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Spatial Distribution of Potential Pollution Load Point Sources of Bedadung River Segment in Urban Area

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Abstract
Land use influences the water quality of rivers. The variety of community activities in urban areas and a poor domestic sewage system are thought to affect the water quality of the Bedadung River, Jember Regency, Indonesia. Point source pollution is the dominant cause of degradation in the quality of the water in the Bedadung River, as identified by dissolved oxygen (DO) and Biochemical Oxygen Demand (BOD). This study was conducted to determine the potential point source pollution load of the Bedadung River in an urban area using land use information and pollution load-BOD data. All data were combined and processed using a Geographical Information System (GIS). The data were analyzed and plotted on a map depicting the distribution of potential point source pollutant loads in the Bedadung River urban area segment in Jember Regency. The results of the land use analysis in the urban area segment show that paddy fields accounted for 18.97% of the total study area, with fields at 5.98%, gardens at 12.85%, and rivers at 12.25%, while settlements covered the largest land area, on 49.96%. The results for the potential point source pollution load show that Kaliwates village had the highest potential pollution load value, at 13.966 kg/day. The lowest was Antirogo village, at 0.004 kg/day, while the total point source pollution load was 36.31 kg/day. An evaluation of point source pollution impact is required to control river pollution in urban areas, namely the development of communal Waste Water Treatment Plant (WWTP) in urban area segments.

Keywords: Pollution level, organic matter, pollution control, quality standard, BOD.

1. Introduction

A river is a natural or artificial channel or a channel in the form of a water drainage network running from the upstream of the mountains to the downstream or emptying into a lake or sea bordered by a river boundary. Rivers also store runoff from residential or domestic areas, agricultural area runoff, and flood runoff, which enables the entry of pollutants (Government Regulation No. 38, 2011). The Bedadung River is one of the large rivers that pass through the urban area of Jember Regency. It is used by the government for irrigation water and as a source of raw water for Perum DAM Tirta Pendalungan in Jember. The river is also widely used by the community for washing, bathing, and defecating (Pradana *et al*., 2019; Pradana *et al*., 2022).

Based on the 2015-2035 Jember Regency Master Plan, the Patrang, Sumbersari, and Kaliwates districts will be developed as an urban system (Perda Kabupaten Jember No.1, 2015). Thus, in line with an expected increase in population and various community activities, the potential for pollution in the Bedadung River will also increase (Puspita *et al.*, 2020; Rahman *et al.*, 2021). River water pollution in urban areas is caused by industrial and household waste. Population density, poor household waste disposal systems, and various community activities in land use along the border of the Bedadung River are thought to affect water quality in the Bedadung watershed (Pradana *et al.*, 2020; Aziza *et* al., 2018; Novita *et al.*, 2022).

Pollutant sources can be categorized as point sources or non-point sources, depending on how the pollutants enter the system. Point-source pollutants originate from known, directly identifiable sources, such as domestic waste disposal, industrial activities, and others (Regulation of the Minister of Environment and Forestry No. 1, 2010). Domestic waste comprises solid and liquid waste originating from settlements or other institutions. High levels of river pollution are caused by the large volumes of polluting waste that enter them, thus increasing the pollution load (Pangestu *et al.*, 2017; Djuwita *et al.*, 2021). Organic pollutants from domestic waste in rivers can reduce the concentration of dissolved oxygen (DO), which can affect river water quality (Wahyuningsih *et al.*, 2019). The Biochemical Oxygen Demand (BOD) value can be used as an indicator of organic matter in the Bedadung River. An increase in the concentration of BOD in water indicates pollution by organic material, with domestic waste as one of the contributors (Liu *et al*., 2015; Pramaningsih *et al*., 2020). Community activities and land use in river basins can alter the physical, chemical, and biological parameters of river waters (French *et al.*,2017; Jamwal *et al*., 2011). While land use change is an impact of population growth and increased human activity, changes in land use that ignore the principles of ecosystem sustainability tend to harm the environment, including a decrease in water quality (Susanti *et al*., 2020). Research to date has tended to focus on evaluating the main Bedadung River only (Wahyuningsih, 2019). Meanwhile, no study has attempted to conduct a detailed examination of the characteristics, distribution, and dynamics of the location of pollution sources, both point and non-point sources, along the Bedadung River in the urban segment. It is therefore necessary to identify details of the characteristics and distribution of pollution sources in the urban area of Jember Regency based on a Geographic Information System (GIS).

Point source contamination derives from a single local and identifiable source. Point sources are relatively easy to identify, measure, and control, and can be integrated with spatial data to identify points and sources that are one dimension on the map and determine the effect of land use on water quality using spatial analysis in GIS software (Camara *et al*., 2019; Maurya *et al*., 2021). A GIS is capable of collecting, storing, transforming, displaying, and correlating spatial data and geographical phenomena, which can then be used to determine the distribution of pollution levels. GIS applications are widely used for purposes ranging from natural resource inventories to regional spatial planning, among others. The use of remote sensing techniques combined with GIS is expected to provide data and analyze data spatially, to produce information that can be used to make integrative decisions (Cahyaningsih *et al*., 2010). This study was conducted to determine the potential point source pollution load of the Bedadung River in the urban area using spatial data and pollution load-BOD data. It refers to Minister of Environment Regulation No. 1 of 2010 concerning the Management of Water Pollution Control.

2. Research Methods

2.1. Location and time of research

This research was conducted where the Bedadung River flows through the urban area segment of Jember Regency, namely in the Patrang, Sumbersari, and Kaliwates districts (Perda Kabupaten Jember No.1, 2015). The water quality was assessed for point source pollutants at the Engineering Laboratory for Environmental Control and Conservation, Jember University. This research was conducted in May–August 2019. Figure 1 contains a map of the research location, indicating the inclusion of the area where the Bedadung River crosses the Patrang-Kaliwates sub-district within the urban segment of Jember Regency. Members of the local community use this segment of the river for their washing, bathing, and latrine activities. As a result, domestic pollution is a contributor to the decline in river water quality.

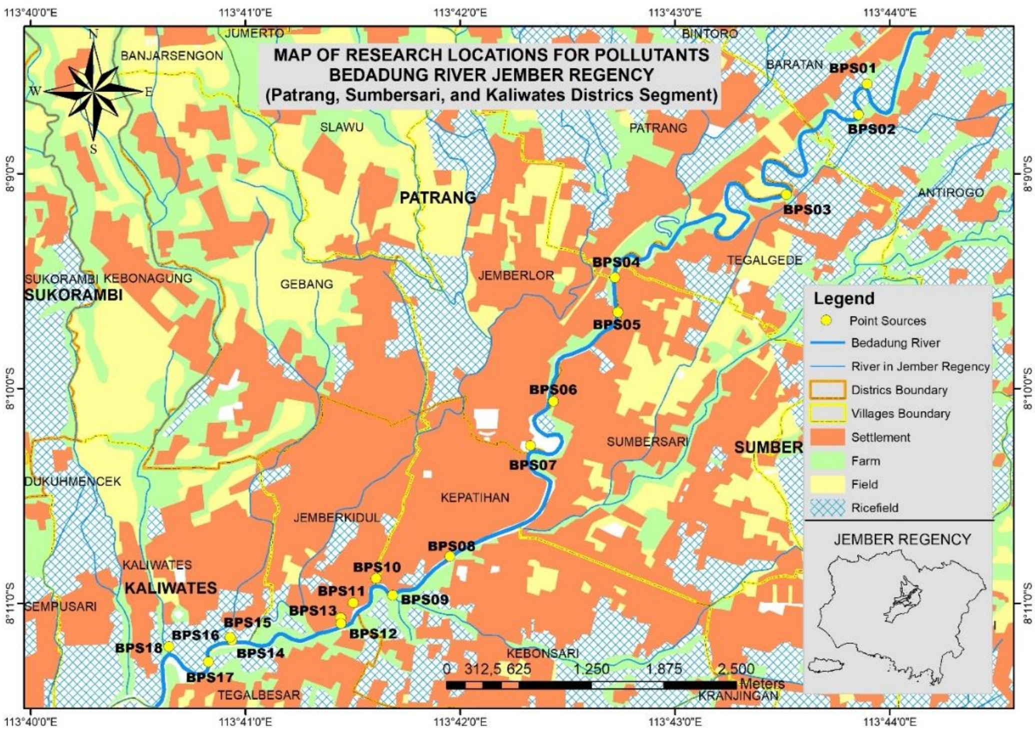

Figure 1. Map of the Research Location.

2.2. Data collection methods

The sampling point was determined through field observations taken along a 15.48-km stretch of the Bedadung River as it passes through three sub-districts that contain the total administrative area of 11 villages. The distribution of the point source pollutants is presented in Table 1.

The primary data comprised the quality and quantity of point source waste from the Bedadung River in the Patrang-Kaliwates segment with BOD parameters, obtained using the Iodometric measurement method / Azide Modification / Winkler Titration SNI 06-6989.14 2004, at 18 monitoring points (BPS01–BPS18). The coordinates of the point sources were obtained from measurements taken in the field using a GPS device (Pangestu *et al*., 2017). Spatial data were then derived from base maps and thematic maps of the research area. Secondary data were obtained from the Minister of Environment and Forestry Regulation Number P.68/Menlhk/Setjen /Kum.1/8/2016 concerning Domestic Waste Quality Standards, Regulation of the Minister of Environment Number 1 of 2010, and Regulation of BIG Number 3 of 2016.

Table 1. Point Distribution of Pollutant Sources in the Bedadung River.

Code	Pollution Source	Source of Wastewater	Sub-District	Sampling Coordinate	
BPS01	Point Source	Domestic	Patrang	8° 8'35.03"S	113°43'53.77"E
BPS02	Point Source	Domestic	Sumbersari	8° 8'42.75"S	113°43'52.85"E
BPS03	Point Source	*Outlet* PDAM	Sumbersari	8° 9'5.92"S	113°43'31.15"E
BPS04	Point Source	Domestic	Sumbersari	8° 9'29.10"S	113°42'43.28"E
BPS05	Point Source	Domestic	Patrang	8° 9'38.79"S	113°42'44.06"E
BPS06	Point Source	Domestic	Sumbersari	8°10'3.66"S	113°42'26.12"E
BPS07	Point Source	Domestic	Patrang	8°10'16.04"S	113°42'19.69"E
BPS08	Point Source	Domestic	Sumbersari	8°10'47.04"S	113°41'57.16"E
BPS09	Point Source	Domestic	Sumbersari	8°10'57.90"S	113°41'41.19"E
BPS10	Point Source	Domestic	Kaliwates	8°10'53.12"S	113°41'36.52"E
BPS11	Point Source	Domestic	Kaliwates	8°10'59.93"S	113°41'30.11"E
BPS12	Point Source	Domestic	Kaliwates	8°11'6.39"S	113°41'26.40"E
BPS13	Point Source	Domestic	Kaliwates	8°11'5.43"S	113°41'26.25"E
BPS14	Point Source	*Outlet* PDAM	Kaliwates	8°11'10.42"S	113°40'56.25"E
BPS15	Point Source	Domestic	Kaliwates	8°11'9.61"S	113°40'55.75"E
BPS16	Point Source	Domestic	Kaliwates	8°11'9.91"S	113°40'51.23"E
BPS17	Point Source	Domestic	Kaliwates	8°11'16.51"S	113°40'49.55"E
BPS18	Point Source	Domestic	Kaliwates	8°11'12.16"S	113°40'38.56"E

2.2. Data analysis

a. Water quantity and quality analysis

Water from around the pollutant sources was sampled three times using the instantaneous method (grab sampling) and water samples were preserved in a cool box containing ice cubes with a temperature of +/- 4 °C (Puspitasari *et al*., 2020). The pollution load was calculated by multiplying the discharge (m^3/sec) and the waste concentration (mg/L) according to the following equation:

$$BP = ((Q \ x \ C) \ / \ 1000) \ x \ 3600 \ x \ 24 \qquad (1)$$

Information:

BP = Pollution load (kg/day)

Q = Discharge (m^3/sec)

C = Concentration of waste (mg/L)

Discharge was measured by determining the width of the input or channel, then measuring the water depth to calculate the overall cross-sectional area. Water velocity was determined using a current meter, with three measurements taken at 10-second intervals. Channel flow discharge was calculated using the following equation (SNI 8006: 2005):

$$Q = A \, x \, V \qquad (2)$$

Information:

Q = Flow rate (m^3/sec)

A = Cross-sectional Area (m^2)

V = Speed (m/sec)

Pollution load concerns the amount of pollutants contained in water or waste. The size of the pollution load greatly affects water quality and can be an indicator of whether the water is polluted or not.

b. Spatial data analysis

The distribution map of point-source organic pollutant load prediction in the Bedadung River segment of the Patrang-Kaliwates District and the effect of land use patterns on water quality were generated from spatial analysis using ArcGIS 10.3 software. The analysis stages include:

- Digitization of the river appearance and land use patterns generated from the Rupa Bumi Indonesia map of the Patrang, Sumbersari, and Kaliwates districts to obtain land cover maps around the study area
- Plotting of monitoring points to obtain a map of the distribution of point-source pollutants
- Plotting the BOD water quality concentration values into the base map
- The plot results in the form of points are then interpolated using the Thiessen Polygon method to obtain a spatial picture of an area
- Tightening of the study area by establishing a sampling area boundary with a radius of 500 meters from the riverbank
- This is then overlayed with information on flow patterns and flow directions as well as the boundary levels of water pollution levels as input in analyzing spatial data to identify pollutant sources (Cahyaningsih *et al.*, 2010; Pei *et al.*, 2022).

A boundary was established because not all pollutants come from households that dispose of their waste in the river; as such, only households located within 500 meters of the riverbank were considered. This was also conducted to determine the number of people in the area based on the percentage of the area (Novitasari, 2015).

3. Results and Discussion

3.1. Pollutant sources identification

The pollutant sources were identified through field observations in the research area. The results of these observations are presented in (Figure 3). In the Bedadung River research area, the Patrang-Kaliwates District segment with 18 monitoring points has various characteristics, including 88.89% domestic waste and 11.11% Perum DAM Tirta Pendalungan sewage. The amount of domestic waste depends on the population in an area (Puspitasari *et al.*, 2020). Domestic waste comprises both solid and liquid waste originating from settlements or other institutions (Pangestu *et al.*, 2017). The distribution of polluted source points in the three sub-district segments consists of 16.67% in Patrang District, 38.89% in Sumbersari District, and 50% in Kaliwates District.

3.2. Land use conditions in pollution source areas

Land cover in the study area was identified through an analysis using spatial data on land use to generate land cover data. The land use patterns in an area provide an overview of previous community activities, which can then be used as an indicator of how the community treats natural resources (Lusiana *et al.*, 2017). The results of the land use/cover analysis of pollutant sources based on boundaries are presented in Figure 2. Rice fields covered 18.97% or 2.24

km2of the study area, paddy fields 5.98% or 0.71 km2, gardens 12.85% or 1.52 km2, and rivers 12.25% or 1.45 km2, while land use for settlements covered the largest area, namely 49.96% or 5.92 km2 of the total study area (Figure 2).

In short, land use patterns along the river have a major effect on river discharge and the pollution load value (Pangestu *et al*., 2017; Ahmad *et al*., 2021). As the population increases, the need for housing leads to the exploitation of natural resources. Built-up areas make the greatest contribution to peak disposal; thus, peak discharge will rise in line with the increase in built land in the Patrang, Sumbersari, and Kaliwates districts (Puspitasari *et al*., 2020). Based on the 2015 Jember Regency Master Plan, the Patrang, Sumbersari, and Kaliwates districts will be designed as an urban system. This will create greater potential for land development compared to other districts. Based on these conditions, agricultural land is predicted to be converted into settlements in Jember Regency, leading to the threat of pollution in the Bedadung River in the city (Pradana *et al*., 2020).

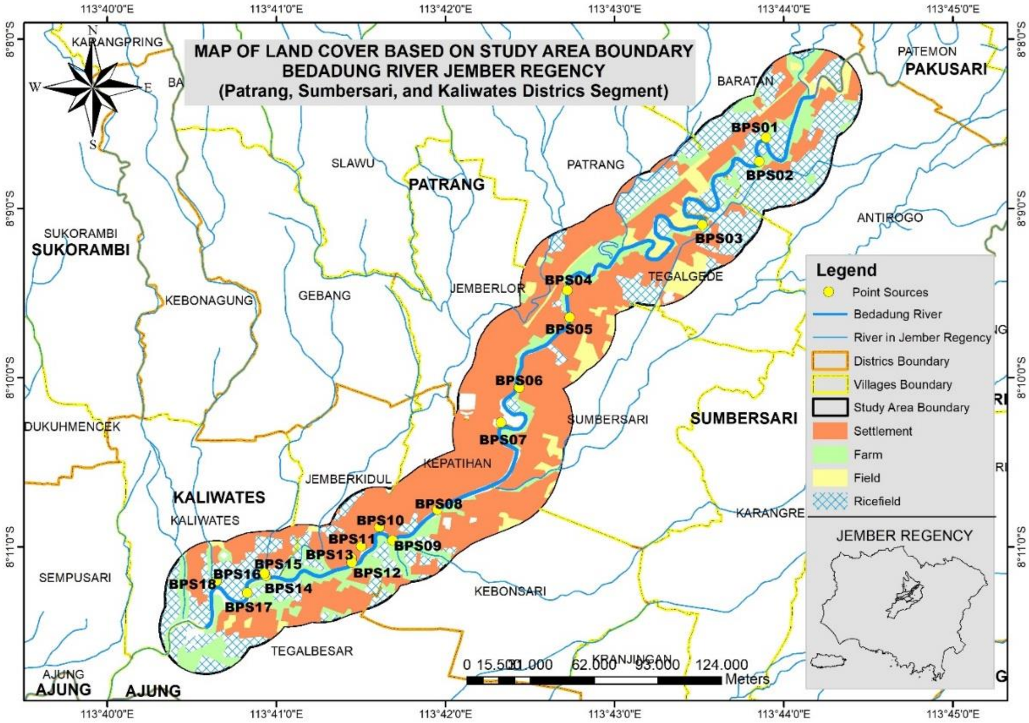

Figure 2. Map of Land Use/Cover According to Boundaries.

3.3. Pollution load of point source organic materials

The results of the measurement of pollutant source water quality are presented in Table 2. The determination of the water quality criteria refers to the Minister of Environment and Forestry Regulation Number P.68/Menlhk/Setjen/Kum.1/8/2016 concerning Domestic Waste Quality Standards and Regulation of the Minister of Environment Number 1 of 2010. The results show that the accumulated value of BOD concentration per village was below the maximum level (30 mg/L). The highest average BOD value of 9.70 mg/L was found in Kelurahan Tegal Besar, while the lowest average BOD of 1.29 mg/L value was noted in Kelurahan Kepatihan (Table 2). A higher BOD level indicates both that the water is polluted (Lusiana *et al*., 2017) and that the concentration of organic matter is high (Sari *et al.*, 2020).

Analysis of the potential point source pollution load considered the various community activities that result in discharge through channels to river bodies. BOD concentration was determined from the results of the wastewater quality test, while discharge was calculated by multiplying the discharge from the pollutant sources by the estimated population according to the boundary of the area (Novitasari, 2015). From the results of the calculation of the potential point source pollution load in the urban segment of the Bedadung River (Table 2), the highest potential value of the pollution load was identified in Kaliwates village, at 13.966 kg/day, with the lowest in Antirogo village, at 0.004 kg/day. The total point source pollution load was 36.31 kg/day. In addition to the pollutants contained in the river flow, in this case, BOD, the amount of discharge affects the value of the pollution load; thus, the higher the discharge value, the higher the pollution load value (Pradana *et al.*, 2019). The quality class criteria for the pollution load were determined using the assimilation approach; as such, pollution loads with low-, medium-, and high-quality classes of domestic waste (BOD) were assigned values of 110 mg/L, 220 mg/L, and 400 mg/L respectively in accordance with Minister of Environment and Forestry Regulation Number 1/2010. In the 11 sub-districts based on the boundary in Figure 3, two color shades, namely medium and high, apply to the values of the potential point source pollution load of the Bedadung River in the urban area segment. The potential for a medium pollution load is seen in Baratan, Jember Lor, Kebonsari, Kepatihan, Jember Kidul, and Antirogo. While the potential for a high pollution load is evident in Tegal Gede, Patrang, Sumbersari, Tegal Besar, and Kaliwates villages (Figure 3).

Table 2. Results of the BOD Water Quality Test for Pollutants.

Sub-District	Villages	Concentration BOD (mg/L)	Discharge (L/s)	Pollution Load (kg/day)
Patrang	Baratan	2.01	0.003012	0.523
	Patrang	2.75	0.001764	0.420
	Jemberlor	2.57	0.000021	0.005
Sumbersari	Antirogo	3.18	0.000013	0.004
	Tegal Gede	1.72	0.000322	0.048
	Sumbersari	4.09	0.001771	0.627
	Kebonsari	2.42	0.019635	4.102
Kaliwates	Kepatihan	1.29	0.007958	0.890
	Jemberkidul	2.08	0.015057	2.703
	Tegal Besar	9.70	0.015552	13.028
	Kaliwates	3.90	0.041488	13.966
Total				36.315

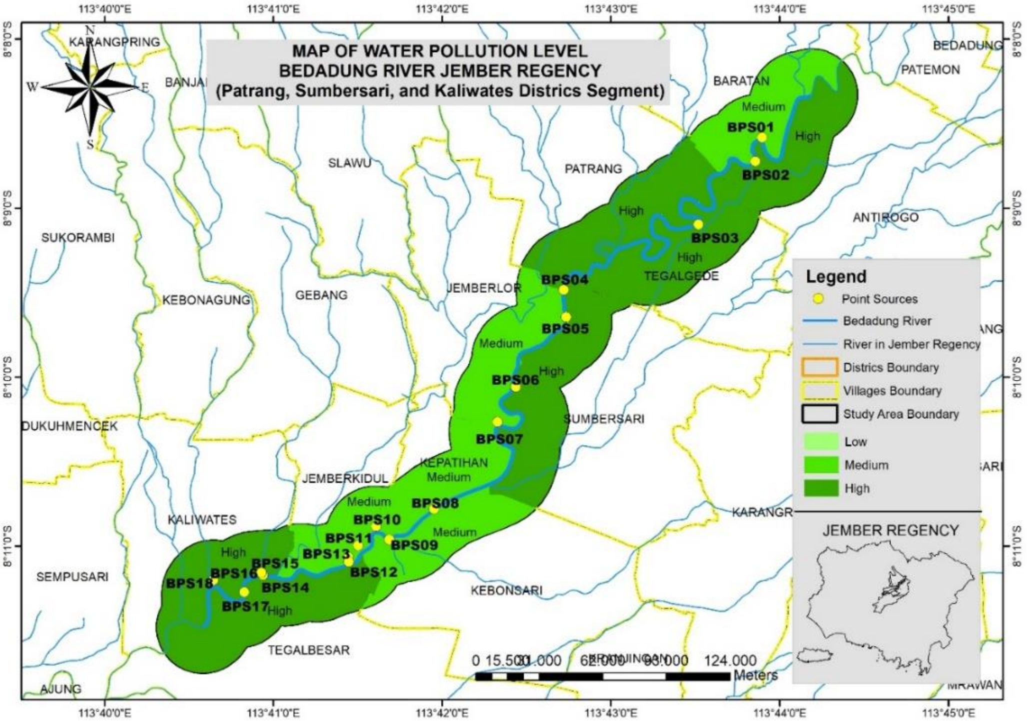

Figure 3. Map of the Point Source Pollution Level of the Bedadung River.

4. Conclusion

The results of the analysis and mapping on the urban area segment of the Bedadung River show that the land cover of the pollutant source area based on the boundary comprises 18.97% rice fields, or an area of 2.24 km2, 5.98% or 0.71 km2 fields, 12.85% or 1.52 km2 gardens, and 12.25% or 1.45 km2 for the river, while settlements account for the largest land area of 49.96%

or 5.92 km2 of the total study area. The results of the calculation of the potential point source pollution load show that the highest potential pollution load value of 13.966 kg/day was obtained in Kaliwates village. The greater the sources of pollution, the greater the value of the pollution load-BOD. These results can be used when considering the potential location of Waste Water Treatment Plant (WWTP) construction in urban areas.

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Author Contributions

Conceptualization: Elida Novita, Ahmad Zaidan Karomi, Hendra Ardiananta Pradana; **methodology**: Elida Novita, Ahmad Zaidan Karomi, Hendra Ardiananta Pradana; **investigation**: Elida Novita, Ahmad Zaidan Karomi, Hendra Ardiananta Pradana; **writing—original draft preparation**: Elida Novita, Ahmad Zaidan Karomi, Hendra Ardiananta Pradana; **writing—review and editing**: ; **visualization**: Elida Novita, Ahmad Zaidan Karomi, Hendra Ardiananta Pradana. All authors have read and agreed to the published version of the manuscript.

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