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Dispersion Model of Crushed Stone Industry Activity Plan in Lanjoboko Village

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ABSTRACT: *The Operational Plan of the Crushed Stone Industry produces Total Suspended Particulate Concentration Data (TSP), PM10, and PM2.5 emissions. These emissions can have an impact not only on the environment but also on health. So, it is necessary to plan environmental management to reduce these emissions. A simulation of the distribution pattern of pollutants to the area around the Industry is needed to find out whether AERMOD Software is used. The study analyzed the emission rate of TSP, PM10, and PM2.5 from the Broken Stone Industry plan and its distribution pattern. Modelling was carried out over a period of 5 years by looking at the worst conditions. The study's results showed the dominant wind pattern that occurred during the last 5 years (2019-2023) from the Northwest direction. Model calculations showed the highest concentration of TSP of 230.33 µg / m3, PM10 86.87 µg / m3 and PM2.5 18.61 µg / m3. The study results showed the industrial area's maximum concentrated dispersed particulate emissions.*

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I. INTRODUCTION

The need for materials to support the implementation of development in various sectors from time to time is increasing. The construction of infrastructure and supporting increasingly developing facilities will also support local to national economic growth. One of the materials needed is crushed stone, which can be used for building or industrial purposes. The Stone Crusher Crushed Stone Industry Activity is an activity that focuses on processing rocks into crushed stones of various sizes that are used as raw materials for construction.

Lonjoboko Village is one of the villages in the Parangloe District, Gowa Regency, which has hilly land at an altitude of 100-600 meters above sea level (MDPL). Crossed by the Je'neberang River, this village has abundant rock mining potential. Some of the rock mining potentials owned by Lonjoboko Village include sand, river stone, soil, mountain stone, and sirtu along the Je'neberang River. In recent years, the number of stone crusher industries in Lonjoboko Village has increased, and changes have occurred in land from agricultural land to industrial areas. The activities of the stone-breaking industry in Lonjoboko Village have the potential for Particulate impacts that can reduce ambient air quality.

Stone crushing and screening generate significant amounts of dust, which disperses into the air and spreads around the crusher site. The extent of dust spread is influenced by wind direction, speed, and air humidity. Inhaling fine dust particles poses serious health risks to workers in the stone-crushing industry, making it an occupational hazard. Transporters of stone and rock, nearby residents, and passersby are also exposed to this dust. Total suspended particles (TSP) impact extends beyond humans, affecting animals and vegetation in the surrounding area by Ravindan, [1].

Total suspended particles (TSP) include airborne particles ranging in size from 10 µm to 100 µm, with a 30 µm aerodynamic diameter commonly used as a representative value [2]. PM_{10} and $PM_{2.5}$ refer to particulate matter that can pass through a size-selective inlet with a 50% efficiency cut-off at aerodynamic diameters of 10 µm and 2.5 µm, respectively [3-4]. Particles measuring 2.5 µm or smaller are generally classified as fine particles, while those of 10 µm or larger are categorized as coarse particles.

According to recent estimates by the World Health Organization (WHO), air pollution is responsible for approximately 2.7 million deaths annually. Prolonged exposure to air pollution remains a global concern. Over the past decades, numerous studies have examined the effects of non-lethal air pollutants on both human health and atmospheric cycles at regional and global levels. Research has primarily focused on total suspended particulates (TSP), particulate matter (PM), nitrogen dioxide, and sulfur dioxide due to their significant health impacts by Kirk-Othmer, [5]. Therefore, it is necessary to control these pollutants. One of the efforts to find air pollution in ambient air is by estimating the distribution pattern of pollutant particles or by air modeling.

The American Meteorological Society Environmental Protection Agency Regulatory Model (AERMOD) is a Gaussian plume model-based software endorsed by the US EPA for air quality simulations by

EPA [6]. Additionally, AERMOD factors in the topographical features of the study area by Steven et al., [7]. and is particularly effective in handling complex terrain, producing reliable results in mountainous regions [8]. Designed as a spatial dispersion model for air quality regulation, AERMOD can simulate pollutant distribution from up to 50 different emission sources, including point, area, and volume sources by (Zou et al.,[9]. By modeling emission dispersion patterns, it allows for estimating pollutant concentrations extending several kilometers from the source [10].

AERMOD has been applied in various studies, including the analysis of PM_{10} dispersion in Pune, India by Kesarkar et al.,[11] and the assessment of road emissions for multiple pollutants such as $PM_{2.5}$ and SO_2 by Cook et al.,[12]. It has also been utilised to create synthetic datasets for $PM_{2.5}$, NOx, and benzene in an exposure study conducted in New Haven Johnson et al., [13] and to examine spatial exposure patterns of SO_2 in Dallas County by Zou et al.,[14]. AERMOD has also been used as a model for predicting intra-urban variation in PM2.5 in Pennsylvania by Michanowicz et al.,[15] and Dispersion of TSP and PM_{10} emissions from quarries in complex terrain in Israel Tartakovsky, Stern, and Broday[16].

II. METHODS

DATA SOURCE

Data collection was carried out by collecting references obtained from journals, books, and other sources related to the dispersion of pollutants in the form of dust in the air. Secondary data used for the analysis of pollutant distribution such as Meteorological condition data for Gowa Regency for 5 years, Ambient air quality measurement data at industrial locations, Lanjoboko Village, Gowa Regency for the last 1 year (2024), and Elevation maps or contour maps are needed because the base map of the study area does not contain such data. The elevation data for the study area was retrieved through the website www.webgis.com. Elevation data is selected according to the coordinates corresponding to the study area.

METHODS OF ANALYSIS

The methodology used in data processing is as follows:

a. Meteorological Data Analysis
The analysed meteorological data include factors such as wind rose patterns, atmospheric stability, and wind speed profiles. This data is processed using AERMET, a component of the AERMOD software suite.

b. Dispersion Model
The dispersion model is developed using AERMOD software, a pollutant dispersion model created by the United States Environmental Protection Agency (EPA). This model applies Multiple Source Modeling, consolidating multiple emission sources into a single unit, represented as emissions per unit area by Macdonald, [17]. If multiple source points are within 100 meters of each other and their combined emissions do not exceed 20%, they are classified as area sources EPA, [18]. The fundamental equation in the AERMOD model is based on the Gaussian function, as represented in Equation 1 below.

$$C\,(x,y,z{:}H) = \frac{Q}{2\pi\sigma_y\sigma_z u}\, exp\left[-\frac{1}{2}\left(\frac{y}{\sigma_y^2}\right)\right]\left\{\left[-\frac{1}{2}\left(\frac{z-H}{\sigma_z^2}\right)\right]^2 + \exp\left[-\frac{1}{2}\left(\frac{z-H}{\sigma_z^2}\right)\right]^2\right\} \quad (1)$$

Where C = pollutant concentration at a point (x,y,z (g/m^3), Q = emission rate (g/s), $\sigma y \sigma z$ = horizontal (y) and vertical (z) dispersion coefficient, is a function of distance (x), u = average wind speed at the height of the chimney (m/s), x = horizontal plume from the pollutant source in the direction of the wind (m), y = horizontal plume perpendicular to the wind direction (m), z = vertical plume from the surface (m), H = effective height (m).

Dewi et al., stated that an additional advantage of the Gauss dispersion model is its ability to facilitate real-time, effective, and representative air quality monitoring for companies [19]. This study specifically models pollutants generated from Crushed Stone Production activities, including crushing, screening, conveyor transfer points, material handling, and stockpiles. Other sources, such as industrial chimneys, motor vehicles, and dust from other industries, are not included in the scope of this research.

c. Prediction of Pollutant Distribution

Total Suspended Particulate Concentration Data (TSP), PM_{10}, and $PM_{2.5}$ in ambient air from field observations and prediction data using a model based on the same coordinates as the study area.

III. RESULTS AND DISCUSSION

STUDY AREA

Astronomically, the study area is at coordinates 5°15.836'S-119°42.255'E, located in Parangloe District. Based on its geographical position, Parangloe District has boundaries: the north borders Maros Regency, the east borders Tinggimoncong District, the south borders Manuju District and the west borders

Pattalassang District. Gowa Regency has a hilly topography of the rocks that form the slopes resulting from the eruption of Mount Lompobattang and Mount Baturape Cindako. The lithology of the area is dominated by volcanic rocks such as volcanic breccia, tuff, and porphyry basalt of the Pleistocene age by Imran et al.,[20]. The height of the land in the study area ranges from 100 - 600 meters above sea level. The map of the study area can be seen in Figure 1.

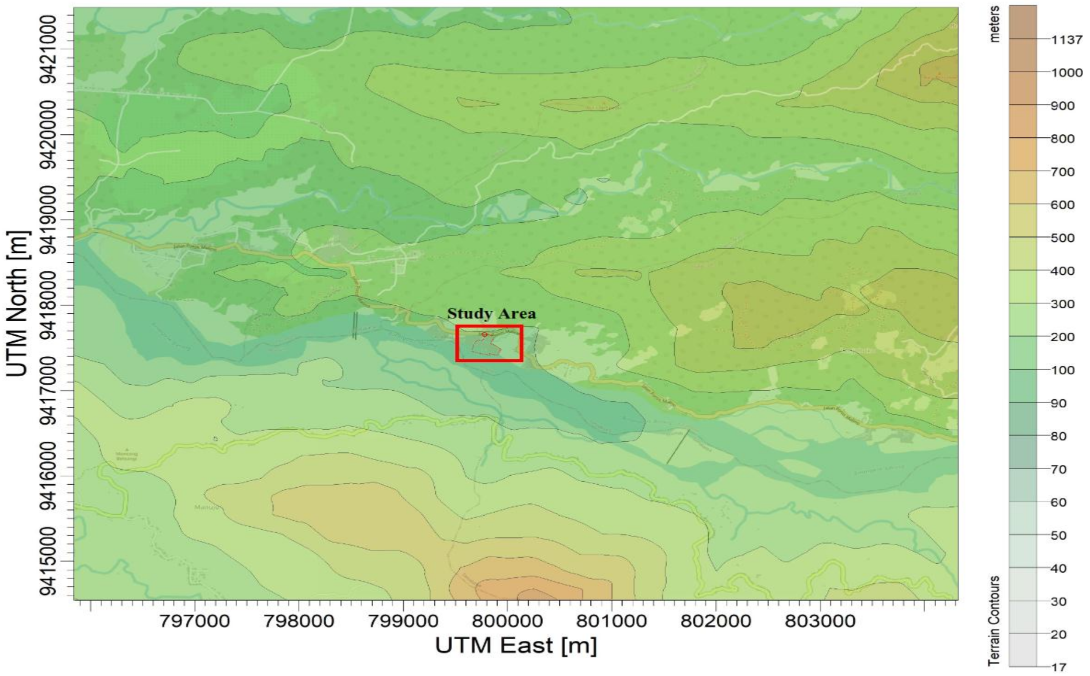

Fig. 1 Study Area & Contour

METEOROLOGICAL DATA

Based on meteorological data obtained at https://power.larc.nasa.gov from 2019-2023 in the study area, the average wind speed at the activity location was 3.96 m/s, with the highest wind speed of 13.6 m/s, and the lowest speed of less than 0.03 m/s. The wind class range with the highest frequency of occurrence occurred at a speed of 3.60 - 5.70 m/s, which was 16,544 times or 37.75%. The frequency of calm wind or wind with a speed below 0.5 m/s was 0.52%. The study's results showed the dominant wind pattern that occurred during the last 5 years (2019-2023) from the Northwest direction. Wind roses of the study area can be seen in Figure 2.

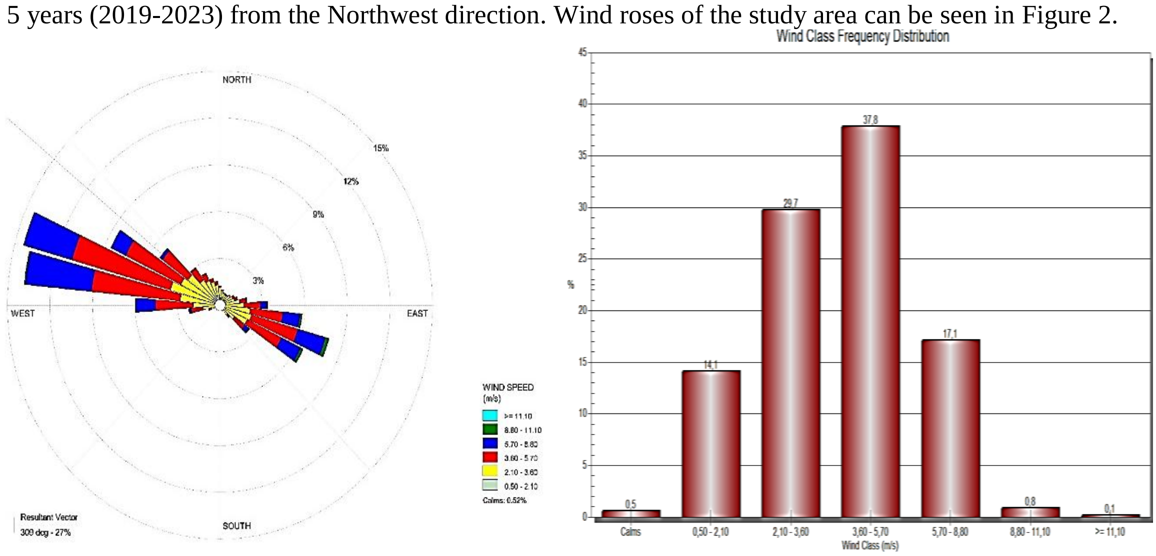

Fig. 2 Wind Roses & Wind Class Distribution

EMISSION SOURCE

Crushed stone processing operations can be in the form of crushing, screening, conveyor transfer points, material handling, and material storage in stockpiles. All of these processes can be a source of emissions, such as significant PM10, if not controlled. From the results of ambient air quality measurements in

2 locations, namely residential and factory, The PM_{10} parameter is still below the quality standard based on Government Regulation No. 22 of 2021 concerning the Implementation of Environmental Protection and Management regarding ambient air quality [21]. Particulate emission factors for various crushed stone processing operations, according to EPA-AP-42, 2004, can be seen in Table 1.

Table (1). Emission Factor.

No	Process	$PM_{2.5}$	PM_{10}	TSP
Emission Factor (kg/ton)				
1	Crushing	0.0006	0.0012	0.0027
2	Screening	0.00028	0.0043	0.0125
3	*Conveyor transfer points*	0.00014	0.00055	0.0015
4	Material Handling	2.67×10^{-5}	1.76×10^{-5}	3.73×10^{-5}
Aerodynamic Factors				
5	Stockpile	0.2	0.5	1

Calculating the emission rate of the stone crushing industry for crushing, screening, conveyor transfer points, and material handling using Equation 2.

$$ER = EF\ x\ M_h\ x\ \left(1 - \frac{CE}{100}\right) \qquad (2)$$

Where ER = Emission Rate (ton/day), EF = Emission Factor (kg/ton), Mh = Production Capacity (ton/day) and Ce = Pollutant control efficiency (%). Calculate the emission rate for a stockpile using the following Equation 3.

$$E = K_{wind\ erosion} x\ AD\ x\ \left(\frac{S}{k_s}\right) x\ \left(\frac{(1-p)}{k_{working\ days}}\right) x\ \left(\frac{I}{k1}\right) x\ A \qquad (3)$$

Where E = Emission Rate (g/s), $k_{winderosion}$ = 0.278 kg/m^2, AD = Aerodynamic Factors, s = average fine sediment load (%), ks = 1.5, p = percentage of rainfall amount below 0.254, $k_{workingdays}$ = 0.644, I = Wind speed percentage >5.36 m/s, k_1 = 15 and A = Stockpile area size (m^2).

The Crushed Stone Industry activity produces 75 tons/hour with a production activity of 7 hours, and the activity site area is watered periodically with an emission reduction efficiency of 70% per day so that the emission rate can be seen in the following calculation:

a. Crushing

TSP ER = 0.0027 kg/ton x 1093.05 ton/day x (1- 75% / 100)
= 0.7378 kg/day = 0.0085 g/s (4)

PM_{10} ER = 0.0012 kg/ton x 1093.05 ton/day x (1- 75% / 100)
= 0.328 kg/day = 0.0038 g/s (5)

$PM_{2.5}$ ER = 0.00006 kg/ton x 1093.05 ton/day x (1- 75% / 100)
= 0.164 kg/day = 0.0019 g/s (6)

b. Screening

TSP ER = 0.0125 kg/ton x 1439.55 ton/day x (1- 50% / 100)
= 8.9972 kg/day = 0.104 g/s (7)

PM_{10} ER = 0.0043 kg/ton x 1439.55 ton/day x (1- 50% / 100)
= 3.095 kg/day = 0.0358 g/s (8)

$PM_{2.5}$ ER = 0.00028 kg/ton x 1439.55 ton/day x (1- 50% / 100)
= 0.201 kg/day = 0.0023 g/s (9)

c. Conveyor Transfer Points

TSP ER = 0.0015 kg/ton x 2554.65 ton/day x (1- 50% / 100)
= 1.916 kg/day = 0.022 g/s (10)

PM_{10} ER = 0.00055 kg/ton x 2554.65 ton/day x (1- 50% / 100)
= 0.702 kg/day = 0.0081g/s (11)

$M_{2.5}$ ER = 0.00014 kg/ton x 2554.65 ton/day x (1- 50% / 100)
= 0,179 kg/day = 0.0021g/s (12)

d. Material Handling

TSP ER = 3.73×10^{-5} kg/ton x 787.5 ton/day x (1- 75% / 100)
= 0.0073 kg/day = $8,499\times10^{-5}$ g/s (13)

PM_{10} ER = 1.764×10^{-5} kg/ton x 787.5 ton/day x (1- 75% / 100)
= 0.0035 kg/day = $4,02\times10^{-5}$ g/s (14)

$PM_{2.5}$ ER = 2.67×10^{-5} kg/ton x 787.5 ton/day x (1- 75% / 100)

= 0.0053 kg/day = 6.087×10^{-5} g/s (15)

e. Stockpile

TSP ER $= 0.278 \times 1 \times \left(\frac{8\%}{1.5}\right) \times \left(\frac{(1-67.7\%)}{0.644}\right) \times \left(\frac{23.3\%}{15}\right) \times 18.823$

= 0.00029 kg/year = 9.38×10^{-9} g/s (16)

PM_{10} ER $= 0.278 \times 0.5 \times \left(\frac{8\%}{1.5}\right) \times \left(\frac{(1-67.7\%)}{0.644}\right) \times \left(\frac{23.3\%}{15}\right) \times 18.823$

= 4,667 kg/year = 3.699×10^{-5} g/s (17)

$PM_{2.5}$ ER $= 0.278 \times 0.2 \times \left(\frac{8\%}{1.5}\right) \times \left(\frac{(1-67.7\%)}{0.644}\right) \times \left(\frac{23.3\%}{15}\right) \times 18.823$

= 1.867 kg/year = 1.469×10^{-5} g/s (18)

Table (2). Emission Rate.

No	Proses	Emission Rate (g/s)		
		$PM_{2.5}$	PM_{10}	TSP
1	Crushing	1.89×10^{-3}	3.79×10^{-3}	8.54×10^{-3}
2	*Screening*	2.33×10^{-3}	3.58×10^{-3}	1.04×10^{-1}
3	Conveyor Tranfer	2.07×10^{-3}	8.13×10^{-3}	2.22×10^{-2}
4	*Material Handling*	6.09×10^{-5}	4.02×10^{-5}	8.50×10^{-5}
5	*Stockpile*	1.48×10^{-5}	3.69×10^{-5}	2.35×10^{-9}
Total (g/s)		**0.00637**	**0.04782**	**0.13493**

POLLUTANT DISPERSION

From the calculation of the emission rate based on Table 2, the concentration of TSP, $PM_{10,}$ and $PM_{2.5}$ pollutants released into the air from all activities of the Stone Crushing Industry is obtained. The concentration of pollutants released into the air for TSP concentration is 0.13493 g/second, PM_{10} 0.04782 g/second and $PM_{2.5}$ 0.00637 g/second. Based on the initial environmental baseline data for wind, the maximum wind speed is 13.6 m/second, simulated as the worst scenario. In this dispersion simulation, the average time is 24 hours according to the national ambient air quality standards based on Government Regulation No. 22 of 2021 concerning the Implementation of Environmental Protection and Management [21]. The results of the pollutant distribution simulation can be seen in the following Figure 3 and Table 3.

Table (3). Stone Crusher Pollutant Simulation Results.

No	Polutant	Concentration µg/m³		Quality standards	Time	Location Coordinates		Affected Locations
		Initial	Model	µg/m³	Hour	x	y	
Highest Concentration Maximum Point								
1	TSP	-	230.332	230	24	-5.26334	119.70385	Area Crusher
2	PM_{10}	-	86.871	75	24	-5.26334	119.70385	Area Crusher
3	$PM_{2.5}$	-	18.610	55	24	-5.26334	119.70385	Area Crusher
Industrial Area Monitoring Point								
1	TSP	42.8	144.888	230	24	-5.26361	119.70333	Area Crusher
2	PM_{10}	12.7	64.531	75	24	-5.26361	119.70333	Area Crusher
3	$PM_{2.5}$	9.1	15.632	55	24	-5.26361	119.70333	Area Crusher
Residential Area Monitoring Point								
1	TSP	31.9	167.299	230	24	-5.26278	119.70500	Residential Area
2	PM_{10}	8.11	56.588	75	24	-5.26278	119.70500	Residential Area
3	$PM_{2.5}$	3.84	14.573	55	24	-5.26278	119.70500	Residential Area

The model simulation for the dispersion of TSP concentration over 24 hours shows that the scope of the dominant TSP emission distribution is in the crusher area with a maximum concentration of 230.33 µg/m³.

According to Dewi et al. [19], Pollutants with maximum concentrations tend to be deposited at a relatively close distance from the source of pollution. This is due to increased turbulence due to increased wind speed, which drives the movement of pollutants vertically. The distribution of emissions outside the industrial location, namely the residential area, has a maximum concentration of 167.29 µg/m^3. On the east side of the planned industrial location, the concentration tends to be towards the Bili-Bili River and agricultural locations without a large contour difference. However, the north side of the planned industrial location, where in that area there is a higher difference in contour pollutants, does not reach that area. In addition to the contour difference, wind direction is another influential factor. The dominant wind blows from the southwest so that pollutants are not concentrated in that area but are spread to other areas.

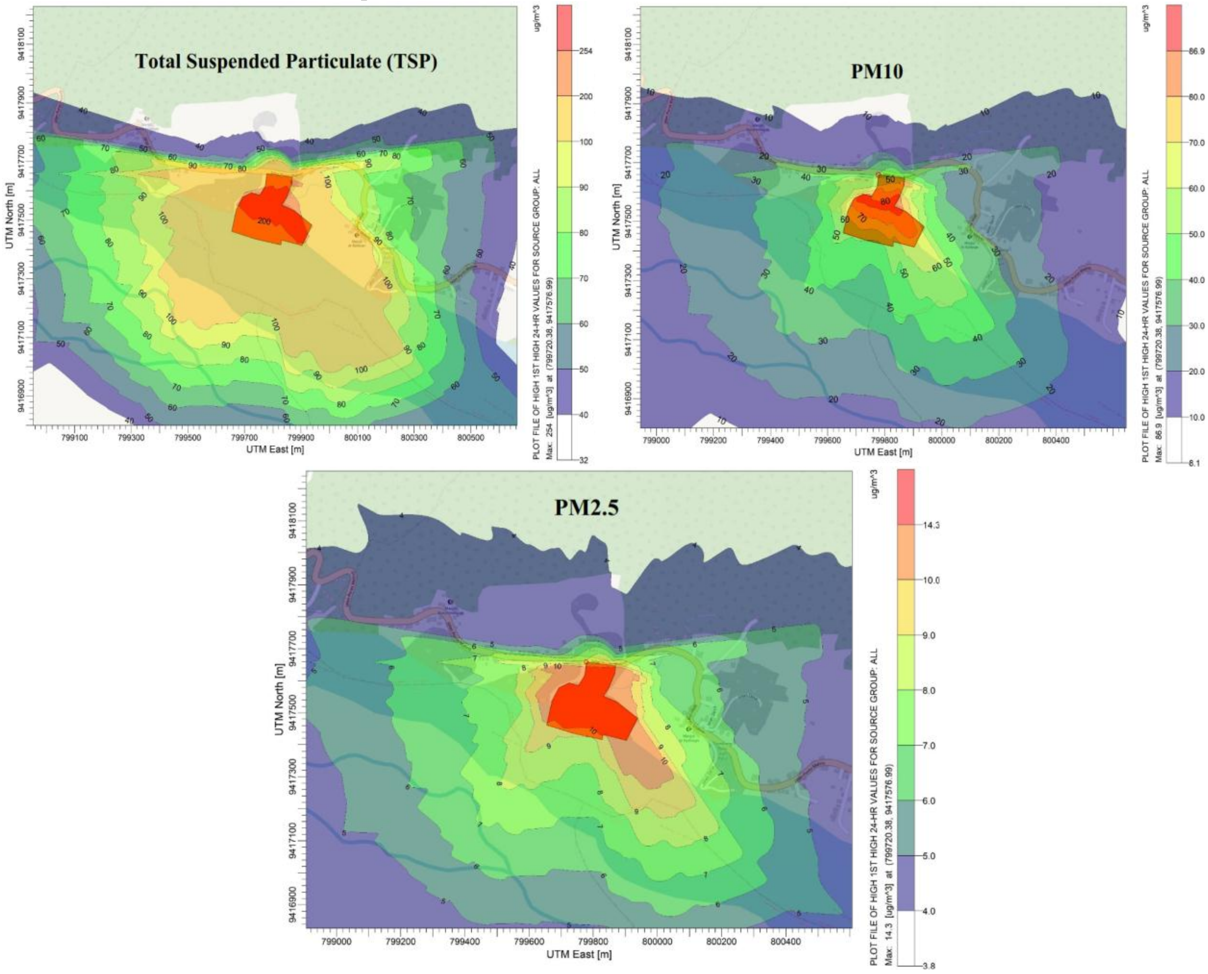

Fig. 3 Emission Dispersion Model

The simulation model for the dispersion of PM_{10} and $PM_{2.5}$ concentrations over 24 hours shows that the scope of PM_{10} and $PM_{2.5}$ emission distribution is dominant in the crusher area with a maximum PM_{10} concentration of 86.87 µg/m^3 and $PM_{2.5}$ of 18.61 µg/m^3. The distribution of emissions outside the industrial location, namely the residential area, has a maximum PM_{10} concentration of 56.58 µg/m^3 and $PM_{2.5}$ of 14.57 µg/m^3. These concentrations are obtained from the results of the distribution model simulation added to the initial historical data for ambient air quality. Based on Figure 3 and Table 3, it is known that the planned crushed stone industry activities have the potential to produce high pollutant concentrations if environmental management is not carried out properly. The comparison results show that ambient air quality in the 2 monitoring locations will tend to experience a decrease in air quality due to the planned activities. To maintain ambient air quality, the person in charge of the activity must implement environmental management in the form of Procurement of Water Sprinklers around the production process, using covers on Conveyors, Planting vegetation as a barrier to the spread of dust or green belts and Watering access roads during the dry season. The types of plants planted in the green belt surrounding the planned industrial location with dense leaves, such as bamboo, mahogany, and rain trees, can reduce the spread of particulates to residential and agricultural areas.

IV. CONCLUSION

Prediction modeling of the distribution of Total Suspended Particulate (TSP), PM_{10}, and $PM_{2.5}$ emissions due to planned stone crushing industry activities originating from the crushing, screening, conveyor transfer points, material handling, and stockpile processes is influenced by meteorological factors, such as wind direction and speed and atmospheric stability, as well as topographic conditions of the study area. The results of dispersion modeling show that concentrations exceeding the threshold quality standards occur in the crusher area for TSP pollutants. This illustrates the scenario of pollutant distribution in the most extreme conditions, which considers environmental management aspects. However, if environmental management is carried out properly, the predicted extreme impacts will not occur. Ambient air quality monitoring in villages around the industrial area in 2024 shows good air quality, but the measured values are still below the established quality standards. Therefore, environmental management efforts must be implemented from the construction stage to the operation of the stone-crushing industry.

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