Mapping seasonal marine debris patterns and potential hotspots in Banten Bay, Indonesia

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Abstract. Banten Bay is a 150 km² sea area which includes the waterfront of Serang City in Banten Province, Indonesia with several large rivers flowing into the Bay. The rapid development of industrial and commerce surrounds this bay added with population growth in Serang City have caused environmental problems. For instance, there has been a surge in the volume of domestic and industrial waste that has been dumped along several rivers and finally leaked into Banten Bay. This study aimed to spatially visualize the existing waste flow from residential area to the location of landfills in order to assist the local government in evaluating their waste management system, and to help prevent the waste leaking into Banten Bay and even further beyond. By using hydrodynamic modeling and ground truthing, we can predict the potential waste hotspots and the seasonal patterns of marine debris around Banten Bay and its surroundings. The results show that plastic litter originating from the Cibanten River will drift to the west during the east monsoon and will move to the east during the west monsoon. Based on this evidence, plastic litter from the Cibanten River estuary has the potential to spread further towards the Sunda Strait during the east monsoon and into Jakarta Bay during the west monsoon. We encourage cooperation among local governments in Banten and West Java throughout the watershed as well as with the Jakarta Provincial Government to establish an integrated waste management system to prevent the waste leakage.

1. Introduction
Poor waste management system in high populated cities mainly located in coastal area, has been identified as the primary contributor to marine debris [1]. Based on a study in 2010, Indonesia was nominated as the second highest contributor to the global marine debris [2]. Marine debris (particularly plastic litter) not only damaging the environment and marine life [3–8] but also threatening human health.
Although there have been many findings of marine debris and microplastic, i.e. microplastic in Jakarta Bay [9,10], Banten [11] or other region in Indonesia [12,13]; addressing marine debris issue is quite problematic for a large archipelagic country such as Indonesia; where the government of Indonesia is comprised of central government and autonomous local governments (Province and Regency). Marine debris (particularly plastic litter) that found in an area usually floated from another place [14,15], hence the handling of marine debris need a solid cooperation among local governments, under supervision of central government. Due to characteristic of plastic debris that moved around from time to time, it is important to forecasting the seasonal marine debris patterns and potential hotspots of debris in a certain time, where result of this study can become the basis for planning the seasonal clean-up debris actions in coastal area and improving the waste management system in each region to prevent waste leaked into the ocean.

This study aimed to spatially visualize the existing waste flow from residential area to the location of landfill in order to assist the local government in evaluating their waste management system, and to help prevent the waste leaking into Banten Bay and even further beyond. By using hydrodynamic modeling and ground truthing, we can predict the potential waste hotspots and the seasonal patterns of marine debris around Banten Bay and its surroundings.

2. Method

2.1. Site description

The studied areas are in Serang (within the administrative region of Serang City and Serang Regency), Banten Province, Indonesia. We conducted survey both in the mainland and Banten Bay (5°7'50"-7°1'11"S and 105°1'11"-106°7'12"E). Banten Bay is a 150 km² sea area which includes the waterfront of Serang in Banten Province - Indonesia, with several large rivers flowing into the bay. The rapid development of industrial and commerce surrounds this bay added with population growth in Serang have caused environmental problems, for instance, there has been a surge in the volume of domestic and industrial waste that has been dumped along several rivers and finally leaked into Banten Bay. Nevertheless, this study only focused on domestic waste management in Serang.

2.2. Methodology

This study comprised of three components:

- Desk study to obtain secondary data and information.
- Field survey by observing landfills managed by local government, residential area by the Cibanten River that traversing Serang City and flown into Banten Bay, as well as in-situ bathymetric data measurement in Banten Bay.
- Mapping the hydrodynamic model simulations of marine debris dispersal for multiple scenarios.

2.2.1. Desk study to obtain secondary data and information. Secondary data is accomplished via literature studies of journals and previous research, also through verbal discussion with related government agencies (e.g. PUSHIDROSAL, Bappeda, DLHK, Bapedalda, BPS, Marine affairs and Fisheries Office) to acquire thematic maps, existing waste management system run by local government and trace the condition of large rivers that flow directly into Banten Bay.

2.2.2. Field survey. On the ground survey, it was conducted in 2018 using purposive sampling approach, by observing temporary and terminal landfills managed by local government, as well as observing residential area near the water body and Cibanten River to find potential waste leakage, also community awareness and participation in waste handling. (Figure 1 (a)). In the bay, bathymetry survey was conducted at 15 stations to validate bathymetry map (map number 78 and 95 released by PUSHIDROSAL) using portable depth meter device. Bathymetry data is required as input for the marine debris dispersion model, particularly in Banten Bay (Figure 1 (b)).
Figure 1. Field observation points: (a) observing landfills provided by local governments and residential area by Cibanten River, (b) measurement of in-situ bathymetric data.

2.2.3. Mapping the hydrodynamic model simulations of marine debris dispersal for multiple scenarios.

In-situ measurement data were processed and plotted using Ocean Data View (ODV) software, a computer application used to plot oceanographic parameters both horizontally and vertically along with other geo-reference profiles. Hydrodynamic model is carried out using MIKE 21 Flow Model Flexible Mesh developed by Danish Hydraulics Institute (DHI) (https://www.mikepoweredbydhi.com) to simulate plastic waste movement started from Cibanten River until entering the bay and forecasting the period and direction of marine debris dispersal (affected areas) if they leave the bay to adjacent waters. Input data setting for this model such as bathymetry map, river discharge, wind, and tidal with resolution of 0,125° are listed in Table 1 below.

| Input | Setting |
|-------|---------|
| Area | Hydrodynamic model setting and MIKE particle tracking from DHI in Banten Bay. |
| Time | Period of January 1-31, 2018 for three scenarios: |
| | - 1st, where generating force only influenced by tidal. |
| | - 2nd, where generating force influenced by tidal and water discharge of Cibanten river. |
| | - 3rd, where generating force influenced by tidal, water discharge of Cibanten river and surface wind in January which represents the west monsoon. |
| | Period of July 1-31, 2018, where generating force influenced by tidal, water discharge of Cibanten river and surface wind in July which represents the east monsoon |
| Modules | Hydrodynamic and particle tracking |
| Technique of solution | Shallow water equations: |
| | Time integration: low order, fast algorithm |
| | Space discretization: low order, fast algorithm |
| | Minimum time step: 0.01 sec. |
| Input                  | Setting                                                                 |
|-----------------------|-------------------------------------------------------------------------|
| Maximum time step:    | 30 sec.                                                                 |
| Critical CFL number:  | 0.8                                                                     |
| Transport equations:  | Minimum time step: 0.01 sec.                                            |
|                       | Maximum time step: 30 sec.                                              |
| Critical CFL number:  | 0.8                                                                     |
| Flood and dry         | Include flood and dry                                                  |
|                       | Drying depth: 0.005 m                                                   |
|                       | Flooding depth: 0.05 m                                                  |
|                       | Wetting depth: 0.1 m                                                   |
| Density               | Barotropic                                                             |
| Eddy viscosity        | Smagorinsky formulation                                                |
|                       | Constant value: 0.28                                                   |
| Bed resistance        | Manning number                                                         |
|                       | Constant value: 32 m\(^{1/3}\)/s                                   |
| Coriolis forcing      | Varying in domain                                                      |
| Wind forcing          | 6-ERA surface winds at an altitude of 10 meters from                    |
|                       | ECMWF January 1 - July 31, 2018                                        |

3. Result and discussion

3.1. Trend of population growth and annual waste production volume in Serang

Data from Statistics Bureau in Serang indicates that population growth is more than ten thousand people per year, consequently solid waste production is increasing about 20 m\(^3\) per year as indicated by solid waste data released by local government. Based on these statistics, we can plot the trend of population growth and solid waste volume as shown in Figure 2. It is estimated that in 2020, the volume of solid waste generated could reach 3,400 m\(^3\) (Figure 2 (b)).

![Figure 2. Trend of population growth (a) and annual solid waste volume in Serang (b).](image)

3.2. Evaluating existing capacity of local government in handling waste and finding the potential waste leakage point

3.2.1. Observing the existing condition of temporary and terminal landfills facilities managed by local government. The flow of waste handling by local government usually started by provisioning temporary landfill facilities that placed adjacent to the residential area or business centre. Ideally, the municipal officer should empty these temporary landfills and transport these wastes to the terminal landfill at Cilowong on daily basis, to be processed further (e.g. incinerated, composted, recycled, etc). There are several temporary landfills (Jembatan Kaliasin, Kaibon, Pasar Karangantu, Kaligandu, Parung, Penancangan, Rusun, Cimuncang, Cipocok) and one terminal landfill facility (at Cilowong) managed by local government. Unfortunately, Figure 3 below indicate that the waste handling process by local
government of Serang is highly insufficient. Solid waste stored at these temporary landfills are unlikely transported to the terminal landfill on daily basis, thus these wastes are spilling out of facility.

(a) Landfills at Kepandean.  
(b) Landfills at Kaligandu.  
(c) Landfills at Cipocok  
(d) Landfills at Parung  

**Figure 3.** Existing temporary landfills facilities managed by local government are inadequate and unable to accommodate daily solid waste.

On the contrary, based on our observation, the 12 ha of terminal landfills at Cilowong is adequate, working well and empty spaces remain available (Figure 4). The volume of waste entering the Cilowong terminal landfills shows an increasing trend annually (Figure 5 (a)). Meanwhile, the type of waste varies from organic materials, plastics, glass, metals, rubber, wood, textiles/fabrics, electronics, and miscellaneous materials. Based on the composition graph of waste types entering the Cilowong terminal landfills, as seen in Figure 5 (b), plastic waste ranks second after organic waste.
Figure 4. Terminal landfills facilities at Cilowong.

Figure 5. Volume (a) and composition of solid waste (b) entering terminal landfill at Cilowong.

Beside landfills managed by local government of Serang, we found unmanaged solid waste in Cantilan, Kroya, Karangantu estuary, and Kaliasin River, where its handling process is remained unclear. These unmanaged solid wastes usually piled on the curb, open area, or even worse, dumped in water channel, river, and estuary (Figure 6).

Figure 6. Unmanaged municipal solid waste on the curb, entering rivers and estuary.

3.2.2. Estimated waste volume and current conditions for handling. The accumulation of waste volume according to district in 2017 is shown in Table 2; vary from the lowest, namely in Curug district (22 m$^3$) to the highest, namely in Serang District (100 m$^3$). Amount of managed waste does not show a significant change between 1$^{st}$ semester and 2$^{nd}$ semester of 2017.
Table 2. Local government capacity in waste handling in 2017.

| No. | Sub-district       | 1st semester 2017 | 2nd semester 2017 |
|-----|--------------------|-------------------|-------------------|
|     |                    | Incoming          | Managed solid     | Incoming          | Managed solid     |
|     |                    | solid waste (m³)  | waste (m³) (%)    | solid waste (m³)  | waste (m³) (%)    |
| 1.  | Cipocok Jaya       | 47,468            | 32,760 69        | 47,468            | 33,228 70        |
| 2.  | Curug              | 22,732            | 6,750 30         | 22,732            | 6,820 30         |
| 3.  | Kasemen            | 42,777            | 12,825 30        | 42,777            | 12,835 30        |
| 4.  | Serang             | 101,095           | 70,245 69        | 101,095           | 70,771 70        |
| 5.  | Taktakan           | 40,187            | 10,430 26        | 40,187            | 11,654 29        |
| 6.  | Walamtaka          | 40,491            | 10,630 26        | 40,491            | 11,742 29        |
|     | Total              | 294,750           | 143,640 49       | 294,750           | 147,050 30       |

From Table 2 above, there are major gaps between the volume of incoming waste and handled waste, which showing lack of local government’s capacity in managing waste; whereas only less than 50% of waste can be transported to the terminal landfill at Cilowong. It is confirmed by our interview with waste transporter in field, we found that local government have insufficient facilities and budget for managing waste. Meanwhile, the rest of unmanaged waste are burned by local community, or piled up in certain locations such as nearest riverbank or dumped in the river (Figure 7). The location where waste entering these waterways will become the land-based waste leakage spots into the sea and can causing problems to local community (e.g. unpleasant odour and disease), also reducing quality of freshwater and other associated aquatic ecosystems.

Figure 7. The potential hot spots of waste leakage found in riverbanks.

By observing waste management system in Serang, we found that (1) public awareness and participation in waste management system remains low; (2) capacity of existing temporary landfills provided by local government are insignificant compared to the amount of incoming waste per day; (3) limited transportation vehicles and number of personnel causing a high volume of waste that cannot be transported to the terminal landfill on daily basis. (4) Based on the findings of potential hot spots of waste leakage along riverbanks, we believe that a large part of waste has entered the water body and already entering Banten Bay.

3.3. Mapping seasonal marine debris dispersal based on hydrodynamic model simulations for multiple scenarios and bathymetry data.

The modeling of seasonal marine debris dispersal (using 1-gram plastic waste) in Banten Bay was carried out through four different scenarios that applicable for this site:

a. For the period of January 1-31, 2018, we ran three scenarios:
b. The 4th scenario for the period of July 1-31, 2018, where generating force influenced by tidal, water discharge of Cibanten river and surface wind in July which represents the east monsoon.

Result of this hydrodynamic model simulation based on four different scenarios is shown in Figure 8. Blue colour indicates forecast of marine debris hotspot during the west monsoon season if only forced by tides (1st scenario). Green colour indicates the plastic waste dispersion pattern during the west monsoon if the 2nd scenario is executed. Based on these scenarios, it appears that the leaked waste from the mainland will likely drifted inside the bay. The result of 3rd scenario is represented by black colour where surface winds in January (representing the west monsoon) is included in the model, while brown colour indicates the result of 4th scenario where the force is influenced by tidal, water discharge of Cibanten River, and surface wind in July which representing the east monsoon. Based on these scenarios, we can observe the great influence of surface wind to the seasonal dispersion pattern of marine debris.

During the east monsoon period, the wind is likely capable to push marine debris which originally merged around Cibanten estuary, until exiting the bay area to the west, where possible to traverse Sunda Strait and reaching Indian Ocean. On the contrary, during the west monsoon period, marine debris could disperse until exiting the bay toward east to Jakarta Bay. Thus, there is the potential exchange of marine debris between Banten Bay and Jakarta Bay.

![Figure 8. Simulation of seasonal marine debris dispersal of plastic waste in Banten Bay in 2018.](image)

Result of this simulation congruent with dispersion pattern of marine debris in Jakarta Bay [16], where debris particle is drifted swiftly eastward until exiting the bay area, follow the dominant wind movement of west monsoon season. This fast movement of debris is also reinforced with the absence of ocean current impediment. On the contrary, during the eastern monsoon season, marine debris is moved slightly slower westward due to impedance of reclamation (man-made) islands in Jakarta Bay, hence particle of debris is expected to exit the bay in a longer period. This situation is similar with the case of
Banten Bay (using 4th scenario), where only small part of debris particles tend to move out of the bay area due to the existence of natural small islands (e.g. Panjang Island, Tarahan Island, Kambing Island, Lima Island, etc), which inhibiting ocean current and leaving majority of particle debris suspended in the bay area. This is aligned with [17] [18] which stating that ocean current pattern in Banten Bay during the west monsoon season, is move eastward exiting the bay along the north coast of Java with velocity of approximately 0-0.4 m/s; and move westward north coast of Cilegon to the Sunda Strait with velocity around 0.025 - 0.2m /s.

4. Conclusion
Limited budget and facilities owned by local government of Serang have causing insufficient capacity of waste management and exacerbated by the low awareness and participation of local community in waste handling. These conditions have caused the high-level of mismanaged waste, and possibly become land-based marine debris that entering Banten Bay through waterways. Marine debris accumulated in Banten Bay has the potential to spread further beyond the bay toward Sunda Strait during east monsoon period and to Jakarta Bay during west monsoon. Integrated waste management system between provincial government of Jakarta and Banten is urgently required to mitigate and reduce the negative impact of marine debris to environment and marine biota. Further research and data collection on plastic debris regarding the size, type, amount, and its characteristics is needed to improve model capacity in simulating and estimating marine debris distribution pattern quantitatively.

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