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Characteristics and Dispersion Model of Wastewater PT Kayu Lapis Indonesia, Kendal, Central Java

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Abstract

PT. Kayu Lapis Indonesia (PT KLI) is a company engaged in the forestry sector, particularly in wood processing. Production activities at PT KLI produce wastewater that is treated and discharged into the sea, and then spreads following ocean currents. This study aimed to analyze the characteristics of wastewater produced by PT KLI and predict the distribution pattern of the waste. The characteristics of the wastewater and seawater were obtained through in situ measurements and sampling, which were analyzed in the laboratory. The distribution pattern of wastewater discharge was modeled using the pollutant model from the hydrodynamic model results around the water. The characteristics of the PT KLI wastewater were dominated by parameters such as pH, biological oxygen demand (BOD), chemical oxygen demand (COD), total suspended solids (TSS), and total ammonia. The wastewater was processed in a Wastewater Treatment Plant (WWTP) until all the parameters met predetermined standards before being discharged into the ocean. The model results show that wastewater tends to move westward both at high tide in the west and east monsoons and at low tide in the west and east monsoons, with little movement to the east.

Keywords: wastewater characteristics, hydrodynamics model, dispersion modeling, plywood industry

1. Introduction

PT. Kayu Lapis Indonesia (PT KLI) is located on the coast of Mororejo Village, Kaliwungu District, Kendal Regency, Central Java Province. This company is engaged in wood processing, specifically the production of plywood, block boards, sawn timber, engineering flooring, and wood. In carrying out its production activities, PT KLI produces liquid waste originating from utilities, glue manufacturing, glue washing, and domestic activities. Before being discharged into the sea, wastewater is treated at a Wastewater Treatment Plant (WWTP) until it meets the set quality standards. When the WWTP treats wastewater as a standard, it is discharged into the sea. The Java Sea is the body of water that receives wastewater from the PT KLI Sea.

For many years, people have not been concerned about marine pollution. This pollution is considered to have no impact, considering the large volume of seawater and its ability to dilute all types of foreign substances. Therefore, the sea is considered to be a waste disposal site. However, this view has begun to change gradually. This is because an increasing amount of waste is dumped into the sea in high concentrations, resulting in environmental pollution on a local to global scale. Water discharged into the sea without proper management can cause serious environmental harm to marine ecosystems, such as acidification (El Zrelli et al., 2018), mass mortality of fish (Elenwo and Akankali, 2015; Sreelekshmy et al., 2016), and can even be harmful to humans when consuming fish obtained from polluted waters (Utomo et al., 2021).

Wastewater discharged into the sea spreads following the movement of ocean currents. The rate of dispersal and dilution of wastewater depends on various factors, such as the type of waste, concentration of the waste, and flow of ocean currents. This current movement determines the Zone of Initial Dilution (ZID) area (Mahmudi and Rani, 2012; Noori et al., 2021). The Initial Dilution Zone is the geographic area where the initial dilution of wastewater occurs, and the wastewater criteria exceed the quality of the receiving water body. Determining the ZID area is an important part of risk management to reduce the impact of waste disposal on the environment and human health (Campos et al., 2022). Therefore, a mathematical model is necessary to predict the distribution of liquid waste to help environmentalists and policymakers manage marine resources more effectively (Aljohani et al., 2022; Baawain et al., 2015; Ben Hamza et al., 2015). This study aims to examine the characteristics of wastewater discharged by PT KLI and to simulate the distribution of wastewater in receiving water bodies.

2. Methods

2.1. Data Collection

The data collected includes wastewater and seawater quality data, as well as data that will be used to build models. Wastewater and seawater quality data were obtained by in situ measurements using the Lutron WA 2017 instrument and water sampling for analysis at the Aquatic Productivity and Environment Laboratory, IPB University. The methods used for data acquisition and water quality analysis for each parameter are presented in Table 1. Wastewater quality measurements were conducted at two locations: the inlet and outlet of the WWTP. In addition, measurements of the seawater quality around the WWTP discharge were completed at four sites. A map of the seawater quality monitoring locations is shows in Figure 1.

The data used to build the hydrodynamic model included bathymetry, tides, wind, and currents. Bathymetry data were obtained by performing in situ measurements using a Garmin GPSmap 585 sounder equipped with a single-beam dual-frequency (50/200 kHz) echosounder and a global positioning system (GPS) antenna. This instrument is often used for bathymetric mapping activities (Febrianto et al., 2015; Karamma et al., 2021; Lubis et al., 2020). Tide data were obtained from the Geospatial Information Agency (BIG) forecast which was validated using in situ measurement data. The results of model validation with in situ data showed the same type and height of tides. The validation results for the model and in situ data are shown in Figure 2. Besides being used as a generating force in the hydrodynamic model, tidal data is also used to correct the sounding depth values. Wind data were obtained from the European Center for Medium-Range Weather Forecasts (ECMWF). The data used were wind speed data u and v at a height of 10 m above sea level. These data are suitable for use in building hydrodynamic models (Bellafiore and Umgiesser, 2010; de Lima et al., 2020; Inan, 2019; Khoirunnisa and Karima, 2019).

2.2. Hydrodynamic Models

The equations used in this model are the continuity equation and the momentum equation with depth alignment. This model uses a finite difference

Table 1. Acquisition and analysis of water quality parameters methods

No	Parameters	Data Acquisition	Analysis/Instruments Methods
1	TSS	Water Sampling	APHA, 23rd Edition,2540-D, 2017
2	BOD	Water Sampling	APHA, 23rd Edition, 5210-B, 2017
3	COD	Water Sampling	APHA, 23rd Edition, 5220-D, 2017
4	Oil and fat	Water Sampling	APHA, 23rd Edition, 5520-B, 2017
5	Ammonia (NH3-N)	Water Sampling	APHA, 23rd Edition, 4500-NH3-F, 2017
6	Phenol	Water Sampling	MU 2. 12 (Discrete Photometry)
7	pH	Insitu	Lutron WA 2017 (in situ)
8	Formaldehyde	Water Sampling	GC-VID
9	Total Coliforms	Water Sampling	APHA, 23rd Edition, 9221 - (B-C), 2017

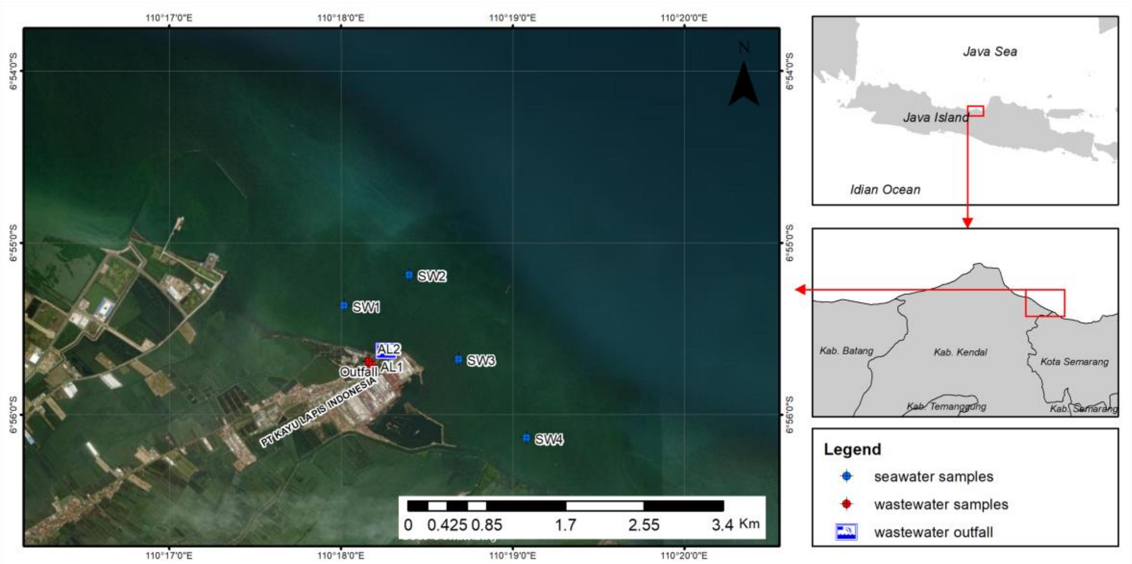

Figure 1. Sampling locations in Kendal Waters

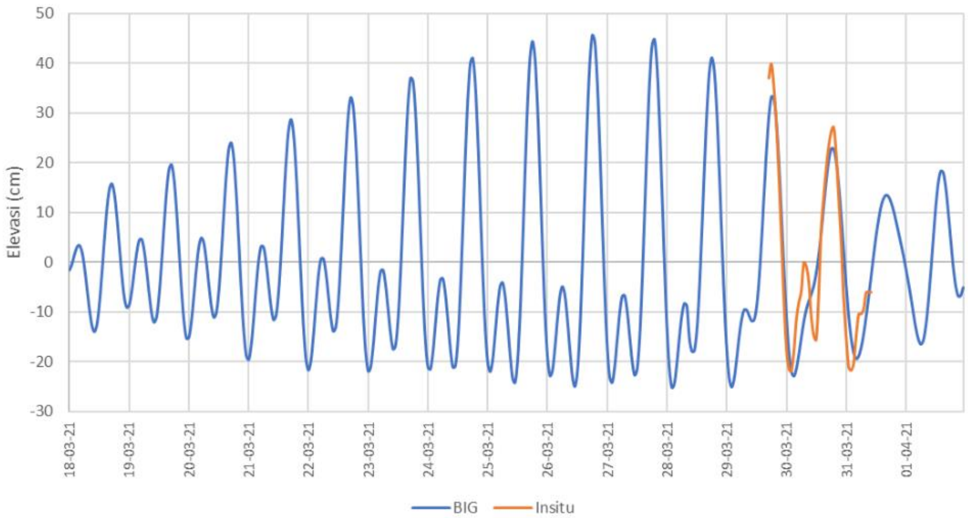

Figure 2. The results of ide graph from model and in-situ measurements

locations is shows in Figure 1. approach to solve the continuity and momentum equations. The equations used are as in equations (1) to (9).

continuity equation:

$$\frac{\partial \zeta}{\partial t}+\frac{\partial p}{\partial x}+\frac{\partial q}{\partial x}=\frac{\partial d}{\partial t} \quad (1)$$

momentum equation:

on the x-axis: $\frac{\partial p}{\partial t}+\frac{\partial}{\partial x}\left(\frac{p^2}{h}\right)+\frac{\partial}{\partial y}\left(\frac{pq}{h}\right)+$

$$gh\frac{\partial \zeta}{\partial x}+\frac{gp\sqrt{p^2+q^2}}{C^2.h^2}-\frac{1}{\rho_w}\left[\frac{\partial}{\partial x}(h\tau_{xx})+\right. \quad (2)$$

$$\left.\frac{\partial}{\partial y}(h\tau_{xy})\right]-\Omega_q-fVV_x+\frac{h}{p_w}\frac{\partial}{\partial x}(\rho_a)=0$$

on the y axis: $\frac{\partial q}{\partial t}+\frac{\partial}{\partial y}\left(\frac{q^2}{h}\right)+\frac{\partial}{\partial x}\left(\frac{pq}{h}\right)+$

$$gh\frac{\partial \zeta}{\partial y}+\frac{gp\sqrt{p^2+q^2}}{C^2.h^2}-\frac{1}{\rho_w}\left[\frac{\partial}{\partial y}(h\tau_{yy})+\right. \quad (3)$$

$$\left.\frac{\partial}{\partial x}(h\tau_{xy})\right]-\Omega_p-fVV_y+\frac{h}{p_w}\frac{\partial}{\partial y}(\rho_a)=0$$

In this equation, $h(x,y,t)$ = water depth (ζ=d); $d(x,y,t)$ = depth varies with time ; ζ(x,y,t) = surface elevation; $p,q(x,y,t)$ = flux density on the x and y axes $(m^3/s)=(uh,uv)$; u,v = velocity averaged over depth on the x and y axes; $C(x,y)$ = chezy resistance $(m^{\frac{1}{2}}/s)$; g = gravitation(m^2/s); $f(V)$ = wind friction factor; $V,V_x,V_y,(x,y,t)$ = wind speed on the x and y axes (m/s); $\Omega(x,y)$ = coriolis parameters; $\rho_a(x,y)$ = atmospheric pressure (kg/m/s^2); ρ_w = seawater density (kg/m^3); $\tau_{xx,}\tau_{xy},\tau_{yy}$ = effective shear stress component.

Bed shear stress in the x and y directions can be calculated by:

$$\tau_{bx}=\rho c_f V\sqrt{U^2+V^2}\left[1+\left(\frac{\partial z_b}{\partial x}\right)^2+\left(\frac{\partial z_b}{\partial y}\right)^2\right]^{\frac{1}{2}} \quad (4)$$

$$\tau_{bx}=pc_f V\sqrt{U^2+V^2}\left[1+\left(\frac{\partial z_b}{\partial x}\right)^2+\left(\frac{\partial z_b}{\partial y}\right)^2\right]^{\frac{1}{2}} \quad (5)$$

c_f is the coefficient of friction and can be calculated as follows:

$$c_f=\frac{g}{C^2}=\frac{gn^2}{\lambda^2 H^{1/3}} \quad (6)$$

where, C = Chezy coefficient; n = manning coefficient; λ =1.486 for British units and 1.0 for SI.

The average depth of friction can be calculated using the Eddy viscosity concept of Boussinesq, by:

$$\tau_{xx}=\rho v_{xx}\left(\frac{\partial U}{\partial x}+\frac{\partial U}{\partial x}\right) \quad (7)$$

$$\tau_{xy}=\tau_{yx}=\rho v_{xy}\left(\frac{\partial U}{\partial y}+\frac{\partial U}{\partial x}\right) \quad (8)$$

$$\tau_{yy}=\rho v_{yy}\left(\frac{\partial V}{\partial y}+\frac{\partial V}{\partial y}\right) \quad (9)$$

where, V = current speed in the y direction; and U = current speed in the x direction.

2.3. Pollutant Model

Marine environmental pollution is a complex process because of the impact of interactions between pollutants and marine hydrodynamics (Cheng et al., 2021; Zhang et al., 2021). Both have characteristics and behaviors that are not fully understood. The distribution and impact of this pollution need to be predicted with a model that simulates the process, although simplifications and assumptions will be used. Based on the phenomenon of environmental pollution, the model is generally used by researchers to understand the processes that occur in detail and determine the level of influence of various parameters on the occurrence of pollution. The pollutant model used in this study used sediment transport and a biological oxygen demand distribution model.

The sediment transport model was based on hydrodynamic conditions and sediment properties. Several factors were considered in the model, including the river flow, sediment properties, and shape of the riverbed, lakebed, and seabed (Lepesqueur et al., 2019). The suspended sediment distribution model was built using the advection-dispersion equation, as shown in equation (10). The advection-dispersion equation is solved explicitly using a third-order finite difference approach.

$$\frac{\partial \bar{c}}{\partial t}+u\frac{\partial \bar{c}}{\partial x}+v\frac{\partial \bar{c}}{\partial y}=\frac{1}{h}\frac{\partial}{\partial h}\left(hD_x\frac{\partial \bar{c}}{\partial x}\right)+\frac{1}{h}\frac{\partial}{\partial y}\left(hD_y\frac{\partial \bar{c}}{\partial y}\right)+Q_L C_L\frac{1}{h}-S \quad (10)$$

In this equation, c = concentration averaged over depth (kg/m^3); u,v = flow velocity averaged over depth (m/s); $D_{x,}D_y$ = dispersion coefficient (m^2/s); S = accretion/erosion (kg/m^3/s); Q_L = source discharge horizontal unit area (m^3/s/m^2); C_L = source concentration (kg/m^3).

BOD distribution is solved by mass transport and processes within the mass. Models will be completed with DHI MIKE21 software containing hydrodynamic modules and the ECO lab. Generally, the equation to solve the BOD model is written as follows (11):

$$\frac{\partial c}{\partial t} + U\frac{\partial c}{\partial x} + V\frac{\partial c}{\partial y} + W\frac{\partial c}{\partial z} = D_x\frac{\partial^2 c}{\partial z^2} + D_y\frac{\partial^2 c}{\partial z^2} + D_z\frac{\partial^2 c}{\partial z^2} + S_c + P_c \quad (11)$$

In this equation, C = concentration; u, v, w = current component; Dx, Dy, Dz = dispersion coefficient; Sc = waste source; Pc = processes that occur in parameters.

3. RESULTS AND DISCUSSION

3.1. Characteristics of Wastewater and Water Quality

The sources of wastewater produced by PT KLI come from utilities, glue manufacturing, glue washing, canteens, and domestic activities. According to Subari and Setiawan (2012), wastewater generated in the plywood production process is generally generated from the washing process of the glue spreader machine and other production equipment; therefore, the composition contained in the wastewater produced is water and materials used in making adhesives. The characteristics of plywood industry wastewater are generally dominated by high values of pH, BOD, COD, TSS, phenol, and total ammonia (Sunny et al., 2016).

The results of the laboratory measurements and analysis of PT KLI wastewater quality and seawater quality against quality standards are shown in Table 2. The inlet point (AL1) was a mixing tank (Equalization Tank I) for glue manufacturing waste, glue washing waste, and domestic activities. At this point, the waste has not gone through a treatment process. The result of mixing wastewater from several waste sources is then processed in the WWTP. The outlet point (AL2) is the wastewater from WWTP processing. From the outlet point, the wastewater flows to the outfall point which is the meeting point for treated wastewater disposal with the receiving water body (sea). The parameters observed included suspended matter (TSS), BOD, COD, oils and fats, ammonia (NH3-N), phenol, pH, and total coliforms. The results of observations compared with predetermined quality standards. The quality standard used was a combined quality standard for plywood industrial waste, glue industrial waste and domestic waste. Water quality measurements were also performed in the receiving water bodies (seawater). The results of water quality measurements were compared with established environmental quality standards (Regulation of the Government of the Republic of Indonesia Number 22 of 2021).

The quality of wastewater discharged by a company or industry must meet quality standards physically, chemically, and biologically. The quality value of wastewater that exceeds the maximum limit is classified as a pollutant. The TSS concentration at the inlet was 93 mg/L and that at the outlet was <8 mg/L. In the plywood industry, high TSS concentrations are caused by the production processes and wood treatment chemicals (Soedarmanto and Setiawati, 2022). Plywood manufacturing processes, such as wood preparation, veneer stripping, drying, gluing, and pressing generate solid waste materials, such as wood particles, sawdust, and other debris. These materials eventually mix with water and produce wastewater. In addition, the plywood industry uses chemicals for wood processing, including adhesives, preservatives, and coatings. These chemicals can contribute to increasing suspended solids in wastewater. Even though the wastewater produced has a high concentration of TSS, the waste is already full when it is released into the sea. The WWTP process can be evaluated by comparing the concentration values at the inlet and outlet. The TSS concentration decreased by 85 mg/L, or with an efficiency of 91.40%. This value is slightly better than that produced by (Ninh et al., 2018). The higher the efficiency presentation, the better the coagulant process (Subari and Setiawan, 2012). Several methods have been developed to reduce the concentration of TSS in the plywood industry wastewater, one of which is the use of chitosan from shrimp shells (Harahap, 2011).

Another water quality parameter is BOD. In the plywood industry wastewater, the BOD parameter is high because the waste generated from the production process contains a lot of organic matter which is easily degraded by microorganisms, thereby increasing the concentration of BOD (Klauson et al., 2015). The results of laboratory tests showed that there was a decrease in the concentration of liquid waste BOD which was measured at the inlet (150 mg/L) and outlet (6 mg/L). The BOD concentration decreased by 144 mg/L, or with an efficiency of 96%. The decrease in BOD concentration occurs in aeration ponds due to a symbiotic metabolic relationship between the organic load of pollutant waste and bacteria from the pond. The growth of bacteria and microalgae in the sewage stabilization pond can not only reduce dissolved

Table 2. The results of the measurement of wastewater and seawater quality against the quality standards

No.	Parameters	Unit	Waste water			Sea water				
			AL1	AL2	Standar	SW1	SW2	SW3	SW4	Standars
1	Total Suspended Solid (TSS)	mg/L	**93**	11	39	8	9	8	9	20
2	BOD	mg/L	**150**	8	50	2	2.5	2.1	2.3	20
3	COD	mg/L	**734.18**	38.52	111	-	-	-	-	-
4	Oil and fat	mg/L	2	2	5	<1	<1	<1	<1	1
5	Ammonia (NH3-N)	mg/L	**10.968**	0.935	7	**0.397**	**0.521**	**0.535**	**1.208**	0.3
6	Phenol	mg/L	**7.25**	<0.001	0.25	<0.0005	<0.0005	<0.0005	<0.0005	0.002
7	pH	mg/L	8.54	7.3	6-9	7.95	7.99	8.03	8.04	7-8.5
8	Total Coliforms	MPN/100mL	23	<1.8	3000	<1.8	<1.8	<1.8	<1.8	1000

Note: values in bold are parameters that exceed the quality standard nutrients and BOD but also produce oxygen needed by aerobic bacteria (Gupta et al., 2021).

From the results of monitoring the quality of wastewater at the inlet and outlet points, it can be said that PT KLI WWTP has good waste processing capabilities and meets wastewater quality standards. This is seen from the ability to reduce all waste parameters that exceed the quality standard. At the inlet point, four parameters do not meet the quality standard, namely TSS, BOD, COD, and ammonia, while at the outlet point, all parameters meet the wastewater quality standard. Production WWTP is designed with a physical, chemical, and aerobic-activated sludge treatment system.

3.2. Hydrodynamic Models

The hydrodynamic model simulates the movement of water, including currents, tides, and other hydrodynamic processes. Hydrodynamic models play an important role in understanding the distribution of waste in the marine environment. The results of the hydrodynamic model show differences in speed and direction in each condition both in the west and east monsoons. The pattern of currents in the coastal waters of Kendal in the west monsoon tends to move east and in the east monsoon, the currents move west. The pattern of current movement at the study site during high and low tide conditions each season is shown in Figure 3.

The pattern of the West Monsoon current during high tide (Figure 3a) shows a mass of water moving from the northwest to the east. When this mass of water enters shallower waters, it is deflected following the contour of the coastline to the east. A different trend is shown when the waters experience low tide (Figure 3b), the mass of water tends to move in one direction, from northwest to east. The difference in mass movement during high tide and low tide becomes more significant due to seasonal influences. According to (Gordon et al., 2012), during the West Monsoon season, the mass of water in the Java Sea predominantly moves east towards the southern part of the Makassar Strait.

During the high tide in the East Monsoon, the mass of water moves towards the west (Figure 3c). The mass of water flows from deeper waters towards the coastal region. When the mass of water approaches the coast, there is a change in the direction of the current, following the coastline to the west. This event shows the interaction between the mass of water and the coastal contour that causes the current to be deflected. The sea current approaching the coast will be affected by the shape of the coast, such as bays, capes, or islands, which can deflect the sea current in a certain direction (Hessner and Bell, 2009).. When the ebb tide occurs, the mass of water moves towards the east and west at a slower speed (Figure 3d).

Based on the value of current velocity, high tide conditions provide stronger currents compared to low tide conditions. At high tide, the average current speed was 0.07 m/s. Current conditions are quite strong near the coast, with speeds reaching 0.3 m/s. This condition is caused by an increase in seawater volume driven by tidal energy. During high tide, the sea level rises, this difference in elevation between high and low tide creates a pressure difference that pushes the water towards areas with lower water levels. This moving mass of water creates stronger currents along the coastline. In addition, the beach geometry also plays a role in strengthening the

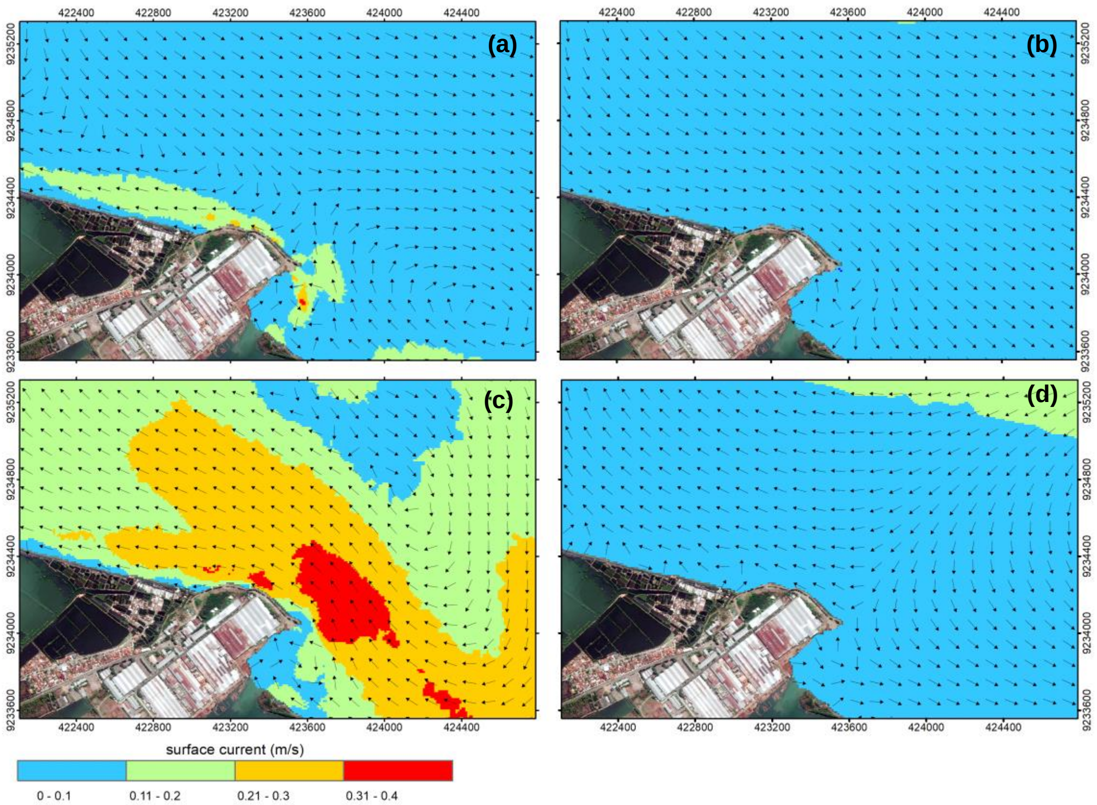

Figure 3. The current movement pattern is west season towards high tide (a), west monsoon towards low tide (b), east monsoon towards high tide (c), east monsoon towards low tide (d)

current speed during high tide conditions. High tide is impacted by coastal characteristics such as headlands, bays, and narrow coastal boundaries. A tide trapped in a more confined area can produce a stronger current as it tries to pass through a narrow gap or an area with a significant difference in level. This difference in current velocity can be caused by factors such as the difference in water level between inland and coastal waters, the influence of the wind, and the local topography. By understanding the pattern of current movement in the west and east monsoons and the changes that occur during high and low tides, we can describe the movement of water masses more comprehensively. Knowledge of these current patterns is of significant importance in a variety of fields, including marine navigation, environmental sustainability, and climate change studies.

3.3. Model of Pollutant Distribution

The waste distribution model was carried out by providing wastewater input of 538 m3/day, waste TSS concentration of 11 mg/L, and TSS concentration in the environment of 8 mg/L. In the west monsoon, wastewater will tend to move westward, and some of it will be distributed eastward. In the west monsoon, TSS with concentrations > 8 mg/L spreads as far as 700 meters from the outfall point. In the east monsoon, TSS with the same concentration spreads closer, up to a distance of 400 meters from the outfall point. The pattern of distribution of TSS concentrations from wastewater can be seen in Figure 5.

The west and east monsoons have similar distribution patterns of TSS concentrations, namely moving along coasts to the west and slightly to the east. This is in accordance with the hydrodynamic model's predictions, which indicate that the mass of water moves west during high tide. During high tide conditions, when sea water rises, the pattern of distribution of wastewater tends to move towards the coast. This is caused by tidal currents that push the mass of water and waste water towards the land. This condition allows wastewater discharged near the coast to spread along the coastline and reach a wider coastal area. However, during low tide, ocean currents that move from land to sea can cause wastewater to easily flush or be pushed towards the open sea. This condition contributes to the dissolving of contaminants in wastewater. When wastewater is discharged into waterways, ebb currents can help transport the waste from nearshore areas to waters farther out in the open ocean. Pollutants contained in wastewater will be dissolved and spread more evenly in a larger volume of water. The dissolving of contaminants in wastewater can be caused by diffusion and dispersion. The diffusion process occurs when contaminants are evenly spread in a large body of water, while the dispersion process occurs when contaminants are mixed with seawater and moved rapidly by currents.

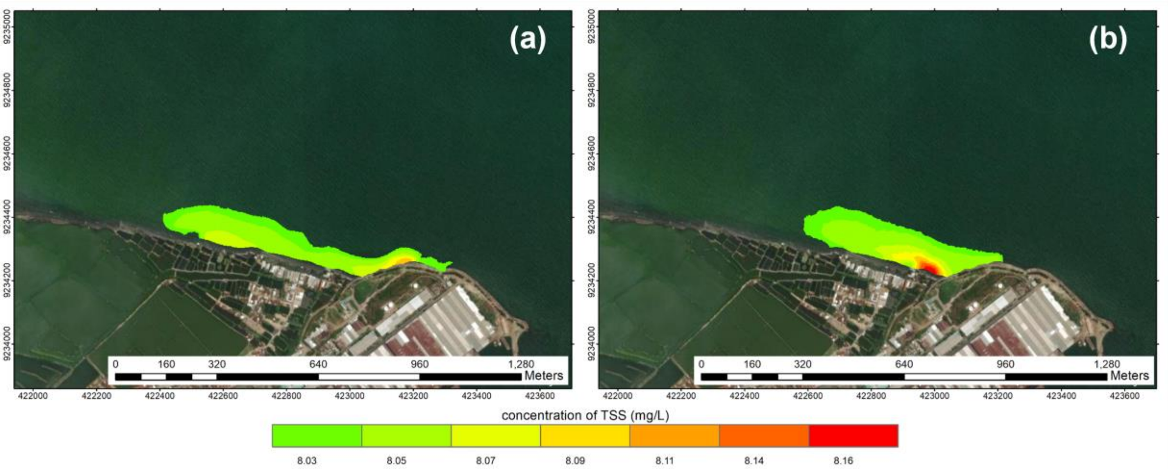

Figure 4. TSS parameter distribution model in the west season (a) and east season (b)

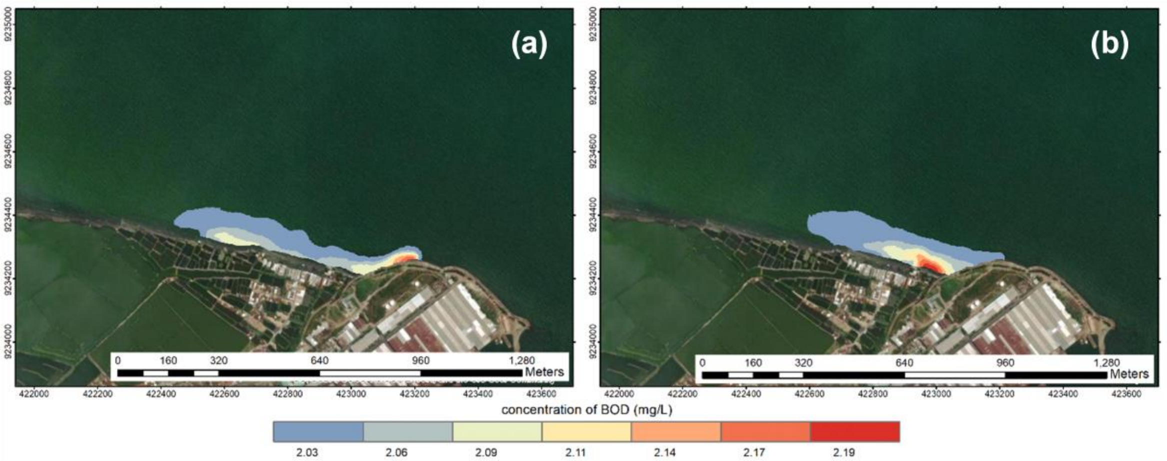

Figure 6. BOD parameter distribution model in the west season (a) and east season (b)

Waste distribution is predicted (modeled) based on wastewater inputs of 538 m3/day, waste BOD concentrations of 10 mg/L, and environmental BOD concentrations of 2 mg/L. Almost the same as the TSS distribution pattern, the distribution of BOD concentrations during the west monsoon tide based on the model results also shows a westward movement following the current tide (Fig 6). Liquid waste with BOD concentration >2.03 mg/L reaches up to 700 meters to the west in the west monsoon and moves up to 400 meters in the east monsoon. The range of waste parameters is farther in the west monsoon than in the east monsoon. According to the resulting hydrodynamic model, east monsoon currents are stronger than west monsoon currents. Stronger currents help the process of dilution in the waste dumped into the sea.

4. CONCLUSION

This study examines the characteristics of wastewater produced by PT KLI and the distribution pattern of the wastewater discharged. The wastewater quality at PT KLI is dominated by pH, BOD, COD, TSS, and total ammonia. The results of the investigation show that PT KLI has been able to manage its waste properly. Wastewater discharged into the sea meets the set quality standards. Based on the results of the waste distribution model, the concentration values of the TSS and BOD parameters are the same as the concentrations in the environment at a distance of 700 meters. In high tide conditions, waste that is disposed of along the beach also moves along the beach due to the mass of water moving towards the shore. This study provides insight into the characteristics of wastewater generated by the plywood industry from PT KLI, as well as the distribution pattern of its discharge. This information can be the basis for designing effective waste management strategies, protecting coastal ecosystems, and maintaining the quality of the waters around PT KLI.

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