



ORIGINAL RESEARCH PAPER

Risk assessment of fine particulate matter exposure attributed to the presence of the cement industry

A. Mallongi^{1,*}, S. Stang², R.D.P Astuti¹, A.U. Rauf¹, M.F. Natsir¹

¹ Department of Environmental Health, Faculty of Public Health, Hasanuddin University, Indonesia

² Department of Biostatistics, Faculty of Public Health, Hasanuddin University, Indonesia

ARTICLE INFO

Article History:

Received 19 March 2022

Revised 29 April 2022

Accepted 04 June 2022

Keywords:

Ambient air pollution

Cement plant

Community health

Fine particulate matter (PM_{2.5})

Non-carcinogenic risk

Potential health risks

ABSTRACT

BACKGROUND AND OBJECTIVES: Chronic exposure to fine particulate matter may cause adverse health impacts on humans. The impact of fine particulate matter collected in the industrial area was explored. Therefore, this study aimed 1) to assess the levels and spatial distribution of fine particulate matter and 2) to estimate the health risks due to the exposure of fine particulate matter in the population surrounding the Maros cement industry. A Monte Carlo Simulation model with 10.000 iterations was used for risk analysis through the inhalation pathway.

FINDINGS: The average fine particulate matter concentration was 23.68 micrograms per cubic meter, above the air quality guidelines of the World Health Organization. However, the Monte Carlo Simulation to assess the health risk with the 95th percentile demonstrated that children and adults are at low risk for developing adverse health effects. The result of sensitivity analysis showed that duration of exposure (27.0%) and concentration of fine particulate matter (25.7%) were the most contributing factors to health risks in adults and children, respectively. This new approach determines the critical factors with major effects on reducing the health risk of the vulnerable population

CONCLUSION: Fine particulate matter poses health risks to adults and children, despite the calculated risks are still acceptable. Thus, limiting exposure duration and maintaining fine particulate matter levels in the residential area are needed.

DOI: [10.22034/gjesm.2023.01](https://doi.org/10.22034/gjesm.2023.01).***



NUMBER OF REFERENCES

78



NUMBER OF FIGURES

5



NUMBER OF TABLES

1

*Corresponding Author:

Email: rawnaenvi@gmail.com

Phone: +62 812 4265 3190

ORCID: [0000-0001-6438-1154](https://orcid.org/0000-0001-6438-1154)

Note: Discussion period for this manuscript open until April 1, 2023 on GJESM website at the "Show Article".

INTRODUCTION

In recent decades, air pollution cases have been broadly recognized as a potential hazard to public health and a threat to economic growth. Approximately, there are 4.2 million deaths annually caused by ambient air pollution (Shaddick *et al.*, 2020). Based on World Health Organization (WHO) data, one out of every nine deaths in 2012 was related this pollution (WHO, 2016). The cement industry is one of the largest contributors to air particulate and 5% of global CO₂ emissions (Abu-Allaban and Abu-Qudais, 2011). There are various pollutants from cement plants, such as sulfur dioxide, radioactive dust, hydrogen chloride, hydrogen fluoride, organic compounds, dioxins, furans, nitrogen oxide, hydrocarbon, heavy metals, and carbon monoxide, which are related to health problems and environmental impacts (Astuti *et al.*, 2021c; Emetere and Dania, 2019; Mallongi *et al.*, 2019; Ogunkunle and Fatoba, 2014; Rauf *et al.*, 2021a, 2021b). Primarily, the air pollutants in cement factories come from the clinker (Schuhmacher *et al.*, 2004). Dust is released from quarrying, stockpiles, raw material transportation, clinker cooler, crusher, grinders, materials-handling equipment, kilns operation, and milling proces (Abu-Allaban and Abu-Qudais, 2011; Mishra and Siddiqui, 2014). It may easily be transported by wind to different places from point sources. Greenhous gases (GHG) such as nitrogen, carbon, and sulfur oxides are mainly produced by fossil fuel combustion for power generation, kiln, and drying. SO₂ is emitted from the oxidation process of limestone as the cement raw material (Abu-Allaban and Abu-Qudais, 2011). The cement factory is one of the main sources of particulates based on many studies (Fell and Nordby, 2017; Kholodov *et al.*, 2020; Mallongi *et al.*, 2021; Mehraj *et al.*, 2013; Mishra and Siddiqui, 2014; Nkhama *et al.*, 2017; Rauf *et al.*, 2021b, 2022). Particulate matter (PM) consists of fine and coarse particles (Mekasha *et al.*, 2018) sourced from cement mills, packaging, fuel combustion and preparation, stacks, and road cleaning in the form of carbon and dust (Mishra and Siddiqui, 2014). Particulate matter is also produced when raw material processing (quarrying, crushing, hauling, grinding of limestone and clay) and clinker. Particles suspended in ambient air have various sizes, grouped to TSP (Total Suspended Particle) up to 100 microns in size, PM₁₀ (particles with a size of < 10 microns) and PM_{2.5}

(particles with a size of < 2.5 microns). PM₁₀ and PM_{2.5} can enter and cause irritation and damage to the respiratory system. Particulate matter (PM) can contain potentially toxic heavy metals such as Pb, Cd, Cr, As, Ni, Mn, Zn, Mo, Cu, and Ba posing adverse health problems (Ahmad *et al.*, 2013). In addition, PM_{2.5} can absorb organic compounds such as nitro-PAH and PAHs, ammonium, nitrate, sulfate, organic carbon, and element carbon from vehicles (Motesaddi Zarandi, 2019). The low concentration of PM_{2.5} is still dangerous to human humans due to its adverse health effects. This emission is toxic because it contains mutagens, immunotoxins, respiratory toxins, neurological toxins, and carcinogenic agents. PM_{2.5} can freely enter the respiratory tract and get deposited in the lungs' alveoli before entering the bloodstream. The dust may enter the human body through the gastrointestinal tract through contaminated foods (Mishra and Siddiqui, 2014). PM_{2.5} is more dangerous to human health than PM₁₀ (Ahmad *et al.*, 2013). Short-term exposure to PM_{2.5} may increase the risk of respiratory and cardiovascular disease. PM_{2.5} is positively related to coronary heart disease mortality (Ahmad *et al.*, 2013). Around 3% and 5% deaths cases are associated with cardiopulmonary disease and lung cancer, respectively which are from PM_{2.5} exposure (Mekasha *et al.*, 2018). Several studies showed that the exposure may significantly reduce lung functions and cancer in cement workers and the community surrounding the plant (Fell and Nordby, 2017; Kholodov *et al.*, 2020; Nkhama *et al.*, 2017). The recent study by Nkhama *et al.* (2017) showed that people exposed to PM_{2.5} had lower lung capacity. Other study by Novirsa and Achmadhi, (2012) showed that several points exceed the US-EPA quality standard of 0.03 mg/m³ based on the findings of ambient air study near the cement industrial area of Padang City. Sampling point at ring 2, 4 and 5 with a distance of 500 - 1000 m, 1,500–2,000 m, and 2,000 – 2,500 m from the center of the factory has PM_{2.5} concentration of 0.041 mg/m³, 0.038 mg/m³ and 0.037 mg/m³ (Novirsa and Achmadi, 2012). In the study by Kholodov *et al.* (2020) adverse health impacts due to cement dust and its related substances exposure are skin irritation and allergic dermatitis, respiratory track (asthma, silicosis, and chronic bronchitis), nasopharyngeal mucosa, and the oral cavity, and digestive tract disorders. Various materials contained

in in $PM_{2.5}$ can cause various respiratory disorders such as infections acute respiratory infection (ARI), lung cancer, cardiovascular disease, premature death, chronic obstructive pulmonary disease (COPD). [Correia et al. \(2013\)](#) showed that a decrease in $PM_{2.5}$ concentrations was associated with an increase in life expectancy of 0.35 years. Another study by [Sánchez-Soberón, \(2017\)](#) stated that heavy metals concentration such as Cr(VI) may cause cancer among cement workers which are exposed from indoor activities (working /leisure and sleeping). WHO recommends a safe level of $PM_{2.5}$ exposure of $25 \mu\text{g}/\text{m}^3$ in a 24-h period (not exceeding 3 days a year) and $10 \mu\text{g}/\text{m}^3$ annually ([Nkhama et al., 2017](#)). Meanwhile, the United States Environmental Protection Agency (USEPA) recommends $35 \mu\text{g}/\text{m}^3$ in 24-h exposure to $PM_{2.5}$ ([Nkhama et al., 2017](#)). Maros Regency has a potential limestone mining area surrounding the karst area. The cement industry is one of the largest companies in Maros regency, producing 1.8 million/tons of cement annually. The plant is near a residential area ($< 50 \text{ m}$), which may expose the people surrounding it to health hazards ([Rauf et al., 2021a](#)). According to [Rauf et al. \(2021b\)](#), TSP emitted by the Maros Cement Plant exceeded the minimum safe level by ambient air quality. As a result, the people living near the plant are at risk of non-carcinogenic cases ($HQ>1$). This may be caused by heavy metals bound in particulate. Based on annual health data in Maros Regency, cough, dermatitis, influenza, and acute respiratory infection are the major morbidity cases in Maros regency ([Dinkes Maros, 2015](#)). Morbidity cases are suspected due to exposure to $PM_{2.5}$ and dust in the air produced by the cement industry in Maros Regency. Therefore, a study related to $PM_{2.5}$ exposure and health risk assessment is needed in this area to predict health risks due to air pollution from the cement factory. A recent study also showed that exposure to heavy metals, which are bounded to dust through inhalation, oral and dermal, may cause non-carcinogenic ($HQ>1$) and carcinogenic cases ($TCR > 10^{-6}$) ([Rauf et al., 2021b](#)). Several studies showed that the presence of the cement industry surrounding the karst area is attributed to an increase in ecological and human health risks ([Astuti et al., 2022](#); [Mallongi et al., 2022](#); [Rauf et al., 2021b](#)) due to the accumulation of heavy metals in the environment. Study associated with $PM_{2.5}$ pollution and its contribution to human health

in South Sulawesi Province is limited. Previous study in Maros regency showed a health risk due to exposure to TSP (Total Suspended Particle) from the cement industry in Maros ([Rauf, 2021a](#)). Furthermore, the Monte Carlo Simulation (MCS) model is still limited to identify health risks due to hazardous substances from ambient air. The model has just been carried out to identify uncertainty in the point estimate of exposure from the conservative human health risk assessment method by USEPA and sensitivity of exposure parameters analysis. Most of the MCS method was used in several studies on the chemical exposure from the soil, water, and food ([Astuti, et al., 2022](#); [Jimenez-Oyola et al., 2021](#); [Rajasekhar et al., 2018](#)). Few studies used MCS to rank exposure pathways, locations, and contaminants from air pollution, particularly $PM_{2.5}$ exposure. Previously, the MCS model estimated health risks from air pollutants such as heavy metals ([Chen et al., 2022](#); [Chen et al., 2022](#); [Dehghani et al., 2021](#); [Rauf et al., 2021b](#); [Wang et al., 2019](#)); sulphate, nitrate, ammonium, organic carbon (OC)-bounded to $PM_{2.5}$ ([Wu et al., 2021](#)); polycyclic aromatic hydrocarbon ([Mo et al., 2019](#); [Motesaddi Zarandi et al., 2019](#)); O_3 ([de Souza Silva et al., 2016](#)). High uncertainty may appear in the risk assessment process when using deterministic parameters. The probabilistic assessment method such as Monte Carlo Simulation can diminish risk assessment uncertainties by analyzing the concentration of pollutants and other toxicity factors ([USEPA, 1997](#)). [Jimenez-Oyola et al., \(2021\)](#) mentioned that human health risk assessment problems lack information about exposure in the population and often use default values from the literature that cannot describe the real condition, leading to under or overestimation of health risks. Probability risk assessment using the MCS method can overcome these constraints. This method is useful for risk assessors making future management actions ([USEPA, 1997](#)). Therefore, the MCS method is used to assess health risks from $PM_{2.5}$ exposure to people surrounding the cement industry of Maros Regency. This is the first study that used this method to assess $PM_{2.5}$ exposure in an industrial area. The study purposes are 1) identification of $PM_{2.5}$ concentration in ambient air environment surrounding area near the largest cement industry in Maros Regency, and 2) estimation of health risk due to $PM_{2.5}$ exposure using Monte Carlo Simulation

method. This study may be useful to make environmental risk management in the future. It was carried out in Maros Regency, South Sulawesi Province, Indonesia, in 2022.

MATERIALS AND METHODS

Sampling process

The $PM_{2.5}$ level was measured for 10 days in March 2022. The total concentrations in the outdoor environments were measured in four major sub-districts of Salenrang, Baruga, Bungaeja, and Tukamasea. The meteorological data (i.e., temperature, relative humidity, and wind speed) and the daily concentration during the sampling period were applied. In this study, 5 selected residences were selected as they were the nearest location to industrial activities. In 2020, total resident in the sampling sites was 30,488 (BPSSMR, 2020). Sites 1, 2, 5, 11, 16 and 18 are within the Lau area, around 2.1 km from the cement factory and 700 m – 2.5

km from traditional rock mining. This area is in the west and southwest regions, where the air quality is influenced by heavy-duty trucks' transportation of raw materials and industrial products distribution as well as vehicles fume from the main road. Sites 6, 7, 12, and 17 are the distinct village areas occupied by residents before the industrial activities began. This area is located in the southwest, Mattoangin region, about 2 - 3.5 km from the main industrial activities in the north. There is always yellow and white dust on residents' terraces, even when the wind does not blow predominantly in this direction, specifically in the morning. Sites 3, 8, 9, 13, 18, and 19 are located in the Baruga area, where the cement factory is in the south, approximately 500 m - 3.4 km from a cement plant and 3.77 km from a marble factory in the southeast. This area was one of the most densely populated residences working as farmers. Sites 4, 10, 14, 15, 20, and 21 are located in Tukamasea and Leang-Leang areas which residents in the east

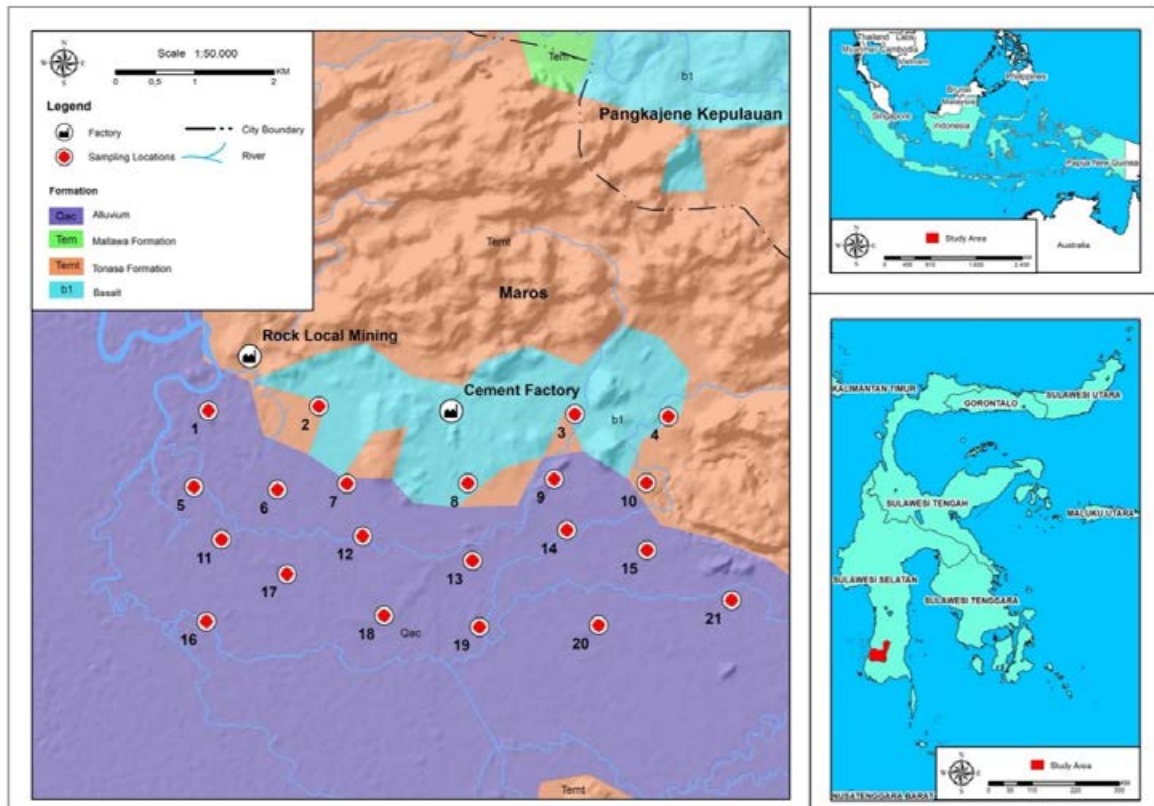


Fig. 1: Geographic location of the study area along with the sampling locations of $PM_{2.5}$ in the in four major sub-districts in Indonesia

and southeast inhabit. In this area, traffic volume was relatively low. The residents mostly worked as blue-collar workers and farmers. No sampling was carried out in the north, northeast, or northwest of the factories, as these areas were uninhabited and surrounded by karst hill (Tonasa limestone Formation). Measurement of PM_{2.5} concentration was carried out at 21 stations, namely 2 points at the front gate, the next 6 points each 100 m from the main gate, then 3 points at the entrance to the residential area, and 10 points inside the settlement (Fig. 1). PM_{2.5} sampling was carried out using direct reading HAZ-Dust EPAM 5000. That equipment uses a laser analyzer to measure particulate. The measurement result or time-weighted average (TWA) value can be directly read after the measurement process is conducted. The meteorological data was collected from Indonesia Agency for Meteorology, Climatology, and Geophysics online database. Fig. 2 showed the wind directions or model dispersion of PM_{2.5} in the cement industry of Maros during the sampling process. That model was carried out using wind rose plot software (WRPLOT 4.0.1 for PM2.5 concentration).

Data analysis

Human health risk analysis by USEPA was used to estimate health risk of PM_{2.5} exposure in people surrounding cement factory. Inhalation is the main route for PM_{2.5}, thus health risk analysis was focus to this route. The equation for inhalation route non-carcinogenic risk analysis is shown in Eqs. 1 and 2 (Edlund *et al.*, 2021; Rauf *et al.*, 2021a, 2021b; USEPA, 2001, 1989).

$$ADD_{inh} = \frac{C \times Inh_{rate} \times EF \times ED \times ET}{BW \times AT} \quad (1)$$

$$HQ = \frac{ADD_{inh}}{RfC} \quad (2)$$

Where, ADD is the average daily doses of PM_{2.5} (µg/kg/day), C is ambient PM_{2.5} concentration (µg/m³); Inh_{rate} is inhalation rate of people, USEPA default value 14.9 m³/day (adult) and 9 m³/day (children) (USEPA, 1989), EF is PM_{2.5} exposure frequency 350 days/year for residential exposure (USEPA, 1991), ED is exposure duration, USEPA default value for adult 24 years and 6 years (Rauf *et al.*, 2021b), BW is body

weight for adult 63.01 kg (adult) and 34.55 (children) (Rauf *et al.*, 2021b), AT is averaging time (ED x 365 days/years for non-carcinogenic risk estimation), RfC is reference concentration for PM_{2.5} inhalation is 10 µg/kg/day (Novirsa and Achmadi, 2012). If HQ value exceeds 1, it indicated that the chronic PM_{2.5} exposure is not safe for the population. It is potentially cause non-carcinogenic health impacts in the future. Otherwise, when the HQ value is lower than 1, there is no non-carcinogenic risk to population or the risk is negligible. Monte Carlo Simulation (MCS) model was used in this study to estimate uncertainty or distribution of probability risk and contribution of variable to non-carcinogenic risk in the Maros cement industry population. The MCS model has been used in many risk estimation study (Astuti *et al.*, 2022; Gao *et al.*, 2019; Mallongi *et al.*, 2022; Pelletier *et al.*, 2017; Rauf *et al.*, 2021b; Saha *et al.*, 2016; Tajdar-oranj *et al.*, 2018) and is recommended by USEPA, (1997) for health risk estimation process. Based on the previous study, default value such as inhalation rate and other variables to estimate health risk is potentially rise the ambiguity and uncertainty of risk (Rauf *et al.*, 2021b). Thus, using MCS to estimate the distribution of probability risk is need to be done. The MCS was performed with 10000 repetitions to examine uncertainties related to non-carcinogenic risk. In this study, the variables that were analyzed for sensitivity test using MCS are ED, EF, C, and BW. This model investigating the distribution of random variables by simulating random numbers (Millard, 1998). Usually the random number expressed as Y, variables in health risk assessment. In this case, the random vector X may represent observations from several kinds of distributions that characterize exposure and dose response. The distribution of the main variables was used to find the correlation between PM_{2.5} exposure and the probability of health risk in human. The function of the selected variables in the Monte Carlo simulation is expressed in Eq. 3.

$$Y = h(X) = h(X_1, X_2, \dots, X_n) \quad (3)$$

The result was presented in graphic of probability risk (uncertainty) and sensitivity of variables. The MCS was carried out using the Oracle Crystall Ball software (11.1.12 ver) in Microsoft excel 2019 add-in. In this study, the mean concentration of PM_{2.5} and risk calculation were performed using Microsoft

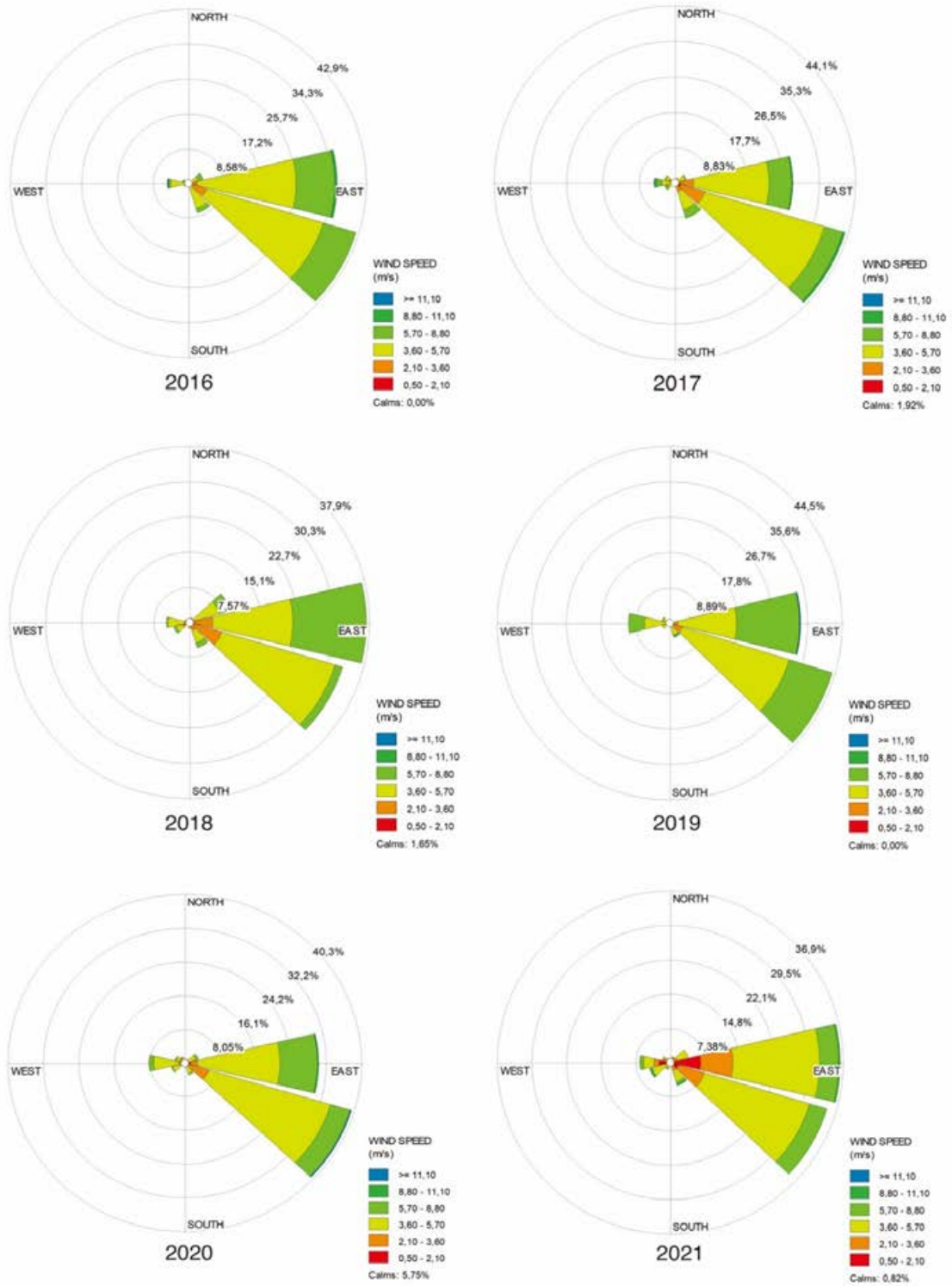


Fig. 2: Annual wind condition around the cement plant complex in 2016 – 2021

Excel version 2019. Spatial distribution of $PM_{2.5}$ concentrations was carried out by ArcGIS.

RESULTS AND DISCUSSION

Meteorological data

Meteorology is an important factor in the distribution and accumulation of particulates. It is the main component in determining the dilution effect of the atmosphere because the released substances are carried by the wind (Goudarzi *et al.*, 2018; Kim *et al.*, 2015). Temperature, wind speed, direction, and humidity were compiled from the Indonesian Meteorological, Climatological and Geophysical Agency (BMKG) online database. During the sampling days, temperatures ranged between 25.6 and 31.08°C, with an average value of 29.02°C, relative humidity ranged between 71.11% and 87%, average 81.6%, and wind speed ranged between 1.8 and 4.0 m/s, average 2.8 m/s. Fig. 2 indicates that the wind was heading Southeast and East. These

locations are the main residential area in Tukamasea and Bungaeja Villages, with a resultant vector of this visualization at 109°. For six years, wind patterns were fairly consistent despite daily changes in direction (2016– 2021). The windrose plot was processed with Microsoft Excel software and WRPLOT 4.0.1 from Lakes Environmental Software. It was confirmed that the particulate concentration near cement plant areas in Southeast and East was higher than in others. Therefore, the residents will continuously be exposed to more particulates due to the wind direction.

$PM_{2.5}$ mass concentration

Direct measurements were carried out from morning to evening. The results showed that the concentration of PM varied at each point. The spatial distributions are presented in Fig. 3, while the differences in $PM_{2.5}$ concentration in Maros Regency and other countries are depicted in Table 1. The average concentration of 23.68 $\mu g/m^3$ was

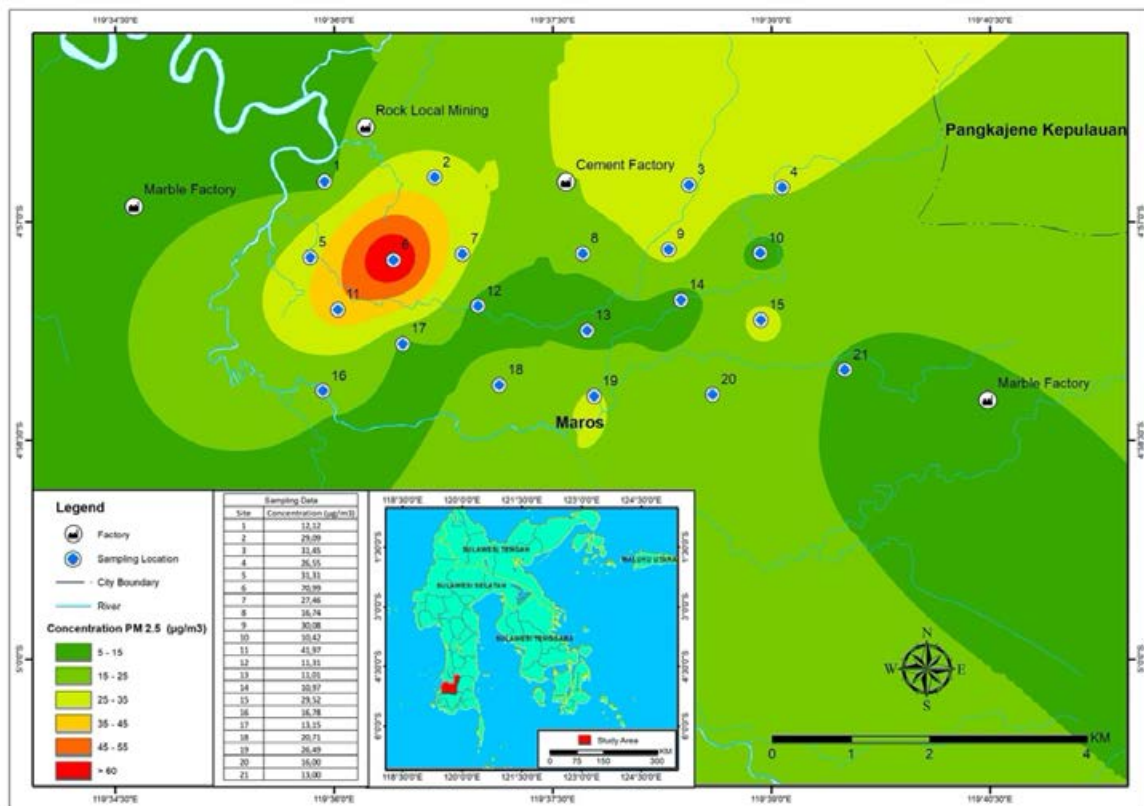


Fig. 3: The spatial distribution of $PM_{2.5}$ levels around the residential areas

found for this study, which was higher than WHO Air Quality Guideline (AQG). WHO-AQGs of PM_{2.5} for short-term (24-h average) and long-term (annual average) exposures are 15 µg/m³ and 5 µg/m³ (WHO, 2021). Alternatively, this concentration is still below the Indonesian standard for air quality (Indonesian government, 2021). The highest concentration of PM_{2.5} found in station 6 (70.99 µg/m³) is located in the south-eastern part of the cement plant, precisely in Tukamasea Village. This area is flat, quite lower, placed on alluvial plain and inhabited by most residents who work as farmers. The distribution of particulates originating from industrial activities from the direction of the Karst mountains in the north may increase PM_{2.5} concentrations. The result was under a previous study, where the highest total suspended particulate (TSP) bound to metals was recorded at this location (Rauf et al., 2021a; Rauf et al., 2021b). According to the literature, PM_{2.5} pollution might be affected by meteorological conditions, anthropogenic activities, and soil resuspension (Nkhama et al., 2017; Peng et al., 2016; Shahri et al., 2019).

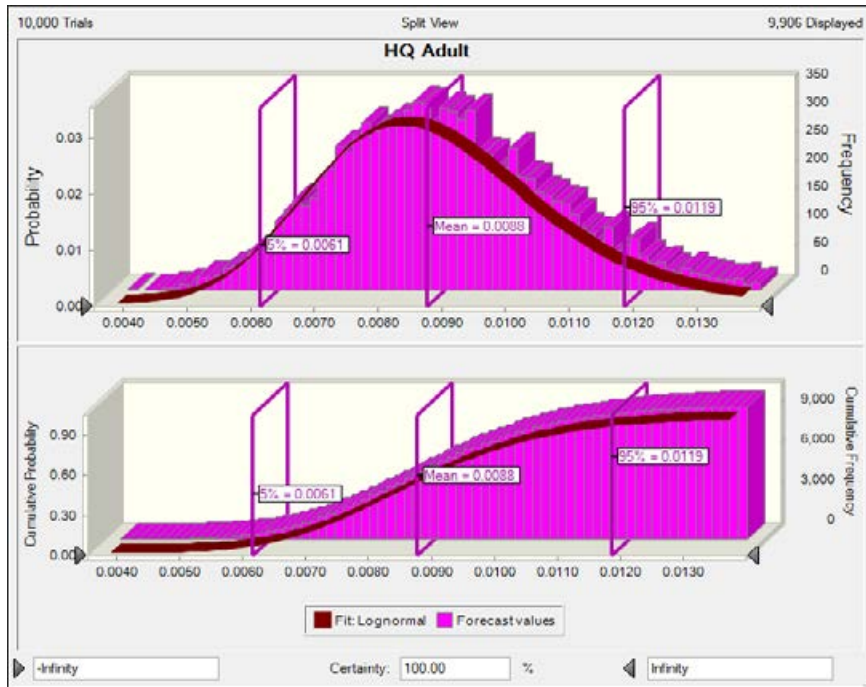
Maros karst area is surrounded by karst quarries, cement, and marble factories operating for the last two decades. The majority of industry in this region involves dry processes and high temperatures in their production activity. In cement factories, the particulates generated from the stacks may carry toxic particulates such as PAHs, heavy metals, and organic matters that are harmful to the surrounding population (Astuti et al., 2021b; Mallongi et al., 2022;

Naeini et al., 2019; Rauf et al., 2021b). In addition, the use of coal in industry releases heavy metal ions involving high temperatures, which are likely to increase the risk to human health (Kim et al., 2015). This indicates the higher the mass of particulates produced from industrial chimneys, the possibility of a high accumulation of toxic elements in other media such as soil and water bodies will increase (Han et al., 2015; Kurt, 2018; Rauf et al., 2022). Based on Table 1, the concentration of PM_{2.5} around cement plants mostly exceeds WHO's standard (WHO, 2021).

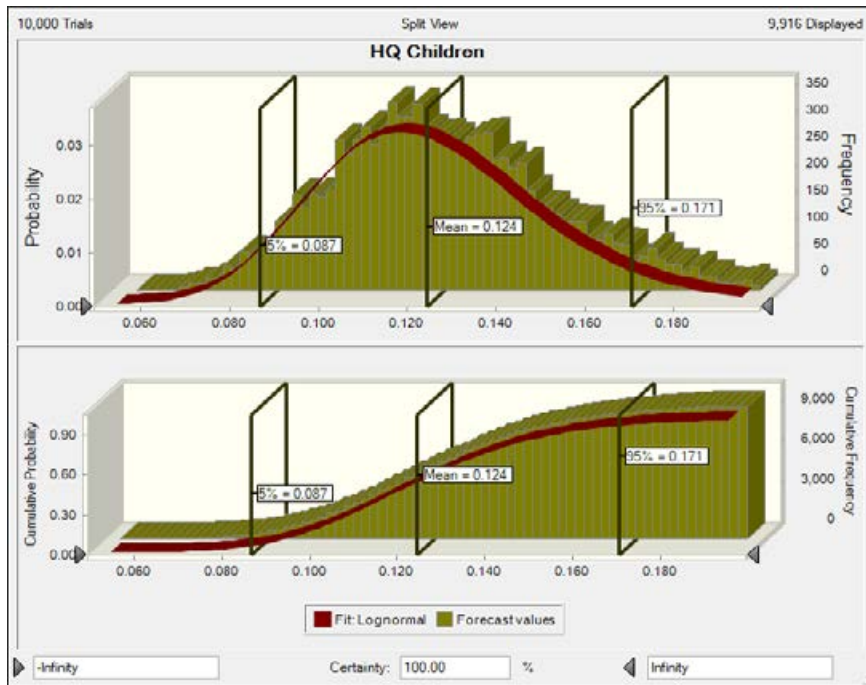
Natural enrichments around karst areas are likely to occur where the wind will consistently blow and move the dust to residential areas (Ayanlade and Oyegbade, 2016; Han et al., 2021; Rauf et al., 2020b). Anthropogenic origin (mostly attributed to secondary particle formation) and natural sources (dust) contribute 17% and 16% to ambient PM in European and Central Asia urban areas (Almeida et al., 2020). In Indonesia, limestone and marble are the main minerals of cement production. The conversion into cement by heat releases carbon dioxide and metals as a waste product (Rauf et al., 2020a). In a study conducted in the Districts of Chelyabinsk, Russia, PM_{2.5} concentrations were higher around industrial areas at 303 ng/m³ than in non-industrialized areas at 192 ng/m³. This is because the area has more intense activities and uses coal-fired stations (Krupnova et al., 2021). In non-industrial areas, the accumulation of PM_{2.5} is mostly caused by vehicle fumes and burning waste. According to the United

Table 1: The comparison between average concentration of PM_{2.5} from Maros cement, other studies and air quality standards.

Region/ country	Concentration (µg/m ³)	References
Maros, Indonesia	23.68	Present study
Chilanga, Zambia	10.21	(Nkhama et al., 2017)
Thohoyandou, South Africa	11.00	(Edlund et al., 2021)
Barcelona, Spain	15.20	(Sánchez-Soberón et al., 2015)
Riyadh, Saudi Arabia	21.00	(Al-Zboon et al., 2021).
Ewekoro, Nigeria	112.14	(Saheed Bada et al., 2013)
Khash, Iran	14.34	(Shahri et al., 2019)
Penglai, China	58.00	(Xue et al., 2022)
Chuncheon and Yeongwol, South Korea	23.00 and 19.70	(Han et al., 2015)
Antofagasta, Chile	42.00	(Jorquera and Barraza, 2013)
Kongo Central Province, Democratic Republic of the Congo (DRC)	48.80	(Mbelambela et al., 2020)
WHO-AQG	5 (annual) 15 (24-h)	(WHO, 2021)
Indonesian Standard for air pollution	15 (annual) 55 (24-h)	(Indonesian government, 2021)



(a)



(b)

Fig. 4: The HQ of adult (a) and children (b) from $PM_{2.5}$ exposure

States Geological Survey, Indonesia produced 75,200 and 74,000 cement in 2017 and 2018. This number outperformed the production in Brazil (53,000), Iran (58,000), Japan (55,300), Republic of Korea (55,000), Russia (57,300) and Turkey (72,500) (USGS, 2020). The possibility of increasing cement factory activity and production will still occur in the next few years. This is worrying because the increase and demand for production can cause air pollution when it is not balanced with environmental protection policies and efforts to protect human health.

Health risk

In this study, $PM_{2.5}$ and health risk implications were assessed. The risk quotient was calculated to estimate the toxicological risk where the average dose of $PM_{2.5}$ was released to the reference. Fig. 4 depicts a health risk analysis with 95 percentile. The result indicates that children face greater risk (HQ = 0.171) than adults (HQ = 0.011) in the year. This result implies that the health risk posed by exposure to ambient air $PM_{2.5}$ around the industrial area was below the USEPA standards (HQ <1). However, long-term exposure can accumulate toxic substances bound to $PM_{2.5}$. Children’s potential health risk is higher than adults due to their daily activities, inhalation rate, body

weight ratio, and immature physiological system (Al-Zboon et al., 2021; de Oliveira et al., 2012; Mallongi et al., 2020). There are likely other groups with higher vulnerability and susceptibility, such as the elderly or people with diseases, at higher risk for the relevant adverse health effects (Alsafran et al., 2021; Astuti et al., 2021a; Celo et al., 2021). This is similar to a previous study conducted in Thohoyandou, South Africa, where children and infants experienced a greater carcinogenic and non-carcinogenic risks from $PM_{2.5}$ exposure than adults (Edlund et al., 2021). Among 185 countries, the population-weighted median decrement in life expectancy from $PM_{2.5}$ (ΔLE) was 1.22 years (IQR of 0.67– 1.51 years) (Apte et al., 2018). The high HQ of adults and children is attributed to the dusty weather in Indonesia for most of the year. Furthermore, the monitoring was conducted in March, which is considered the month with the windiest days (Astuti et al., 2021a; Rauf et al., 2022). Prevailing wind greatly contributes to particulate distribution in the air. Therefore, settlements that experience innate winds will accumulate more dust, particularly when they are located near industrial activities or roads (Han et al., 2021; Kim et al., 2015). This is in accordance with previous studies where the nearest area to cement will experience a higher

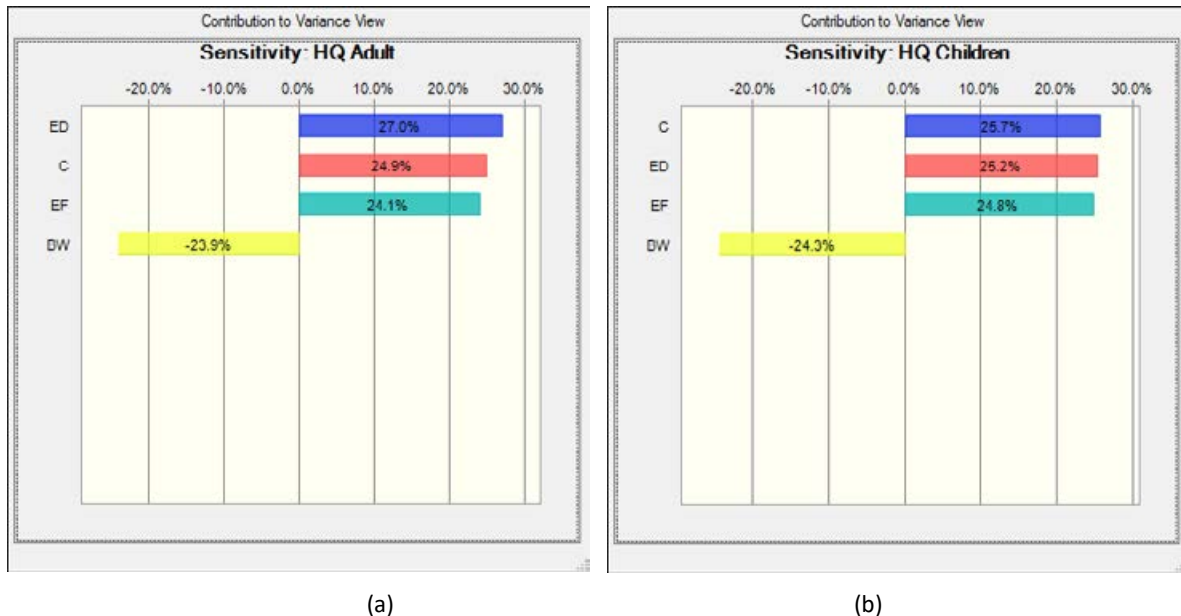


Fig. 5: The sensitivity analysis of the main variables in health risk assessment using Monte Carlo Simulation (MCS)

accumulation of dust/ash and metals in ambient air, deposited to surface soil and bodies of water. Residents who inhabit this area are threatened with respiratory diseases and skin disorders (Astuti *et al.*, 2022; García-Pérez *et al.*, 2015; Kridin *et al.*, 2016).

In Fig. 5, the sensitivity chart revealed the exposure duration (ED) was the most significant factor for increasing the health problem in adult is exposure duration (ED) (27.0%), followed by concentration (C) of $PM_{2.5}$ (24.9%). Whereas in children, the highest contribution was the concentration (C) of $PM_{2.5}$ (25.7%), followed by ED (25.2%). It means that the exposure to pollutants and their concentration had the highest impact on developing adverse health effects in humans. Therefore, the most suitable scenarios focus on periodic industrial emissions monitoring near residential areas and limiting exposure duration. This indicates the more often discrete exposure events occur, the higher the possibility that residents will be at risk. Hence, children and adults should reduce their activities and use protection to decrease their contact with the air pollution that possibly contains harmful materials. The contribution of body weight (BW) was negative, indicating a low effect and can be ignored.

CONCLUSION

This study measured the outdoor level of $PM_{2.5}$ samplings continuously over 24 hours in 21 different sites. The focus was on the residential area around the cement industry in Maros Regency. The dominant wind direction, which blows from the northeast to the southeast, causes the Tukamasea region to experience a higher accumulation of particulates from factory production. As a result, the average concentration of $PM_{2.5}$ was higher than WHO-AQG for the short-term (24-h average) and the long-term standard (annual average). A health risk assessment was conducted through Monte Carlo Simulation (MCS) to determine the uncertainty. The proposed method identifies the potential health risks from $PM_{2.5}$ exposure through the inhalation pathway. The 95th percentile and 10.000 trials simulation showed that adults' and children's hazard quotient (HQ) were still tolerable and within safe limits. In sensitivity analysis, exposure duration and pollutant concentration are the most influential variables in the health risks of residents in the study area. This indicates that long-

term exposure duration will still threaten human health, specifically for those close to factories. For the regulations to effectively protect the health of all age groups, the accepted levels and contact need to be reduced. This study recommends that $PM_{2.5}$ concentration around the residential areas be maintained. Personal protective equipment such as masks is suggested. For future analysis, integrating the MCS model and health risks assessment can be considered appropriate tools for monitoring air pollution and a scientific basis to predict health risk estimation. The MCS model can assess health risks due to $PM_{2.5}$ emissions in industrial areas and overcome the uncertainty related to health risk assessment. It may not apply to everyone, but the right scenarios and policies can go a long way toward ensuring that everyone's health is protected. Future study should focus on measuring the concentration of other pollutants bound to $PM_{2.5}$ and its health risks.

AUTHOR CONTRIBUTIONS

A. Mallongi performed the experimental design, prepared the manuscript text and conceptualization. S. Stang did the statistical analysis and validation. R.D.P. Astuti helped the literature review, sample collection, manuscript preparation and visualization. A.U. Rauf performed the project administration, sample collection, and data analysis. M.F. Natsir performed the sample collection and reviewing.

ACKNOWLEDGMENTS

Thanks to all Lecturers of Environmental Health Department, Faculty of Public Health, Hasanuddin University and to thank BTKL for the $PM_{2.5}$ sampling and analysis accordingly. All Authors are very grateful to Higher Education Directorate, Republic of Indonesia for the research grant [No. 8044/UN4.1.2.3/PL.02.00/2022] for this research through LPPM of Hasanuddin University.

CONFLICT OF INTEREST

The author declares that there is no conflict of interests regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, and redundancy have been completely observed by the authors.

OPEN ACCESS

This article is licensed under a Creative Commons Attribution 4.0 International License, which permits use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons license, and indicate if changes were made. The images or other third-party material in this article are included in the article's Creative Commons license, unless indicated otherwise in a credit line to the material. If material is not included in the article's Creative Commons license and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder. To view a copy of this license, visit:

<http://creativecommons.org/licenses/by/4.0/>

PUBLISHER'S NOTE

GJESM Publisher remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

ABBREVIATIONS

$^{\circ}\text{C}$	Celcius degree	<i>Cd</i>	Cadmium
$\mu\text{g}/\text{m}^3$	Microgram per meter cubic	<i>Cu</i>	Copper
$\mu\text{g}/\text{kg}/\text{day}$	Microgram per kilogram per day	<i>COPD</i>	Chronic obstructive pulmonary disease
%	percent	<i>Cr</i>	Chromium
<i>24-h</i>	24 hours	<i>Cr(VI)</i>	Hexavalent Chromium
ΔLE	Life Expectancy	CO_2	Carbon dioxide
<i>ADD</i>	Average daily dose	<i>DRC</i>	Democratic Republic of the Congo
<i>AQG</i>	Air quality guideline	<i>ED</i>	Exposure duration
<i>ARI</i>	Acute respiratory infection	<i>EF</i>	Exposure frequency
<i>As</i>	Arsenic	<i>EPAM</i>	Environmental particulate air monitoring
<i>AT</i>	Averaging time	<i>ET</i>	Exposure time
<i>Ba</i>	Barium	<i>GHG</i>	Greenhouse gas
<i>BMKG</i>	Indonesian Meteorological, Climatological, and Geophysical Agency or Badan Meteorologi, Klimatologi dan Geofisika	Inh_{rate}	Inhalation rate
<i>BW</i>	Body weight	<i>IQR</i>	Interquartile range
<i>C</i>	Concentration of $\text{PM}_{2.5}$	<i>HQ</i>	Hazard quotient
		<i>Mn</i>	Manganese
		<i>m</i>	Meter
		m^3/day	Meter cubic per day
		<i>m/s</i>	Meter per second
		<i>PAH</i>	Polyaromatic hydrocarbon
		<i>Pb</i>	Lead
		<i>PM</i>	Particulate matter
		PM_{10}	Particles with a size of < 10 microns
		$\text{PM}_{2.5}$	Particles with a size < 2.5 microns
		<i>RfC</i>	Reference concentration
		SO_2	Sulphur dioxide
		<i>TCR</i>	Total carcinogenic risk
		<i>TSP</i>	Total Suspended Particle
		<i>TWA</i>	Time weighted average
		<i>USEPA</i>	United states Environmental Protection Agency
		<i>WHO</i>	World Health Organization
		<i>WRPLOT</i>	Wind rose plot
		<i>Zn</i>	Zinc

REFERENCES

- Abu-Allaban, M.; Abu-Qudais, H., (2011). Impact assessment of ambient air quality by cement industry: A case study in Jordan. *Aerosol Air Qual. Res.*, 11: 802–810 **(8 pages)**.
- Ahmad, W.; Nisa, S.; Nafees, M.; Hussain, R., (2013). Assessment of particulate matter (pm = 10 and pm = 2.5) and associated health problems in different areas of cement industry, Hattar, Haripur. *J. Sci. Technol.*, 37: 7–15 **(9 pages)**.
- Almeida, S.M.; Manousakas, M.; Diapouli, E.; Kertesz, Z.; Samek, L.; Hristova, E.; Šega, K.; Alvarez, R.P.; Belis, C.A.; Eleftheriadis, K., (2020). Ambient particulate matter source apportionment using receptor modelling in European and Central Asia urban areas. *Environ. Pollut.*, 266: 115199.
- Alsafran, M.; Usman, K.; Al Jabri, H.; Rizwan, M., (2021). Ecological and health risks assessment of potentially toxic metals and metalloids contaminants: A case study of agricultural soils in Qatar. *Toxics*, 9(2): 1–15 **(15 pages)**.
- Al-Zboon, K.; Matalqah, W.; Ammary, B., (2021). Effect of cement industry on ambient air quality and potential health risk- A case study from Riyadh, Saudi Arabia. *Jordan. J. Eng. Chem. Ind.*, 4(1): 14-23 **(10 pages)**.
- Apte, J.S.; Brauer, M.; Cohen, A.J.; Ezzati, M.; Pope, C.A., (2018). Ambient PM_{2.5} Reduces Global and Regional Life Expectancy. *Environ. Sci. Technol. Lett.*, 5(9): 546–551 **(6 pages)**.
- Astuti, R.D.P.; Mallongi, A.; Amiruddin, R.; Hatta, M.; Rauf, A.U., (2021a). Risk identification of heavy metals in well water surrounds watershed area of Pangkajene, Indonesia. *Gac. Sanit.*, 35: S33–S37 **(5 pages)**.
- Astuti, R.D.P.; Mallongi, A.; Choi, K.; Amiruddin, R.; Hatta, M.; Tantrakarnapa, K.; Rauf, A.U., (2022). Health risks from multiroute exposure of potentially toxic elements in a coastal community: A probabilistic risk approach in Pangkep Regency, Indonesia. *Geomatics, Nat. Hazards Risk.*, 13(1): 705 -735 **(32 pages)**.
- Astuti, R.D.P.; Mallongi, A.; Rauf, A.U., (2021b). Natural enrichment of chromium and nickel in the soil surrounds the karst watershed. *Global J. Environ. Sci., Manage.* 7(3): 383 – 400 **(18 pages)**.
- Astuti, R.D.P.; Mallongi, A.; Rauf, A.U., (2021c). Risk identification of Hg and Pb in soil: a case study from Pangkep Regency, Indonesia. *Soil Sci. Annu.*, 72(1): 1–15 **(15 pages)**.
- Ayanlade, A.; Oyegbade, E.F., (2016). Influences of wind speed and direction on atmospheric particle concentrations and industrially induced noise. *SpringerPlus.*, 5(1): 1-13 **(13 pages)**.
- BPSSMR, (2020). Maros regency in figures 2020. BPS-Statistics Maros Regency.
- Celo, V.; Yassine, M.M.; Dabek-Zlotorzynska, E., (2021). Insights into Elemental Composition and Sources of Fine and Coarse Particulate Matter in Dense Traffic Areas in Toronto and Vancouver, Canada. *Toxics.*, 9(10): 1-18 **(18 pages)**.
- Chen, R.; Zhao, Y.; Tian, Y.; Feng, X.; Feng, Y. (2022). Sources and uncertainties of health risk for PM_{2.5}-bound heavy metals based on synchronous online and offline filter-based measurements in a Chinese megacity. *Environ. Int.*, 164:107236 **(10 pages)**.
- Chen, X.; Ward, T.J.; Sarkar, C.; Ho, K.F.; Webster, C., (2022). Health risk of adults in Hong Kong to inhalation of particle-bound heavy metal(loid)s. *Air Qual. Atmos. Health.*, 15: 691–706 **(16 pages)**.
- Correia, A.W.; Pope, C.A.; Dockery, D.W.; Wang, Y.; Ezzati, M.; Dominici, F., (2013). Effect of Air Pollution Control on Life Expectancy in the United States. *Epidemiology.* 24(1): 23–31 **(9 pages)**.
- Dehghani, F.; Omid, F.; Fallahzadeh, R. A.; Pourhassan, B., (2021). Health risk assessment of occupational exposure to heavy metals in a steel casting unit of a steelmaking plant using Monte–Carlo simulation technique. *Toxicol. Ind. Health.*, 37(7): 431–440 **(10 pages)**.
- de Oliveira, B.F.A.; Ignotti, E.; Artaxo, P.; do Nascimento Saldiva, P.H.; Junger, W.L.; Hacon, S., (2012). Risk assessment of PM_{2.5} to child residents in Brazilian Amazon region with biofuel production. *Environ. Health.*, 11(1): 64 **(11 pages)**.
- de Souza Silva, P.R.; Ignotti, E.; de Oliveira, B.F.A.; Junger, W.L.; Morais, F.; Artaxo, P.; Hacon, S., (2016). High risk of respiratory disease in children in the fire period in western amazon. *Rev. Saude. Publ.*, 50(29): 1-11 **(11 pages)**.
- Dinkes Maros, (2015). Profil kesehatan Kabupaten Maros tahun 2014. Health profile Maros Regency's residents. Maros Regency **(156 pages)**.
- Edlund, K.K.; Killman, F.; Molnár, P.; Boman, J.; Stockfelt, L.; Wichmann, J., (2021). Health risk assessment of PM_{2.5} and PM_{2.5}-bound trace elements in thohoyandou, south africa. *Int. J. Environ. Res. Public Health.*, 18: 1359 **(11 pages)**.
- Emetere, M.E.; Dania, E., (2019). Short review on air pollution from cement factories. *J. Phys. Conf. Ser.*, 1299: 012033 **(7 pages)**.
- Fell, A.K.M.; Nordby, K.C., (2017). Association between exposure in the cement production industry and non-malignant respiratory effects: a systematic review. *BMJ Open.*, 7: e012381 **(12 pages)**.
- Gao, B.; Gao, L.; Gao, J.; Xu, D.; Wang, Q.; Sun, K., (2019). Simultaneous evaluations of occurrence and probabilistic human health risk associated with trace elements in typical drinking water sources from major river basins in China. *Sci. Total Environ.*, 666: 139–146 **(8 pages)**.
- García-Pérez, J.; López-Abente, G.; Castelló, A.; González-Sánchez, M.; Fernández-Navarro, P., (2015). Cancer mortality in towns in the vicinity of installations for the production of cement, lime, plaster, and magnesium oxide. *Chemosphere.* 128: 103–110 **(8 pages)**.
- Goudarzi, G.; Alavi, N.; Geravandi, S.; Idani, E.; Behrooz, H.R.A.; Babaei, A.A.; Alamdari, F. A.; Dobaradaran, S.; Farhadi, M.; Mohammadi, M.J., (2018). Health risk assessment on human exposed to heavy metals in the ambient air PM₁₀ in Ahvaz, southwest Iran. *Int. J. Biometeorol.*, 62(6): 1075–1083 **(9 pages)**.
- Han, Q.; Liu, Y.; Feng, X.; Mao, P.; Sun, A.; Wang, M.; Wang, M., (2021). Pollution effect assessment of industrial activities on potentially toxic metal distribution in windowsill dust and surface soil in central China. *Sci. Total Environ.*, 759: 144023 **(11 pages)**.
- Han, Y.J.; Kim, H.W.; Cho, S.H.; Kim, P.R.; Kim, W.J., (2015).

- Metallic elements in PM_{2.5} in different functional areas of Korea: Concentrations and source identification. *Atmos. Res.*, 153: 416–428 **(13 pages)**.
- Indonesian Government, (2021). Peraturan Pemerintah, Peraturan Pemerintah (PP) Republik Indonesia No. 22 Tentang Penyelenggaraan Perlindungan dan Pengelolaan Lingkungan Hidup **(374 pages)**.
- Jimenez-Oyola, S.; Chavez, E.; Garcia-Martinez, M.J.; Ortega, M.F.; Bolonio, D.; Guzman-Martinez, F.; Garcia-Garizabal, I.; Romero, P., (2021). Probabilistic multi-pathway human health risk assessment due to heavy meta(loid)s in a traditional gold mining area in equador. *Ecotoxicol. Environ. Saf.*, 224: 112629 **(12 pages)**.
- Jorquera, H.; Barraza, F., (2013). Source apportionment of PM₁₀ and PM_{2.5} in a desert region in northern Chile. *Sci. Total Environ.*, 444: 327–335 **(9 pages)**.
- Kim, S.H.; Lee, C.G.; Song, H.S.; Lee, H.S.; Jung, M.S.; Kim, J.Y.; Park, C.H.; Ahn, S.C.; Yu, S.D., (2015). Ventilation impairment of residents around a cement plant. *Ann. Occup. Environ. Med.*, 27(1): 3 **(10 pages)**.
- Kholodov, A.; Zakharenko, A.; Drozd, V.; Chernyshev, V.; Kirichenko, K.; Seryodkin, I.; Karabtsov, A.; Olesik, S.; Khvost, E.; Vakhnyuk, I.; Chaika, V.; Stratidakis, A.; Vinceti, M.; Sarigiannis, D.; Hayes, A.W.; Tsatsakis, A.; Golokhvast, K., (2020). Identification of cement in atmospheric particulate matter using the hybrid method of laser diffraction analysis and Raman spectroscopy. *Heliyon*, 6: e03299 **(8 pages)**.
- Kridin, K.; Bergman, R.; Khamaisi, M.; Zelber-Sagi, S.; Weltfriend, S., (2016). Cement-Induced Chromate Occupational Allergic Contact Dermatitis. *Dermatitis*, 27(4): 208–214 **(7 pages)**.
- Krupnova, T.G.; Rakova, O.V.; Bondarenko, K.A.; Saifullin, A.F.; Popova, D.A.; Potgieter-Vermaak, S.; Godoi, R.H.M., (2021). Elemental composition of PM_{2.5} and PM₁₀ and health risks assessment in the industrial districts of Chelyabinsk, South Ural Region, Russia. *Int. J. Environ. Res. Public Health*, 18(23): 12354 **(16 pages)**.
- Kurt, M.A., (2018). Comparison of trace element and heavy metal concentrations of top and bottom soils in a complex land use area. *Carpathian J. Earth Environ. Sci.*, 13(1): 47–56 **(10 pages)**.
- Mallongi, A.; Astuti, R.D.P.; Amiruddin, R.; Hatta, M.; Rauf, A.U., (2021). Identification Source and Human Health Risk Assessment of Potentially Toxic Metal in Soil Samples around Karst Watershed of Pangkajene, Indonesia. *Environ. Nanotechnology, Monit. Manage.*, 17: 100634 **(10 pages)**.
- Mallongi, A.; Rauf, A. U.; Daud, A.; Hatta, M.; Al-Madhoun, W.; Amiruddin, R.; Stang; Wahyu, A.; Astuti, R.D.P., (2022). Health risk assessment of potentially toxic elements in Maros karst groundwater: A monte carlo simulation approach. *Geomatics, Nat. Hazards Risk*, 13(1): 338–363 **(27 pages)**.
- Mallongi, A.; Stang; Manyullei, S.; Natsir, M.F.; Astuti, R.D.P.; Rauf, A.U., (2019). Risks assessment of silica contamination on the communities living surround the cement industry, pangkep indonesia. *Indian J. Public Health. Res. Dev.*, 10: 1619 **(4 pages)**.
- Mallongi, A.; Stang; Syamsuar; Natsir, M.F.; Astuti, R.D.P.; Rauf, A.U., Rachmat, M.; Muhith, A., (2020). Potential ecological risks of mercury contamination along communities area in tonasa cement industry Pangkep, Indonesia. *Enfermería Clínica*, 30: 119–122 **(4 pages)**.
- Mbelambela, E.P.; Muchanga, S.M.J.; Villanueva, A.F.; Eitoku, M.; Yasumitsu-Lovell, K.; Hirota, R.; Shimotake, Y.; Sokolo, G.J.; Mori, A.; Suganuma, N., (2020). Biomass energy, particulate matter (PM_{2.5}), and the prevalence of chronic obstructive pulmonary disease (COPD) among Congolese women living near of a cement plant, in Kongo Central Province. *Environ. Sci. Pollut. Res.*, 27(32): 40706–40714 **(9 pages)**.
- Mehraj, S.S.; Bhat, G.A.; Balkhi, H.M.; Gul, T., (2013). Health risks for population living in the neighborhood of a cement factory. *African J. Environ. Sci. Technol.*, 7(12): 1044–1052 **(9 pages)**.
- Mekasha, M.; Haddis, A.; Shaweno, T.; Mereta, S.T., (2018). Emission Level of PM_{2.5} and its Association With Chronic Respiratory Symptoms Among Workers in Cement Industry: A Case of Muger Cement Industry, Central Ethiopia. *Avicenna J. Environ. Health. Eng.*, 5: 1–7 **(7 pages)**.
- Millard, S.P., (1998). Monte Carlo Simulation and Risk Assessment. In: *EnvironmentalStats for S-Plus*, Springer., New York **(74 pages)**.
- Mishra, S.; Siddiqui, N.A., (2014). A review on environmental and health impacts of cement manufacturing emissions. *Int. J. Geol. Agric. Environ. Sci.* 2: 26–31 **(6 pages)**.
- Mo, Z.; Wang, Z.; Mao, G.; Pan, X.; Wu, L.; Xu, P.; Chen, S.; Wang, A.; Zhang, Y.; Luo, J.; Ye, X.; Wang, X.; Chen, Z.; Lou, X., (2019). Characterization and health risk assessment of PM_{2.5}- bound polycyclic aromatic hydrocarbons in 5 urban cities of Zhejiang Province, China. *Sci. Rep.*, 9:7296 **(11 pages)**.
- Motesaddi Zarandi, S.; Shahsavani, A.; Khodaghali, F., (2019). Concentration, sources and human health risk of heavy metals and polycyclic aromatic hydrocarbons bound PM_{2.5} ambient air, Tehran, Iran. *Environ. Geochem. Health*, 41: 1473–1487 **(15 pages)**.
- Naeini, F.Y.; Azimzadeh, H.; Arani, A.M.; Sotoudeh, A.; Kiani, B., (2019). Ecological risk assessment of heavy metals from cement factory dust. *Environ. Health. Eng. Manage. J.*, 6(2): 129–137 **(9 pages)**.
- Nkhama, E.; Ndhlovu, M.; Dvonch, J.; Lynam, M.; Mentz, G.; Siziya, S.; Voyi, K., (2017). Effects of Airborne Particulate Matter on Respiratory Health in a Community near a Cement Factory in Chilanga, Zambia: Results from a Panel Study. *Int. J. Environ. Res. Public Health*, 14: 1351 **(16 pages)**.
- Novirsa, R.; Achmadi, U.F., (2012). Analisis Risiko Pajanan PM_{2.5} di Udara Ambien Siang Hari terhadap Masyarakat di Kawasan Industri Semen. *Kesmas Natl. Public Health. J.*, 7(4): 173 – 179 **(7 pages)**.
- Ogunkunle, C.O.; Fatoba, P.O., (2014). Contamination and spatial distribution of heavy metals in topsoil surrounding a mega cement factory. *Atmos. Pollut. Res.*, 5: 270–282 **(13 pages)**.
- Pelletier, M.; Bonvallot, N.; Ramalho, O.; Blanchard, O.; Mercier, F.; Mandin, C.; Le, B.; Gloennec, P., (2017). Dermal absorption of semivolatile organic compounds from the gas phase : Sensitivity of exposure assessment by steady state modeling to key parameters. *Environ. Int.*, 102: 106–113 **(8 pages)**.
- Peng, X.; Shi, G.L.; Zheng, J.; Liu, J.Y.; Shi, X.R.; Xu, J.; Feng, Y.C.,

- (2016). Influence of quarry mining dust on $PM_{2.5}$ in a city adjacent to a limestone quarry: Seasonal characteristics and source contributions. *Sci. Total Environ.*, 550: 940–949 **(10 pages)**.
- Rajasekhar, B.; Nambi, I.M.; Govindarajan, S.K., (2018). Human health risk assessment of ground water contaminated with petroleum PAHs using monte carlo simulations: a case study of an Indian metropolitan city. *J. Environ. Manage.*, 205: 183–191 **(9 pages)**.
- Rauf, A.U.; Mallongi, A.; Astuti, R.D.P., (2020a). Heavy metal contributions on human skin disease near cement plant: A systematic review. *Open Access Maced. J. Med. Sci.*, 8: 117–122 **(6 pages)**.
- Rauf, A.U.; Mallongi, A.; Astuti, R.D.P., (2020b). Mercury and chromium distribution in soil near maros karst ecosystem. *Carpathian J. Earth Environ. Sci.*, 15(2): 453–460 **(8 pages)**.
- Rauf, A.U.; Mallongi, A.; Daud, A.; Amiruddin, R.; Stang, S.; Wahyu, A.; Astuti, R.D.P., (2022). Spatial Distribution and Ecological Risk of Potentially Toxic Elements in Maros Regency, Indonesia. *Carpathian J. Earth Environ. Sci.*, 17(1): 93–100 **(8 pages)**.
- Rauf, A.U.; Mallongi, A.; Daud, A.; Hatta, M.; Al-Madhoun, W.; Amiruddin, R.; Rahman, S.A.; Wahyu, A.; Astuti, R.D.P., (2021a). Community Health Risk Assessment of Total Suspended Particulates near a Cement Plant in Maros Regency, Indonesia. *J. Health. Pollut.*, 11: 1–13 **(13 pages)**.
- Rauf, A.U.; Mallongi, A.; Lee, K.; Daud, A.; Hatta, M.; Al Madhoun, W.; Astuti, R.D.P., (2021b). Potentially Toxic Element Levels in Atmospheric Particulates and Health Risk Estimation around Industrial Areas of Maros, Indonesia. *Toxics*, 9: 328 **(14 pages)**.
- Saha, N.; Rahman, M.S.; Ahmed, M.B.; Zhou, J.L.; Ngo, H.H.; Guo, W., (2016). Industrial metal pollution in water and probabilistic assessment of human health risk. *J. Environ. Manage.*, 185: 70–78 **(9 pages)**.
- Saheed Bada, B.; Olatunde, K.A.; Oluwajana, A., (2013). Air quality assessment in the vicinity of cement company. *Int. Res. J. Nat. Sci.*, 1(2): 34 – 42 **(9 pages)**.
- Sánchez-Soberón, F.; Rovira, J.; Mari, M.; Sierra, J.; Nadal, M.; Domingo, J.L.; Schuhmacher, M., (2015). Main components and human health risks assessment of PM_{10} , $PM_{2.5}$, and PM_1 in two areas influenced by cement plants. *Atmos. Environ.*, 120: 109–116 **(8 pages)**.
- Sánchez-Soberón, F., (2017). Assessment of the human health risks and toxicity associated to particles (PM_{10} , $PM_{2.5}$, and PM_1), organic pollutants and metals around cement plants. Thesis. Universitat Rovira i Virgili **(290 pages)**.
- Schuhmacher, M.; Domingo, J.L.; Garreta, J., (2004). Pollutants emitted by a cement plant: health risks for the population living in the neighborhood. *Environ. Res.*, 95: 198–206 **(9 pages)**.
- Shaddick, G.; Thomas, M.L.; Mudu, P.; Ruggeri, G.; Gummy, S., (2020). Half the world's population are exposed to increasing air pollution. *npj. Clim. Atmos. Sci.*, 3: 23 **(5 pages)**.
- Shahri, E.; Velayatzadeh, M.; Sayadi, M.H. (2019). Evaluation of particulate matter $PM_{2.5}$ and PM_{10} (Case study: Khash cement company, Sistan and Baluchestan). *J. Air Pollut. Health.*, 4(4): 221–226 **(6 pages)**.
- Tajdar-oranj, B.; Shariatifar, N.; Alimohammadi, M.; Peivasteh-roudsari, L.; Khaniki, G.J.; Fakhri, Y.; Mousavi Khaneghah, A., (2018). The concentration of heavy metals in noodle samples from Iran's market: probabilistic health risk assessment. *Environ. Sci. Pollut. Res.*, 25: 30928–30937 **(10 pages)**.
- USEPA, (2001). Risk assessment guidance for superfund (rags) volume iii – part a: Process for conducting probabilistic risk assessment. United States Environmental Protection Agency Off. Emerg. Remedial Response U.S. Environ. Prot. Agency III, 1 – 385 **(385 pages)**.
- USEPA, (1997). Guiding principles for Monte Carlo Analysis. EPA/630/R-97/001. Washington DC.
- USEPA, (1997). Policy for use of probabilistic analysis in risk assessment. United States Environmental Protection Agency **(4 pages)**.
- USEPA, (1991). Risk Assessment Guidance for Superfund. Volume I Human Health Evaluation Manual Part (B, Development of Risk-based Preliminary Remediation Goals). United States Environmental Protection Agency. I: 66 **(57 pages)**.
- USEPA, (1989). Risk Assessment Guidance for Superfund. Volume I Human Health Evaluation Manual (Part A). **(291 pages)**.
- USGS, (2020). Mineral commodities summaries. United States Geological Survey **(204 pages)**.
- Wang, F.; Wang, J.; Han, M.; Jia, C.; Zhou, Y., (2019). Heavy metal characteristics and health risk assessment of $PM_{2.5}$ in students dormitories in a university in Nanjing, China. *Build. Environ.*, 160: 106206 **(10 pages)**.
- WHO, (2016). Ambient air pollution: A Global assessment and Burden of Disease. World Health Organization. Geneva. **(121 Pages)**.
- WHO, (2021). WHO global air quality guidelines: particulate matter ($PM_{2.5}$ and PM_{10}), ozone, nitrogen dioxide, sulfur dioxide and carbon monoxide. World Health Organization **(300 pages)**.
- Wu, Q., Tang, X., Kong, L., Liu, Z., Chen, D., Lu, M., Wu, H., Shen, J., Wu, L., Pan, X., Li, J., Zhu, J., Wang, Z. (2021). Model evaluation and uncertainty analysis of $PM_{2.5}$ components over Pearl River Delta Region using Monte Carlo Simulations. *Aerosol Air Qual. Res.*, 21: 200075 **(17 pages)**.
- Xue, Q.; Tian, Y.; Liu, X.; Wang, X.; Huang, B.; Zhu, H.; Feng, Y., (2022). Potential Risks of $PM_{2.5}$ -Bound Polycyclic Aromatic Hydrocarbons and Heavy Metals from Inland and Marine Directions for a Marine Background Site in North China. *Toxics*, 10(1): 32 **(15 pages)**.

AUTHOR (S) BIOSKETCHES

Mallongi, A., Ph.D., Professor, Department of Environmental Health, Faculty of Public Health, Hasanuddin University, Indonesia. Jl. Perintis Kemerdekaan KM 10, Tamalanrea, Kota Makassar, 90245 Indonesia.

- Email: rawnaenvi@gmail.com
- ORCID: [0000-0001-6438-1154](https://orcid.org/0000-0001-6438-1154)
- Web of Science ResearcherID: NA
- Scopus Author ID: 57196100558
- Homepage: <https://fkm.unhas.ac.id/teacher/anwar-mallongi-skm-phd/?lang=en>

Stang, S., Ph.D., Professor, Department of Biostatistics, Faculty of Public Health, Hasanuddin University, Indonesia. Jl. Perintis Kemerdekaan KM 10, Tamalanrea, Kota Makassar, 90245 Indonesia.

- Email: pakbregos88@gmail.com
- ORCID: [0000-0002-9757-6668](https://orcid.org/0000-0002-9757-6668)
- Web of Science ResearcherID: AGE-9284-2022
- Scopus Author ID: 57193113729
- Homepage: <https://fkm.unhas.ac.id/teacher/dr-stang-m-kes/?lang=en>

Astuti, R.D.P., Ph.D. Candidate. Department of Environmental Health, Faculty of Public Health, Hasanuddin University, Indonesia. Jl. Perintis Kemerdekaan KM 10, Tamalanrea, Kota Makassar, 90245 Indonesia.

- Email: ratnadwipujastuti@gmail.com
- ORCID: [0000-0001-9693-557X](https://orcid.org/0000-0001-9693-557X)
- Web of Science ResearcherID: ABB-2962-2020
- Scopus Author ID: 57215353200
- Homepage: <https://fkm.unhas.ac.id/ilmu-kesehatan-masyarakat-dr-km/>

Rauf, A.U., Ph.D. Candidate, Department of Environmental Health, Faculty of Public Health, Hasanuddin University, Indonesia. Jl. Perintis Kemerdekaan KM 10, Tamalanrea, Kota Makassar, 90245 Indonesia.

- Email: annisautamirauf@gmail.com
- ORCID: [0000-0002-7808-3374](https://orcid.org/0000-0002-7808-3374)
- Web of Science ResearcherID: AAY-2834-2020
- Scopus Author ID: 57215346048
- Homepage: <https://fkm.unhas.ac.id/ilmu-kesehatan-masyarakat-dr-km/>

Natsir, M.F., M.Sc., Instructor, Lecturer. Department of Environmental Health, Faculty of Public Health, Hasanuddin University, Indonesia. Jl. Perintis Kemerdekaan KM 10, Tamalanrea, Kota Makassar, 90245, Indonesia.

- Email: ahmadfajarislam@gmail.com
- ORCID: [0000-0003-1585-1169](https://orcid.org/0000-0003-1585-1169)
- Web of Science ResearcherID: NA
- Scopus Author ID: 57208302128
- Homepage: <https://fkm.unhas.ac.id/teacher/57-2/>

HOW TO CITE THIS ARTICLE

Mallongi, A.; Stang S.; Astuti, R.D.P.; Rauf, A.U.; Natsir M.F., (2023). Risk assessment of fine particulate matter exposure attributed to the presence of the cement industry. *Global J. Environ. Sci.Manage.*, 9(1): 1-16.

DOI: [10.22034/gjesm.2023.01](https://doi.org/10.22034/gjesm.2023.01).***

url: ***

