The effects of hydrodynamic process and mangrove ecosystem on sedimentation rate in Kendal coastal area, Indonesia

A A Risanti1 and M A Marfai1*

1Department of Environmental Geography, Universitas Gadjah Mada, 55281, Indonesia

*Corresponding author: arismarfai@ugm.ac.id

Abstract. The Coastal Area of Kendal Regency is subjected to continually changing morphodynamic processes. The density of mangroves contributes to the extent of accretion, sediment distribution, and high surface elevation. The study aimed to identify the effects of hydrodynamics on sedimentation, calculate the sedimentation rate, and analyze the significance of mangrove ecosystems in shaping this rate. Located on the west side of Bodri River, the research area includes a mangrove ecosystem directly facing the open water. This quantitative research involved analysis and validation of hydrodynamic parameters, quantification of sedimentation rate, identification of mangrove species, and calculation of the Importance Value Index (IVI) of mangrove at each growth stage. Parameters in November-February represented intensive hydrodynamic processes with the highest monthly average detected in February, meaning that sediment movement is also the most intensive in this month. The lowest sedimentation rate was 0.1501 mg/cm²/day, while the highest was 23.4938 mg/cm²/day. *Rhizophora apiculata* and *Avicennia alba* were the two mangrove species growing in the area. *A. alba* had the highest relative dominance score in the community, as indicated by its IVI. Mangrove density and sedimentation rate showed a directly proportional relationship in Plot 3 at two growth stages, namely, sapling and seedling.

1. Introduction
Coastal areas and oceans in Indonesia are rich of diverse renewable natural resources, such as fisheries, mangrove forests, and coral reefs, and non-renewable ones, for example, oil and minerals [1]. Mangroves serve as belts that absorb the energy of seawater flowing to the mainland, maintain coastline stability and water quality, prevent abrasion, control intrusion and floods, and retain mud and sediments [2][3]. The mangrove ecosystem is a tropical coastal vegetation community dominated by several species of mangrove trees that can grow and develop in muddy coastal tidal areas [4].

The dynamics of the coastal areas in Central Java are often affected by, one of which, population activities. Kendal Regency is part of the Northern Coastline that forms a busy transportation route [5]. From 2001 to 2008, constant change in the coastal area was the result of abrasion by 111.67 ha and accretion up to 80.37 ha [6]. According to the Ministry of Maritime Affairs and Fisheries [7], the dynamics of this coastal regency are likely to comprise abrasion and accretion that have been predicted to reach, respectively, 16.34 ha and 102.67 ha in 2020. Owing to the significant function of mangrove in maintaining coastline stability, mangrove planting has been therefore encouraged in Kendal Regency.
According to [8], mangrove density contributes to the extent of accretion, sediment distribution, and height of surface elevation. Aside from this factor, sediment movement on the coast is triggered by waves, currents, and tides. This warrants the need to study the Effects of Hydrodynamic Process and Mangrove Ecosystem on the Sedimentation Rate in Kendal Coastal Area. This research aimed to identify the effects of hydrodynamics on sedimentation, calculate the sedimentation rate, and analyze the significance of mangrove ecosystems in shaping the sedimentation rates in parts of the Coastal Area of Kendal Regency.

2. Methods
2.1. Research Design and Location
This research was designed qualitatively. Kendal Regency has open waters that connect to the relatively calmer Java Sea. The study took place along Bodri River, particularly on the west side that directly faces open water and has mangrove ecosystems.

2.2. Research Tools, Materials, and Data Collection
The primary data were wind speed and direction (velocity; measured with a hand anemometer), current velocity (simple current meter), wave height (from wind speed data processing), aerial photography (captured with a set of UAVs), mangrove data (identified from making plots), and sediments (obtained with sediment traps). The sediment traps were made of PVC pipes with h= 50 cm and randomly placed holes 20 cm from the top. The two ends of the pipes were covered with lids, one of which was randomly drilled, creating holes with a diameter of 11 cm (Figure 1). The research also used several types of software, namely ArcGIS, Agisoft, and Ms. Office, as well as tools like GPS, sample bottles, dry weight measurement kit for the sediments, cameras, and motor boats. The secondary data were satellite imagery from Google Earth in 2018, tides data acquired from UNESCO/IOC (www.ioc-sealevelmonitoring.org), and a set of data containing current velocity, wave height and direction, and wind velocity in 2017 from the BMKG Maritime Meteorological Station in Tanjung Mas Semarang.

Figure 1. Research Equipment: (a) Hand anemometer, (b) simple current meter, and (c) sediment trap (Source: Documentation, 2018)

2.3. Population and Sample
The sampling site was determined from the appearance of mangrove ecosystems on the satellite images of parts of Kendal Coastal Area, while the sampling points were selected and validated based on the condition of the field, which was represented by the aerial photographs taken by a set of UAVs. The sampling was performed by creating 10 x 10 m² square transects at an interval of 100 m between the transects [9]. A systematic sampling method was employed and carried out in every plot within the mangrove area and three others in open waters. In total, there were 16 plots (Figure 3). The hydrodynamic parameters were measured further towards the sea with 5x repetitions. For mangrove ecosystem characterization, the size of the sampling plots was according to the growth stage of the mangrove plants (Figure 2), namely:

a. 10x10 m² plots for trees with a stem diameter of >10 cm and a height of >1.5 m.

b. 5x5 m² sample plots for saplings with a diameter of <10 cm and a height of >1.5 m.

c. 2x2 m² sample plots for seedlings with a height of <1.5 m.
2.4. Data Processing and Analysis Techniques

The wind velocity data were compared with the Beaufort Scale table (Table 1) to pinpoint the relationship between wind speed and wave height [10]. Together with the hydrodynamics information, these data were processed statistically to obtain their mean, maximum, and minimum values and present them in tables and graphs.
Table 1. The Relationship between Beaufort Scale (Number) and Wind Speed

| Beaufort Scales | Description | Wind Speed (m/s) | Wave Height (m) |
|----------------|-------------|------------------|-----------------|
| 1              | Calm        | 0 – 0.3          | 0               |
| 2              | Light air   | 0.3 – 1.5        | 0 – 0.2         |
| 3              | Light breeze| 1.3 – 3.3        | 0.2 – 0.5       |
| 4              | Gentle breeze| 3.3 – 5.5      | 0.5 – 1         |
| 5              | Moderate breeze| 5.5 – 8       | 1 – 2           |
| 6              | Fresh breeze| 8 – 10.8         | 2 – 3           |
| 7              | String breeze| 10.8 – 13.9   | 3 – 4           |
| 8              | Near gale   | 13.9 – 17.2      | 4 – 5.5         |
| 9              | Gale        | 17.2 – 20.8      | 5.5 – 7.5       |
| 10             | Strong gale | 20.8 – 24.5      | 7.5 – 10        |
| 11             | Storm       | 24.5 – 28.4      | 10 – 12.5       |
| 12             | Violent storm| 28.4 – 32.6    | 12.5 – 16       |
| 13             | Hurricane   | ≥ 32.7          | ≥ 16            |

Source: [10]

After the calculation and in situ measurement of mangrove ecosystem parameters, the obtained values were analyzed with mangrove vegetation data [4]. The data processing was as follows (Figure 4):

Notes:
- \( n_i \) = total number of individuals from species \( i \)
- \( A \) = total area of sampling (plot).
- \( \Sigma n \) = total stands of all species
- \( P_i \) = number of plots identified with species \( i \)
- \( \Sigma P \) = total number of observed sample plots
- \( F_i \) = frequency of species \( i \)
- \( \Sigma F \) = total frequency of all species
- \( \pi \) = constant (3.14)
- \( DBH \) = diameter at breast height of species \( i \)
- \( D_i \) = comparison between the dominance of individuals from species \( i \)
- \( \Sigma D \) = total number of dominances of all individuals

Sedimentation rates are expressed in mg.cm\(^{-2}\).day\(^{-1}\) [11]. To identify these rates, sediment samples were collected with sediment trap devices that were planted in a sampling point with a depth of 30 cm using 1.5m-high bamboos or stakes and operated for 50 days. The trapped sediments were analyzed in the laboratory to obtain their dry weight (mg) (Figure 5). Afterward, the sedimentation rate was quantified using the following equation (APHA, 1976 [12]):

\[
\text{Sedimentation rate (mg/cm}^2\text{/day)} = \frac{BS}{\text{Number of days} \times \pi r^2}
\]

where:
- \( BS \) = dry weight (mg)
- \( \pi \) = constant (3.14)
- \( r \) = diameter of sediment trap (cm).
Figure 5. Dry Weight Measurement in the Laboratory (Source: Private Documentation, 2018). a) The filter paper was heated in the oven at 105°C for 30 minutes. b) The filter paper was put in a vacuum desiccator for 15 minutes to absorb the moisture generated during cooling. c) The filter paper was weighed on an analytical scale. d) The water sample was filtered through these papers with the help of a funnel, and 500 mL of the filtrate was collected. e) The used filter paper, along with the retained sediments, was heated in the oven at 105°C for 1 hour. f) This filter paper was placed in a vacuum desiccator for 15 minutes and g) weighed on an analytical scale. h) The weight difference between the filter papers with and without the sediments was calculated to find out the dry weight.

3. Results and Discussion

3.1. The Effects of Hydrodynamics on Sedimentation in the Coastal Area of Kendal Regency

Hydrodynamic is one of the processes that shape the dynamics or changes in coastal areas [13]. In some parts of Kendal Coastal Area, these processes were identified and analyzed using current velocity, wave height and direction, and tides. According to [14], these main parameters of water dynamics define the changes occurring in coastal areas. Current as water mass circulation from one place to another [15]. The sea currents occurred at high speed in January, February, and November, coinciding with the rainy season (Figure 6). The current speed data were validated on October 31, 2017, with a simple current meter, and it was conducted five times. The results showed that the average current speed in Kendal Coastal Area was 9.6 cm/s, and the secondary data recorded a current speed of 15 cm/s on this day. These figures have a relatively small difference, proving that the secondary data are representative of the actual conditions in the study area.

The current speed ranged between 6.3 cm/s (May) and 33.6 cm/s (February). This finding means that the mass of water in February is moved as far as 33.6 cm per second following the dominant current direction, that is, from the west. Meanwhile, the calmest current in May is marked with the transport of the mass of water as far as 6.3 cm per second from the southwest—the dominant current direction in this month.
The formations of currents and waves are interrelated, viz. waves generate currents in a perpendicular direction and along the coast [16]. Incoming waves break at a certain depth and, at the same time, generate wave energy runoff that erodes particles on the seabed [17]. The minimum wave height was 0.5 m, occurring in every month in 2017, while the maximum one was 4 m, happening only once in December (Figure 7). The highest average of the wave height was identified in February, i.e., 1.38 m. In this month, the waves mainly moved from the southeast. October had the lowest average of wave height, 0.57 m, and the prevailing wave direction was from the southwest.

![Figure 6. Daily Current Speed in 2017 (Source: Data Analysis, 2018).](image)

![Figure 7. Daily Wave Height in 2017 (Source: Data Analysis, 2018).](image)
Tides are the fluctuating movement of water mass caused by the pulling force that celestial objects, particularly the sun and moon, exert toward the earth. Water moves periodically and harmonically [14]. The tide records were observed at the same time as the 50-day sediment sampling by the trap devices, i.e., from February 7 to March 23, 2018. They showed that the sea level rise and fall did not exceed 1 m. Based on the categorization [17], the tides in the study area fall under the category ‘microtidal’ since the tidal range is less than 2 m.

The study area has a mixed tidal cycle with the prevalence of diurnal or called ‘mixed tide-prevailing diurnal’ [18][19]. This tidal pattern has one high tide and one low tide each day but sometimes two highs and two lows with a different interval. The mouth of Bodri River has mixed tides with a single pair of components (flow and ebb) [20]. This pair occurred on February 20, 2018, while the two flows and ebbs were detected on February 25, 2018 (Figure 8).

The wind is the main generating force of waves [21][22][23][24]. In other words, there is a correlation between wind speed and wave height. Surface currents, another hydrodynamic process, create a pattern following that of the occurring seasonal wind [10][25]. The relationship between wind speed and wave height with the Beaufort scale table [10]. Daily wind speed data show that the study area has a relatively more fluctuating pattern from November to February (Figure 9).

In average, February had the fastest wind speed, 13.8 knots, and the wind dominantly blew from the southwest. In this month, the fastest wind speed was 25 knots. On the contrary, the wind speed average was the lowest in October, i.e., 5.4 knots. For the validation, the wind velocity on October 2, 2017, was measured five times. The results showed that the wind blew from the east at a speed of 2.7 knots, and since the secondary data recorded winds flowing from the east at 4 knots on this day, it could be used to represent the study area. As mentioned in [26], Bretschneider (1954) and Kamiludin et al. (1991) argue...
that only winds with a minimum speed of 10 knots or 19 km/h or 5 m/s can form waves. Therefore, the waves in the study area were affected by the winds occurring in January, February, June-September, and December because the wind speed in the other months did not reach 10 knots. The table below shows the relationship between wind speed and wave height (Table 2).

| No | Months    | V (average) | Beaufort Scale | Description      |
|----|-----------|-------------|----------------|------------------|
|    |           | knot    | m/s      | Wave Height | Description |
| 1  | January   | 10.8   | 5.57    | 1 - 2      | Moderate breeze |
| 2  | February  | 9.3    | 4.80    | 0.5 - 1    | Gentle breeze  |
| 3  | March     | 9.4    | 4.82    | 0.5 - 1    | Gentle breeze  |
| 4  | April     | 10.0   | 5.14    | 0.5 - 1    | Gentle breeze  |
| 5  | May       | 11.2   | 5.76    | 1 - 2      | Moderate breeze |
| 6  | June      | 9.9    | 5.10    | 0.5 - 1    | Gentle breeze  |
| 7  | July      | 10.0   | 5.14    | 0.5 - 1    | Gentle breeze  |
| 8  | August    | 12.5   | 6.41    | 1 - 2      | Moderate breeze |
| 9  | September | 12.5   | 6.43    | 1 - 2      | Moderate breeze |
| 10 | October   | 5.4    | 2.78    | 0.2 - 0.5  | Light breeze   |
| 11 | November  | 9.9    | 5.08    | 0.5 - 1    | Gentle breeze  |
| 12 | December  | 12.6   | 6.50    | 1 - 2      | Moderate breeze |

Source: BMKG Semarang, 2017 (processed)

Table 2 shows that theoretically, based on wind speed, the height of the waves in the study area ranges between 0.2 m and 2 m, which is in accordance with the actual average, that is, 0.57-1.38 m. The validation in field recorded wind speed of 2.7 knots or 1.39 m/s, and when compared with the Beaufort scale table, this wind likely generates waves with a height of 0.2-0.2 m. Because the secondary data on the day of validation day showed a wave height of 0.5 m, the Beaufort scale is thereby quite effective for determining the height of the wind-generated waves in the study area.

Wind functions as the driver of sediment and wave generation [19], and waves can lead to currents [15][16]. This asserts the connection between wind, wave, and current. In the study area, these three parameters formed more intensive fluctuating patterns from November to February. The relationship was also evident in their monthly average in February. These hydrodynamic activities affect sediment transport. Referring to the hydrodynamic processes that are dominant in February, the most intensive sediment transports throughout the year also occurs in February.

3.2. Sedimentation Rate in Some Parts of the Coastal Area of Kendal Regency

The grain size was determined by identifying sediments that did not pass through the 0.45 μm filter paper. The mouth of Bodri River has fine-grained sediments (i.e., sandy silt) that become coarser near the sea (sand) [20]. Sedimentation, according to Rijn (1993 in [27], is the entry of sediment loads through water medium that are then deposited in aquatic environments. The potential of coastal circulation cells in Kendal Coastal Area shows a tendency at the end of Bodri River mouth, as indicated by the different results of the circulation suspension analysis at each surface flow current [28]. The sampling location is on the west side of the Bodri River mouth and consists of 16 points with 13 of them in the mangrove ecosystem and 3 in the open water. There are variations in the installation of the sediment traps in mangroves. Plots 1 to 5 were placed inside the mangrove area and close to the land or ponds, and plots located near the land had denser mangrove forest than the others. The mangroves in Plots 6 to 9 were rather scarce and, therefore, made a condition as if they were directly adjacent to open waters. Although
Plots 10 to 13 were within the mangrove area and abutted the open sea, interviews with the residents and fishers who collected seashells revealed that these plots were only flooded at high tides.

Total Suspended Solids (TSS) analysis can predict sedimentation rate [29]. It was employed to measure the dry weight of the sediments. However, four samples had a lot of sediments and, for this reason, could not be tested with TSS. These samples were from Points 6, 13, 14, and 15. Points 6 and 13 were within the mangrove ecosystem area, while Points 14 and 15 were in open waters. The calculation results showed that the sedimentation rates varied greatly both in open waters and in mangroves. The lowest rate (0.1501 mg/cm²/day) was identified in Point 11, which is inundated at high tides, while the highest one (23.4938 mg/cm²/day) was in Point 16—an open water body (Table 3).

### Table 3 The Calculation of Sedimentation Rates in the Study Area.

| No | Sample Points | Filter Paper (gram) | Filter Paper + Suspension (gram) | Dry Weight of Sediment (gram) | Dry Weight of Sediment (mg) | Number of Days | $\pi$ | $r$ | Sedimentation Rates (mg/cm²/day) |
|----|---------------|---------------------|----------------------------------|------------------------------|-----------------------------|----------------|------|----|-------------------------------|
| 1  | 1             | 1.7481              | 4.8060                           | 3.0579                       | 3057.9                      | 50             | 3.14 | 5.5 | 0.6439                        |
| 2  | 2             | 1.7758              | 5.0040                           | 3.2282                       | 3228.2                      | 50             | 3.14 | 5.5 | 0.6797                        |
| 3  | 3             | 1.7431              | 13.0221                          | 11.2790                      | 11279.0                     | 50             | 3.14 | 5.5 | 2.3749                        |
| 4  | 4             | 1.7671              | 5.9343                           | 4.1672                       | 4167.2                      | 50             | 3.14 | 5.5 | 0.8774                        |
| 5  | 5             | 1.7578              | 5.1994                           | 3.4416                       | 3441.6                      | 50             | 3.14 | 5.5 | 0.7247                        |
| 6  | 7             | 1.7839              | 8.7782                           | 6.9943                       | 6994.3                      | 50             | 3.14 | 5.5 | 1.4727                        |
| 7  | 8             | 1.7282              | 42.0136                          | 40.2854                      | 40285.4                     | 50             | 3.14 | 5.5 | 8.4825                         |
| 8  | 9             | 1.8197              | 71.8361                          | 70.0164                      | 70016.4                     | 50             | 3.14 | 5.5 | 14.7426                       |
| 9  | 10            | 1.7894              | 2.9059                           | 1.1165                       | 1116.5                      | 50             | 3.14 | 5.5 | 0.2351                        |
| 10 | 11            | 1.7916              | 2.5043                           | 0.7127                       | 712.7                       | 50             | 3.14 | 5.5 | 0.1501                        |
| 11 | 12            | 1.7939              | 3.4975                           | 1.7036                       | 1703.6                      | 50             | 3.14 | 5.5 | 0.3587                        |
| 12 | 16            | 1.8538              | 113.4317                         | 111.5779                     | 111577.9                    | 50             | 3.14 | 5.5 | 23.4938                       |

Source: Data Analysis, 2018

Sedimentation is more intensive in front of the mouth of Bodri River due to the influence of wave energy [20]. Waves, currents, tides, wind, water depth, coastal corals, and vegetation can define the distribution of sediments [20]. In the study area, the variation in the sedimentation rate is shaped by several factors, including the presence of mangrove vegetation, current velocity, wave height (that depends on wind speed), and tides.

### 3.3. The Effects of Mangrove Ecosystem on Sedimentation Rates in Parts of the Coastal Area of Kendal Regency

As explained in [2][6][3], the functions of mangroves include periodic sediment retention by capturing mud and sediment, as well as intrusion and coastline stability control. These are based on image interpretation, field check, and aerial photography using UAVs. UAV-captured photographs and satellite images show that mangroves are directly adjacent to open waters and approximately 1.4 km in length. Considering the influence of the hydrodynamic processes, this research selected mangrove areas that directly faced the open waters for the identification of the mangrove ecosystem. The vegetation analysis involved identifying the composition of vegetation, which can provide quantitative information about the structure and composition of a plant community. The mangrove species were defined by observing the shape of mangrove leaves, roots, flowers, and fruits [30].

The results showed that there were two mangrove species in the study area, namely *Rhizophora apiculata* and *Avicennia alba* (Figure 10). These species were identified using a guidebook entitled The
Handbook of Mangrove in Indonesia [31]. The observed roots, leaves, flowers, and fruits in the field were matched with the guidebook.

Analysis of plant communities is a way of studying the composition of the species and shape or structure of vegetation. In this study, mangroves were identified using quantitative parameters to obtain absolute numbers or values. The quantitative parameters can express the dominance of species in a plant community [25]. As for the Importance Value Index (IVI), it was calculated at three growth stages: trees and saplings with a range of 0-300%, while seedlings with a variety of 0-200% because their calculation did not include stem diameter. Accordingly, the IVIs of mangrove trees and saplings are the sum of FR, KR, and DR, while that of seedlings is the sum of FR and KR [32].

The Importance Value Index of *Avicennia alba* trees was 287.49%, while the IVI of *Rhizophora apiculata* trees was 12.51%. At the sapling stage, the IVIs of *A. alba* and *R. apiculata* were 270.22% and 29.78%, respectively. IVI shows which species is dominant in a plant community (Indriyanto, 2006 in [33]). Therefore, at the stages of tree and sapling, *A. alba* is deemed dominant and plays a role in the mangrove community in the study area. The IVI of *R. apiculata* seedlings was the highest among the three growth stages (81.67%, maximum scale= 200%), but the IVI of *A. alba* seedlings remained higher than *R. apiculata* (118.33%). The higher the IVI, the greater the dominance of a species in the community. In other words, *A. alba* highly dominates the mangrove community in the study area [25].

The regeneration or proliferation of *R. apiculata* was detected from the increasing IVIs from the tree to the sapling and seedling stage. Data on mangrove species at the seedling stage showed that the number of *R. apiculata* was not considerably higher from *A. alba*, namely 15 and 21 (Tables 4, 5, and 6).

The relationship between mangrove ecosystems and sedimentation rates was analyzed using the data of Plots 1-5. These data were selected based on the condition of the plots and the locations of the sediment trap devices, i.e., close to the land or ponds with a higher density of mangrove trees nearby the land than in the other plots. The highest sedimentation rate was located in Plot 3, i.e., 2.37 mg/cm²/day, but the mangrove species were found with the highest density at the sapling and seedling stages. The highest density of mangrove trees was detected in Plot 4; however, the lowest sedimentation rate was identified in Plot 1. The lowest mangrove density at the tree stage was found in Plot 5, while at the sapling and seedling stages, it was identified in Plot 2 (Figure 11). A directly proportional relationship between the mangrove density at each growth stage and sedimentation rate did not occur in the study area, except for Plot 3 where the mangrove density at the sapling and seedling stage was directly proportional to the sedimentation rate. The shape and trend of the relationship are presented in Table 7 and Figure 11.
Mangrove root systems can bind the substrates on the coastline and stabilize it [34]. The higher the density of mangroves, the more the deposited particles [35]. However, the data from Plots 1-5 do not demonstrate this correlation. The placement of the sediment traps in plots with different conditions significantly influences the measured sedimentation rates. For instance, sediments can enter the device from two directions in Plot 1 but only from one direction in Plot 2. The entry of sediments from different sources can determine the sedimentation rate occurring in the plot.

**Figure 11.** Analysis of the Relationship between Mangrove Density and Sedimentation Rate on a Graph (Source: Data Analysis, 2018).
Table 4. The IVI Calculation Results of Mangrove Trees in the Study Area.

| Growth State | Plot Area (m²) | Species         | Total Individuals | Perimeters (cm) | Diameters (cm) | Frequencies of Occurrence | K       | KR (%) | F | FR (%) | BA | D | DR (%) | INP (%) |
|--------------|----------------|-----------------|-------------------|-----------------|----------------|---------------------------|---------|--------|---|--------|----|----|--------|---------|
| Tree         | 100 Rhizophora apiculata | 1 | 84 | 26.75 | 0.01 | 100 | 1.33 | 0.08 | 11.11 | 56178.34 | 56178.34 | 0.06 | 12.51 |
|              | 100 Avicennia alba      | 74 | 3392 | 1080.25 | 0.99 | 7400 | 98.67 | 0.62 | 88.89 | 916056.05 | 91605605 | 99.94 | 287.49 |
| Total        | 75 3476 1107.00637 | 1 | 7500 | 100 | 0.69 | 100 | 916617.83 | 91661783 | 100 | 300 |

Source: Data Analysis, 2018

Table 5. The IVI Calculation Results of Mangroves at the Sapling Stage in the Study Area.

| Growth State | Plot Area (m²) | Species         | Total Individuals | Perimeters (cm) | Diameters (cm) | Frequencies of Occurrence | K       | KR (%) | F | FR (%) | BA | D | DR (%) | INP (%) |
|--------------|----------------|-----------------|-------------------|-----------------|-----------------|---------------------------|---------|--------|---|--------|----|----|--------|---------|
| Sapling      | 25 Rhizophora apiculata | 18 | 189 | 60.19 | 0.2 | 7200 | 19.78 | 0.08 | 7.69 | 2844.03 | 113761.5 | 2.31 | 29.78 |
|              | 25 Avicennia alba     | 73 | 1230 | 391.72 | 0.8 | 29200 | 80.22 | 0.92 | 92.31 | 120453.82 | 48181529 | 97.69 | 270.22 |
| Total        | 91 1419 451.910828 | 1 | 36400 | 100 | 1 | 100 | 123297.85 | 49319140 | 100 | 300 |

Source: Data Analysis, 2018

Table 6. The IVI Calculation Results of Mangroves at the Seedling Stage in the Study Area.

| Growth State | Plot Area (m²) | Species         | Total Individuals | Perimeters (cm) | Diameters (cm) | Frequencies of Occurrence | K       | KR (%) | F | FR (%) | BA | D | DR (%) | INP (%) |
|--------------|----------------|-----------------|-------------------|-----------------|-----------------|---------------------------|---------|--------|---|--------|----|----|--------|---------|
| Seedling     | 4 Rhizophora apiculata | 15 | 0.42 | 6000 | 41.67 | 0.31 | 40 | 81.67 |
|              | 4 Avicennia alba      | 21 | 0.58 | 8400 | 58.33 | 0.46 | 60 | 118.8 |
| Total        | 36 1 | | 14400 | 100 | 0.77 | 100 | 200 |

Source: Data Analysis, 2018

Table 7. Correlation Analysis of Mangrove Density and Sedimentation Rate in Some Parts of the Study Area.

| No | Plot Numbers | LS (mg/cm²/day) | Tree | Sapling | Seedling |
|----|--------------|-----------------|------|---------|----------|
|    |              |                 | A (m²) | ni (indv.) | K (indv./m²) | A (m²) | ni (indv.) | K (indv./m²) | A (m²) | ni (indv.) | K (indv./m²) |
| 1  | 1            | 0.64            | 100   | 11      | 0.11      | 25     | 3         | 0.12       | 4      | 1         | 0.25       |
| 2  | 2            | 0.68            | 100   | 12      | 0.12      | 25     | 2         | 0.08       | 4      | 0         | 0.25       |
| 3  | 3            | 2.37            | 100   | 13      | 0.13      | 25     | 7         | 0.28       | 4      | 2         | 0.5        |
| 4  | 4            | 0.88            | 100   | 26      | 0.26      | 25     | 5         | 0.2        | 4      | 2         | 0.5        |
| 5  | 5            | 0.72            | 100   | 7       | 0.07      | 25     | 4         | 0.16       | 4      | 1         | 0.25       |

Source: Data Analysis, 2018
4. Conclusion

The hydrodynamic process in the study area consists of currents that reach the highest average (33.6 cm/s) in February and mainly flow from the west. In May, the sea currents have the lowest average (6.3 cm/s) and originate in the southwest. The highest average of the wave height occurs in February (1.38 m) and flows from the southeast, whereas in October, the wave height is the lowest in average (0.57 m), and the dominant direction is coming from the southwest. Kendal Coastal Area has mixed tide-prevailing diurnal. The wind, wave, and current conditions form an intensively fluctuating pattern from November until February. The correlation between the wind, wave, and current activities is evident from their monthly averages, all of which are the highest in February. Accordingly, the sediment moves intensively in this month. The lowest sedimentation rate is 0.1501 mg/cm²/day, identified at a location commonly inundated during the highest tides (Point 11), while the highest one is 23.4938 mg/cm²/day, measured in an open water body (Point 16). These figures show that the sedimentation rates in open waters are faster than within the mangrove areas. The study area has two species of mangroves, namely *Rhizophora apiculata* and *Avicennia alba*. *A. alba* has a high level of dominance in the community, as indicated by its higher Importance Value Indices (IVIs) than *R. apiculata* at each growth stage. The IVIs of *A. alba* trees, saplings, and seedlings were 287.49%, 270.22%, and 118.33% (from the scale of 200%), while the IVIs of *R. apiculata* trees, saplings, and seedlings were 12.51%, 29.78%, and 81.67% (from the scale of 200%). The density of mangrove and sedimentation rates form a directly proportional relationship in Plot 3 at the sapling and seedling stages.

Acknowledgement

This research has been completed with the support and assistance of many parties. Authors would like to thank Prof. Dr. Sunarto, M.Sc., Dr. Djati Mardianto, M.Sc., and Muhammad Kamal, M.GIS., Ph.D., for their invaluable input. Authors would also like to acknowledge the local governments for granting the research permit and the communities in Kendal Coastal Area for their assistance and cooperation. Deep gratitude also extends to Edy Trihatmoko, M.Sc., Wulandari, S.Si., Irvan Agung Kurniawan, S.Si., and other parties for their help in data collection and research completion. This research was financially supported by the Final Assignment Recognition (RTA) grant from Universitas Gadjah Mada.

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