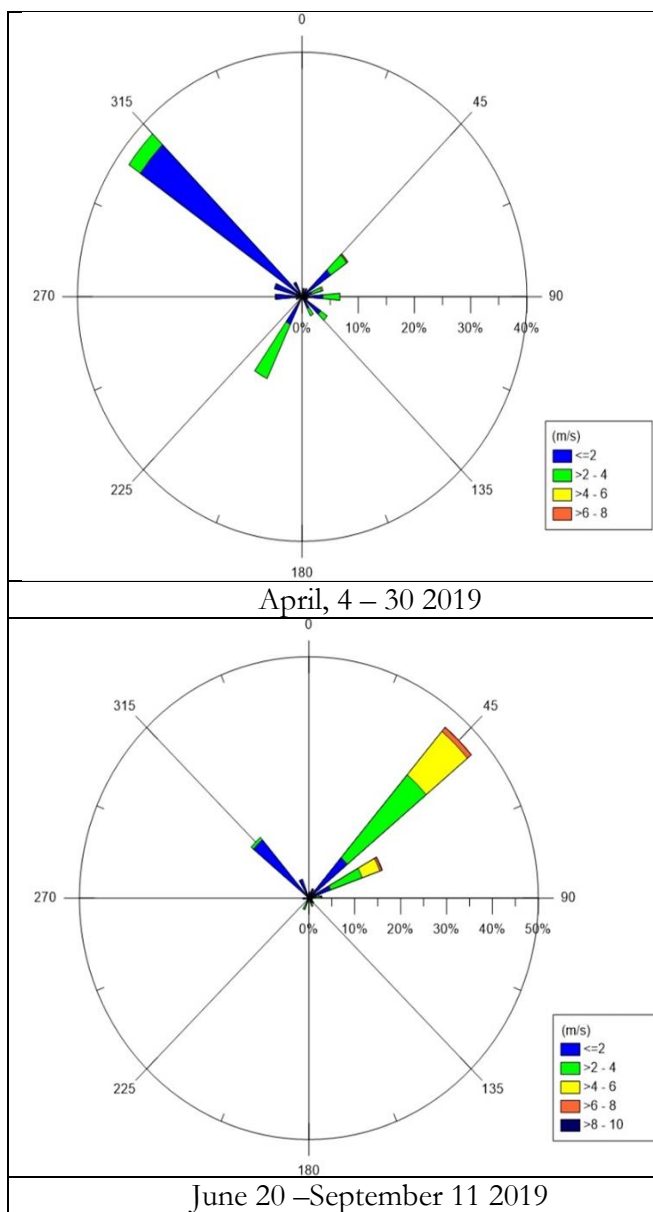


Figure 3. Banda Aceh coastal wind rose.

Bathymetry

The depth of the Krueng Aceh River was measured using a dual-frequency teledyne

odometer echo track. The working principle of this tool is an acoustic signal emitted to the bottom of the water. The depth obtained was the real-time depth which was connected to the GPS antenna to determine the position of the measured depth. The recording data of the water depth measuring device were in the form of raw data, which were then processed to obtain the true depth value. The tidal reduction was performed to determine the fluctuations in the depth values obtained against tidal conditions of the bathymetry measurements. The reference for the depth used was the sea level for the nearest tidal station, namely Sabang Station, which was processed based on observations for 30 days. Secondary bathymetry data were used, obtained from BIG, NGDC, BODC, BPPT, LIPI, P3GL, and other institutions with a spatial resolution of 6 arc-second datum MSL to complete the bathymetry data that was not included in the measurement area (Ondara et al., 2018).

The depth of the Krueng Aceh and Lampulo rivers was divided into 2 (two) areas: the depth in the river and the depth in the sea. The depth of the Krueng Aceh -river was limited to the end of the estuary (Figure 4), while the depth in the sea is limited from the estuary to 650 meters to the sea. The water's ground state shape was described in a 2 (two) dimensional state in the form of contour lines containing the depth value.

The depth of the waters at Ulee Lheue ranges from 0-4.5 meters in the coastal area to a distance of 370 meters to the high seas (Figure 5). Meanwhile, in the river area, has a maximum depth of 7.6 m. The depth under the bridge is 2.5-4.5 meters, the darker the color of the waters indicates that the area is an area that has a deeper depth among other colors.

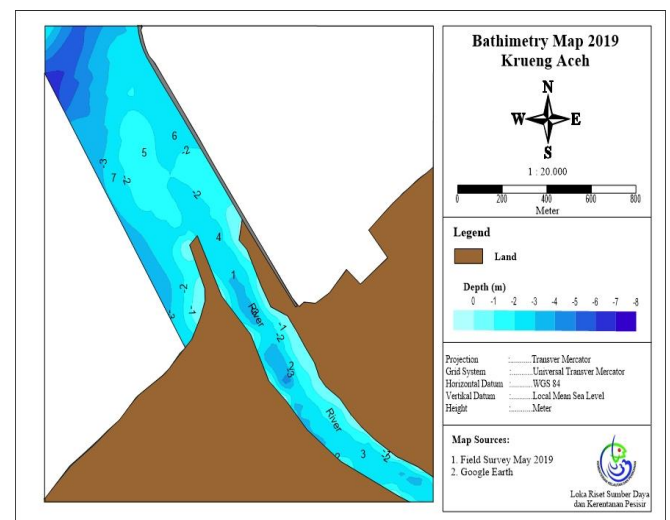


Figure 4. Bathymetry map of the Krueng Aceh River.

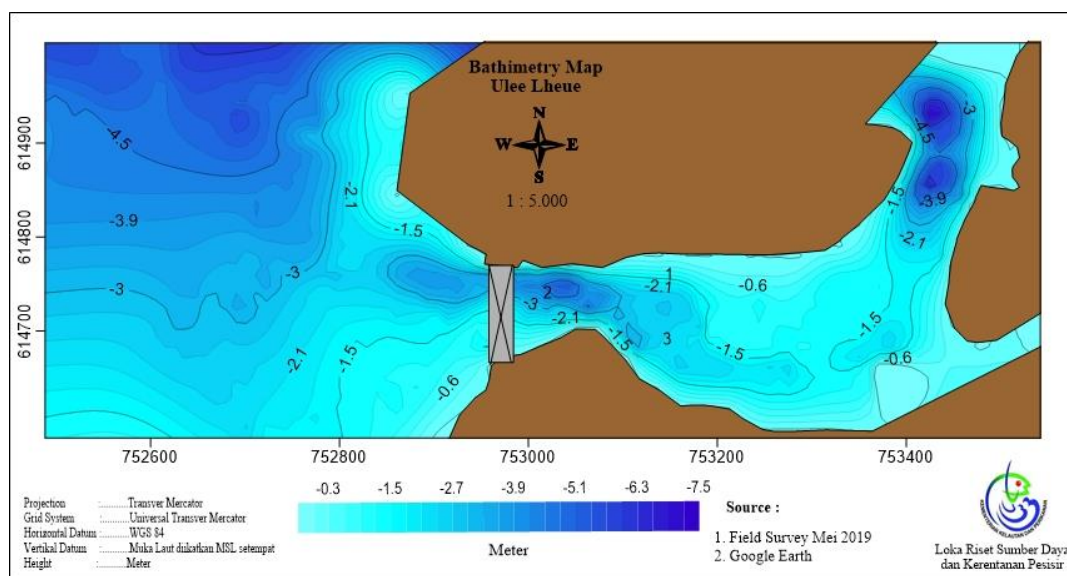


Figure 5. Bathymetry map of Ulee Lheue.

Figure 6 is a depth image of the local fishing boat Ulee Lheue shipping lane. The maximum depth at the study site is 8.5 meters. These results were the result of field data processing using interpolation to fill the data gaps. The existence of coastal structures such as breakwaters and port facilities effected the depth of the waters. The coastal structures will directly change the flow pattern and sediment transports, resulting in accretion and abrasion in the coastal areas. Sediment transports play an essential role and cause silting in the port area. Generally, the current around the port has a low speed and strength, so it is possible for silting in the port area.

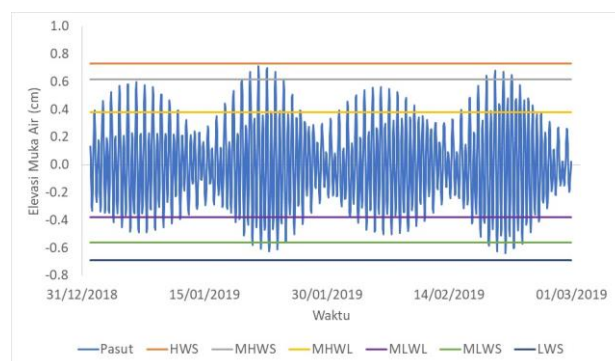


Figure 7. Banda Aceh water level elevation.

The value of HWS (High Water Spring) is 0.73 cm, MHWS (Mean High Water Spring) is 0.62 cm, MHWL (Mean High Water Level) is 0.38 cm, MLWL (Mean low Water Level) is -0.38 cm, MLWS (Mean Low Water Spring) is -0.56 cm and LWS (Low Water Spring) is -0.69 cm. The tide value is 1.42 cm and the tide type of Banda Aceh waters is a mixed tide prevailing diurnal, wherein one day there are two tides and two ebbs with almost the same height.

Discussion

Marine debris particles in open waters analyzed based on simulations for 7 months showed that the surface currents carried marine debris in four different sources of debris at a speed of 0.2 m/s to 0.4 m/s. All marine debris can be seen passing through the boundary condition within 67 hours from the initial time to the northeast of the Aceh waters. The dynamics movement of marine debris for sources from the western area can be seen in Figure 8.

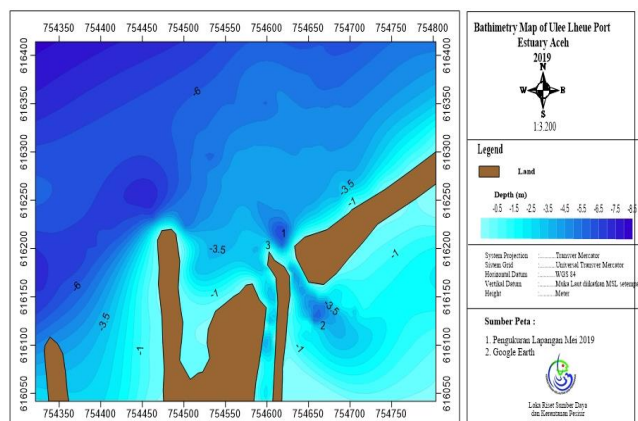


Figure 6. Bathymetry map around the Ulee Lheue port.

Hydrodynamic

The highest tide in 2019 occurred on January 21, 2019 at 15.00 and the lowest low tide was on February 20, 2019 at 22.00. The condition of the water level elevation in Banda Aceh is shown in Figure 7.

The current velocity during the simulation time ranges from 0.2 m/s to 0.4 m/s. Current conditions in the western waters around Breueh Island and Nasi Island have a more dynamic direction (Setiawan et al., 2018). The current movement spread to all directions with radial currents due to changes in topography, wind conditions, and dry land morphology. Marine debris particles originating from the western part spread out in different paths and move towards the northeast, passing through the boundary condition. The simulations were carried out for 5 months and showed that the garbage would not return to Aceh waters.

The 5 months simulation of marine debris originating from the north showed movements towards the northeast. Current velocity ranges from 0.0006 m/s to 2.5 m/s with the direction of the currents on the dominant coastal area moving along the coast (longshore current). In the western part of the Lampulo Port, a radiation stress current phenomenon occurs where there is a momentum gradient due to high variations in the component of coastal currents caused by the wind (Figure 9).

The movement of marine debris from sources in the eastern part of Banda Aceh will continue to move to the northeast until it passes through the boundary conditions. Within 6 hours from the start of the simulation, marine debris particles tended to move around the initial source of waste and further continued to move towards the northeast with surface water currents ranging from 0.001 m/s to 0.87 m/s (Figure 10).

Within 122 hours from the start of the simulation, marine debris particles continue to move towards the east and northeast through boundary conditions. There is a movement path for marine debris near Banda Aceh coastal area and because of the dominant longshore current, marine debris moves in the same direction as the coastline. The potential for debris accumulation in the estuary and around Lampulo Port is quite significant in the western and eastern parts of the port (Figure 11).

Marine debris particles in the northern part initially moved westward but then changed direction and tended to continue moving to the northeast. The movement of marine debris in the western and eastern parts tends to spread in all directions until it approaches the coast and then moves towards the northeast. Marine debris particles located in the estuary will spread towards the west coast and northern part of the river estuary and then more dominantly change towards the northeast. The potential for debris accumulation will occur at the

river estuaries and the west coast of the river mouth (Figure 12)

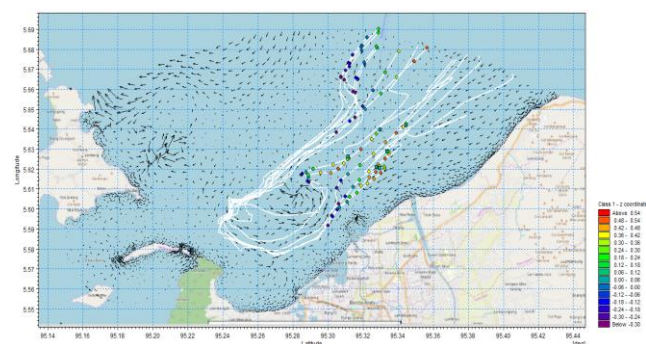


Figure 8. The movement of marine debris with source debris from the west area.

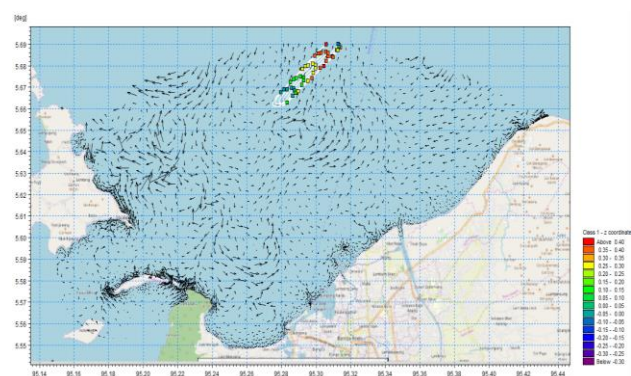


Figure 9. The movement of marine debris with source debris from the north area.

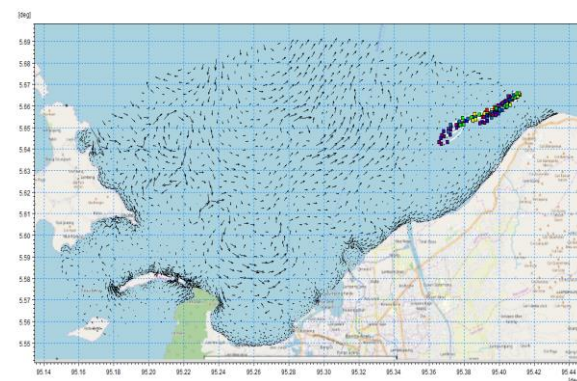


Figure 10. The movement of marine debris with source debris from the east area.

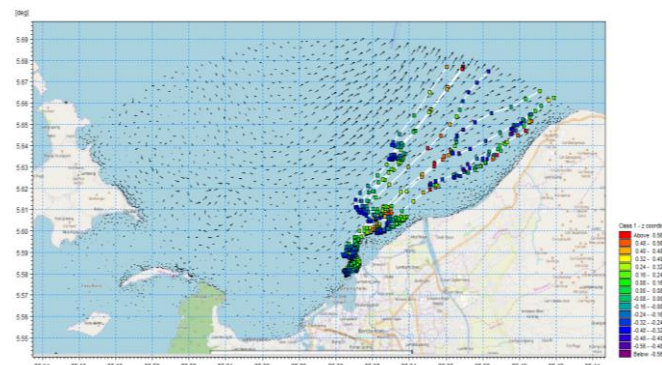


Figure 11. The movement of marine debris with source debris from estuary area.

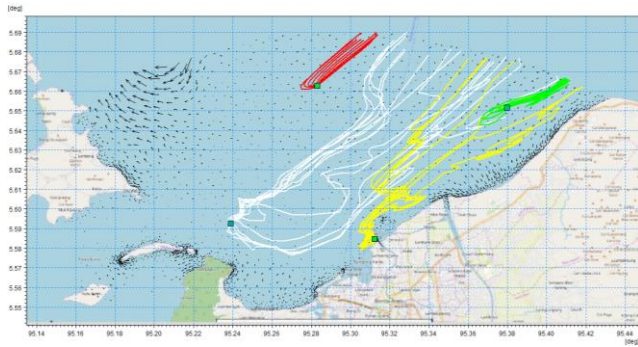


Figure 12. The movement of marine debris with source debris from the west, east, north and south area.

Conclusion

The wind direction on the Banda Aceh coastal area is dominant to the Northwest and Northeast with a maximum speed of up to 9 m/s. Wind direction will strongly affect the dynamics of sea surface currents producing longshore currents and radiation currents in the coastal areas. The simulation of marine debris particles showed that from January to May 2019, the particles moved towards the northeast through boundary conditions (towards the offshore) and did not return to Aceh waters. Based on the simulation results, marine debris originating from open waters will not go to the coastal area, but a small portion of debris originating from river estuaries was stranded on the west coast and the rest went to the northeast of Aceh waters.

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