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Original Article

Health risk assessments of exposure carbon dioxide among communities and children around Tonasa cement plant, Pangkep Regency, Indonesia. Monte Carlo Simulation (MCS) application

Avaliações de risco à saúde na exposição ao dióxido de carbono entre comunidades e crianças ao redor da fábrica de cimento Tonasa, Pangkep Regency, Indonésia. Aplicação da Simulação de Monte Carlo (MCS)

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Abstract

Chronic exposure to carbon dioxide (CO_2) can have a negative influence on one's health and be hazardous to the environment. It could be both directly and indirectly to those communities who are living near the CO_2 point sources. This study aimed to investigate the magnitude of CO_2 level in ambient air and its spatial distribution which then continued to assess the potential health risks posed by communities living surround the site as well as applied the Monte Carlo Simulation (MCS) approach to predict the risks magnitude among adult and children due to CO_2 air pollution from the cement industry activities in Pangkep. This observational analytic study applied health risk assessment due to the CO_2 exposure both to adult and children population. To estimate the non carcinogenic risk, study used the Monte Carlo Simulation model with 10,000 iterations to estimate the risk through the inhalation pathway suffered by communities, as well as analyzing the sensitivity level every single health risk parameter. The highest risks for the adults was in station 7 with 7,641 whereas the lowest risks was in station 3 with 1,194, respectively. Furthermore, the highest risks for child was in station 4 with 498 whereas the lowest one was in station 15 with 32, respectively. Those non carcinogenic HQ were exceed the standard for adult but not at risks for children. The results of the Monte Carlo Simulation that assessed the non risks cancer probability with the 5^{th} and 95^{th} percentiles demonstrated that adult population were at value of 0.83 and 1.53 0.83 and 1.53 respectively, that still indicated at low risk for developing adverse health effects among those communities temporarily. However, at the same percentiles children indicated at value of 199 and 388 that indicated at risk for developing adverse health effects among those children. In addition, level of sensitivity analysis result indicated that exposure frequency with (20,9%) for adult and the exposure duration with (25,6%) for children were the most contributing factors to health risks among, respectively. Simulation determines the critical factors with major effects in reducing health risks. The CO_2 magnitude not poses risks to adults, by contrast, children are at risk. Thus, limiting exposure frequency and inhalation of CO_2 levels in the school for children area are highly demanded.

Keywords: carbon dioxide, health effect, children and adult exposures, Monte Carlo Simulation, health risks.

Resumo

A exposição crônica ao dióxido de carbono (CO_2) pode ter uma influência negativa sobre a saúde e ser perigosa para o meio ambiente. Pode ser direta ou indiretamente para as comunidades que vivem perto das fontes pontuais de CO_2. Este estudo teve como objetivo investigar a magnitude do nível de CO_2 no ar ambiente e sua distribuição espacial, que então continuou a avaliar os riscos potenciais à saúde apresentados pelas comunidades que vivem no entorno do local, bem como aplicou a abordagem da Simulação de Monte Carlo (MCS) para prever a magnitude dos riscos entre adultos e crianças devido à poluição do ar por CO_2 das atividades da indústria de cimento em Pangkep. Este estudo analítico observacional aplicou a avaliação de risco à saúde devido à exposição ao CO_2 tanto na população adulta quanto na infantil. Para estimar o risco não cancerígeno, o estudo utilizou o modelo da Simulação de Monte Carlo com 10.000 iterações para estimar o risco pela via inalatória sofrida pelas comunidades, bem como analisar o nível de sensibilidade de cada parâmetro de risco à saúde. O maior risco para os adultos foi na estação 7 com 7.641 enquanto o menor risco foi na estação 3 com 1.194, respectivamente. Além disso, o maior risco para crianças estava na estação 4 com 498 enquanto o menor estava na estação 15 com 32, respectivamente. Aqueles HQ não cancerígenos excederam o padrão para adultos, mas não representam riscos para crianças. Os

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resultados da Simulação de Monte Carlo que avaliaram a probabilidade de câncer sem riscos com os percentis 5 e 95 demonstraram que a população adulta estava no valor de 0,83 e 1,53 respectivamente, que ainda indicava baixo risco para desenvolver efeitos adversos à saúde entre essas comunidades temporariamente. No entanto, nos mesmos percentis, as crianças indicaram valores de 199 e 388, que mostraram risco de desenvolver efeitos adversos à saúde entre essas crianças. Além disso, o resultado da análise de nível de sensibilidade indicou que a frequência de exposição com 20,9% para adultos e a duração da exposição com 25,6% para crianças foram os fatores que mais contribuíram para riscos à saúde, respectivamente. A simulação determina os fatores críticos com efeitos importantes na redução dos riscos à saúde. A magnitude do CO_2 não oferece riscos aos adultos, ao contrário, as crianças correm risco. Assim, a limitação da frequência de exposição e inalação de níveis de CO_2 na área escolar para crianças é altamente exigida.

Palavras-chave: dióxido de carbono, efeitos na saúde, exposições de crianças e adultos, Simulação de Monte Carlo, riscos à saúde.

1. Introduction

The greenhouse gases reduction emitted both by industry and human activities has bec

ome a great challenging in Indonesia particularly in the area of Industrial site like in Makassar City, Indonesia. It become of a buffer of the climate change mitigation in this century. Particularly carbon dioxide (CO_2) emissions as at the top on the list of the threats to the environment degradation and threat to human health (Lin et al., 2014).

Serious impact of climate change globally due to mainly CO_2 on environment, human society, social economy and human health has highly require a focused and smart effective management regarding the emission of greenhouse gas on every single country (Mi et al., 2017). As a result, intellectual controlling, management in order to reducing CO_2 gas emissions has become a together necessary common goal for all researchers, academia, industries, government, NGO, and the global community (National Development and Reform Commission of China, 2022).

Only by togetherness of planners that vision and commitment the initiated program will be achieved in advance successfully. Furthermore, all countries including Indonesia has also announced a target of reducing its carbon intensity by 50–60% from the 2015 level of reaching the peak of its CO_2 emissions around 2030 and of neutralizing its emissions by 2060 (Rose and Casler, 1996; Zhou and Ang, 2008; Liao et al., 2022). The present studies on the energy consumption and the carbon gas emissions mostly focuses on traditional factors such as emission factors, energy structure, energy intensity, industrial structure and economic activities and there is a consensus that economic activity is the most important factor leading to increased carbon emissions (The State Council the People's Republic of China, 2016). In fact, it is obviously, that in reducing of carbon gas emission need energy intensity which is an necessary factor to be implemented immediately (Lin and Ouyang, 2014).

The very fast rapid progress of industrial manufacture generate great amount of carbon dioxide emissions which then trans boundary to all countries in the world particularly cement industry as the highly demanded production materials (Lin and Ouyang, 2014). Therefore, it is of great research, theoretical and practical significance to explore the factors that influence CO_2 emissions in manufacturing industry and the driving factors of CO_2 emissions in different sectors of the manufacturing industry to reduce CO_2 emissions, develop a low-carbon economy and the realize green sustainable development of manufacturing as soon as possible (Shao et al., 2017).

Recently research results indicated that the industrial activity effect is the main factor that promotes the increase of CO_2 emissions and the energy continuously used effect is the great factor that inhibits an increase in CO_2 emissions, which is consistent with most previous studies (Liu et al., 2019; Ren et al., 2014). Economic development is the core of USA and China's reform and opening-up in the past 40 years. The manufacturing industry is one of the most important sectors of economic development (Ma et al., 2016; Xu et al., 2011), which have been generate huge income as well as great CO_2 pollutants.

In Asia and cement producers countries including Indonesia, if the cement industry were a country, it would be the third largest polluters in the world - behind China and the US. It produces more CO_2 than aircraft fuel (2.5%) and is not far behind the global agriculture industry (12%) (Rodgers, 2018). Cement industry leaders were met in Poland for the United Nations climate change conference - COP24 - to discuss ways to meet the terms of the Paris Agreement on climate change. To do this, annual emissions from cement need to fall by at least 16% by 2030 (Kompas.com, 2018).

Prospectively, The Intergovernmental Panel on Climate Change - the leading international body on global warming - several last month argued that global average temperature rise should be kept below 1.5 Celsius - not the 2 Celsius as stipulated in the Paris Agreement. This means CO_2 emissions should fall by 45% from 2010 levels by 2030 (Republik Indonesia, 2023). Carbon dioxide in the Earth's atmosphere is considered a trace gas with a concentration of approximately 385 ppm by volume and 582 ppm by mass. The mass of Earth's atmosphere is 5.14×10^{18} kg, so the total mass of atmospheric carbon dioxide is 3.0×10^{15} kg (3,000). The concentration of carbon dioxide varies seasonally. In urban areas, CO_2 concentrations are generally higher, whereas in closed spaces, carbon dioxide can be up to 10 times greater than the concentration in the open atmosphere. Many of these concentrations result from a number of large operating industries (Mitchell et al., 2018).

The emissions of CO_2 produced form cement industry are resulted through 2 processes. First, CO_2 is produced from the limestone decarbonation when the burned of raw materials occurs stated of $CaCO_3 \Leftrightarrow CaO + CO_2$. The second results from heavy fuel burning at temperatures above 2000°C. The cement industry facility contributed a significant quantity of CO_2 pollution through the use of electric fuel and from the by-products of the production process due to the high energy consumption during production.

The concentration of CO_2 in greenhouse gas emissions is the most critical, it has increased from 280 ppm in per-industrial times to over 380 ppm is increasing by more than 2ppm per year driven by global CO_2 emissions which are currently increasing at more than 3.3% per year (Barker et al., 2009; Hegerland et al., 2006; Blamey et al., 2010; Gardarsdottir et al., 2019).

According to the meeting report for the United Nations climatic Change Secretariat, changes in climatic indicators such heat, rainfall, temperature rise, and ocean acidification are what cause the elevated CO2 concentration levels (United Nation Frame of Convention on Climate Change, 2019). Particularly on the pollution spot close to the point source, those changes have the ability to affect both the environment and the health of populations (Rauf et al., 2021).

Calcination is the term for the chemical process that results in the direct emissions of cement. When calcium carbonate, the main component of limestone, is heated, calcium oxide and carbon dioxide are produced. About 50% of all pollution emissions from cement manufacture occur at this step. Whereas the indirect pollutant emissions are resulted by the burning of fossil fuels to heat the kiln that heated by coal, natural gas, or oil, and where the combustion of these fuels generates additional carbon dioxide emissions when it starting to produce electricity which represents around 40% of cement emissions (Boden et al., 2011; Mun et al., 2017).

However, in the near future, due to environmental threats and the phenomenon of global warming, cement plants were allocated to devote budget and time to mitigate the strategies of pollution. Initially, studies were conducted to increase energy efficiency, minimize fuel use, and optimize cost (Benhelal et al., 2012).

Similarly, according to Bakhtyar et al. (2017) almost all emissions burning CO_2 is produced by four different sources fuel is related to production cement, with an estimated 8% of global CO_2 is produced by four different sources emissions. During cement production, clinker is charred at around 1450°C. As a result, ecological contamination and global warming continue growing and natural resources, and shrinking energy from day to day. Clinker production is the most production process results in an increase in energy, of which about 80% energy used in cement manufacturing.

In Tonasa cement industry, Pangkep Regency in Indonesia where this study conducted. The largest source of CO_2 is produced by four main different sources emissions such as the burning of fossil fuels coal, oil and gas in power plants, cars, industrial facilities and emission from sources. Fossil fuels are burned to produce energy from the carbon stored in them. Huge Emission of CO_2 is produced during the extraction and maintenance processes in the Pangkep cement industry.

Therefore, it is of great and significance research to explore the multi health risks assessment factors due to exposure to CO_2 emissions from cement manufacturing industry in Indonesia and the driving factors of CO_2 emissions due to sectors involved in the process to reduce pollutant to communities and school children surround the plant.

The research applied both health risks assessment and the Monte Carlo Simulation approach that is expected to improve public health, environmental air quality and to overcome CO_2 pollution due to air pollution from the Pangkep cement industry activities.

2. Materials and Methods

2.1. Study area

This observational analytic research was conducted at 18 sampling points within the 6 residential areas where 3 points samples each around the Pangkep cement industry. occupies a land area of 715 ha in Biring Ere Village, Bungoro Subdistrict, Pangkep Regency, Indonesia. This Industry was established in 1968 and has capacity of 59,80000 tons of cement per year. The locations are; Bontoa district (three stations), Taraweang district (three stations), district of Taqwa mosque (three stations), Biringere district (three stations), Kampung Sela dist (three stations), and Mangilu dist (three stations), in total of 18 stations. Data collection is carried out on a scale of outside, in community housing areas and in schools around the cement factory.

2.2. Meteorological data

Meteorological data such as the wind speed, wind direction , temperature, and solar radiation was collected from Maros Climatology Station website. The meteorological data were analyzed for estimating the concentrations of CO_2 from the cement industry stacks. The monthly average air temperature, solar radiation, wind speed and direction are applied to trends in meteorological parameters.

2.3. Acceptable Daily Intake (ADI)

The adverse effects posed by pollutant in environmental media can be predicted using the health risk assessment formulation. Air that is contaminated with CO_2 and other pollution may pose a health risk due to human exposure to CO_2 through inhalation and skin (Barker et al., 2009; Hegerland et al., 2006; Blamey et al., 2010; Gardarsdottir et al., 2019), by using the given Equations 1 and 2.

$$ADDinh = \frac{Chm \times IR\,inh \times EF \times ED}{PEF \times BW \times AT} \times 10^{-6} \tag{1}$$

$$HQ = \frac{\sum ADD}{RfC} \tag{2}$$

2.4. Monte Carlo Simulation (MCS)

The simulation of Monte Carlo is applied in order to calculate the potential risks occur on the population subject using a mathematical approach. In the past however, communities' health risks due exposure of chemical substances were determined merely by calculating the available manual data which frequently culminate only for a single point of risk which may contain ambiguity results.

By using the MCS, all inputted uncertainty factors correlated to risk estimation able to be identified in the calculation results which then attributed as a probability distribution to predict risk or exposure correctly (Astuti et al.., 2021; Rauf et al., 2021). Here on this study, the Monte Carlo Simulation design was performed to forecast the total cancer risk variability and determine the influential factors that contribute to cancer risk in the Pangkep Regency's community. This method used the random parameter of interest (Y), with the Equation 3 (Millard, 2002).

$$Y = h(X) = h(X_1, X_2, X_3 \ldots\ldots\ldots X_k 0) \quad (3)$$

On this study, X represents the input parameters or the distribution of variables that characterize dose–response and exposure, h represents the elements of random vector X, and Y is the probability distribution. This study used 10,000 repetitions of each health risk variable using Crystal Ball software (11.1.2 ver inc USA) in Microsoft Excel. The final results were presented in the 5th percentile, mean, 95th percentile.

3. Results

3.1. Meteorological data

Meteorology is an important factor in the distribution and accumulation of gas and particulates pollutants. 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). Temperature, wind speed, direction, and humidity were compiled from the Indonesian Meteorological, Climatological and Geophysical Agency (BMKG, 2023) 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 4.0 m/s, average 2.8 m/s. Figure 1 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 wind rose 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.

Below is the definitions, units, values as well as the sources used to determine the health risk assessment are presented in Table 1.

3.2. Carbon dioxide emissions by the cement sector

Currently, cement production is considered as responsible for approximately 7.4% of the global carbon dioxide emission (2.9 Gtons in 2016). Thus, the cement industry will play a key role in reducing carbon dioxide emissions to minimize climate change. The cement industry has hugely reduced the carbon dioxide emissions per ton

Table 1. Definitions, units, and values for the health risk assessment.

No	Definitions	Units	Symbol	Value	Sources
1	CO_2 concentration	mg/m^3 for ADDinhalation, and $mg.kg^{-1}$ for ADDoral and ADDdermal	C	Results of Laboratory Analysis	Ernyasih et al. (2023)
2	Inhalation rate	$M^3.day^{-1}$	inh_{rate}	7.6 children; 20 adult	Qadeer et al. (2019)
3	Skin rate	Cm^2	SA	-	Mallongi et al., 2022
4	Exposure frequency	Days/year	EF	350	Mallongi et al. (2022)
5	Exposure duration	Year	ED	Site data	United States Environmental Protection Agency (2002)
6	Conversion factor	$Kg.mg^{-1}$	CF	$1x10^{-6}$	United States Environmental Protection Agency (2002)
7	Body weight	Kg	BW	Site data	Mallongi et al. (2022)
8	Exposure even	Per day	EV	2	Mallongi et al. (2022)
9	Average time	Days	AT	ED x 365 days	Ernyasih et al. (2023)
10	Dermal absorption	Unit less	ABS	0.001	Mallongi et al. (2022)
11	Skin surface area	cm^2	SA	Site data	Mallongi et al. (2022)
12	Skin adherence factor	$mg.cm^{-2}$ h	SL	0.07, adults 0.2, children	United States Environmental Protection Agency (2002)
13	Reference Concentration	-	RFC	EPA IRIS	Mallongi et al. (2022)

SA = skin area; EF = Exposure Frequency; ED = Exposure duration; CF = Conversion factor; BW = body weight; EV = exposure even; AT = average time; ABS = absorption factor (unitless); SA = skin area; SL = Skin adherence factor; RFC = reference concentration.

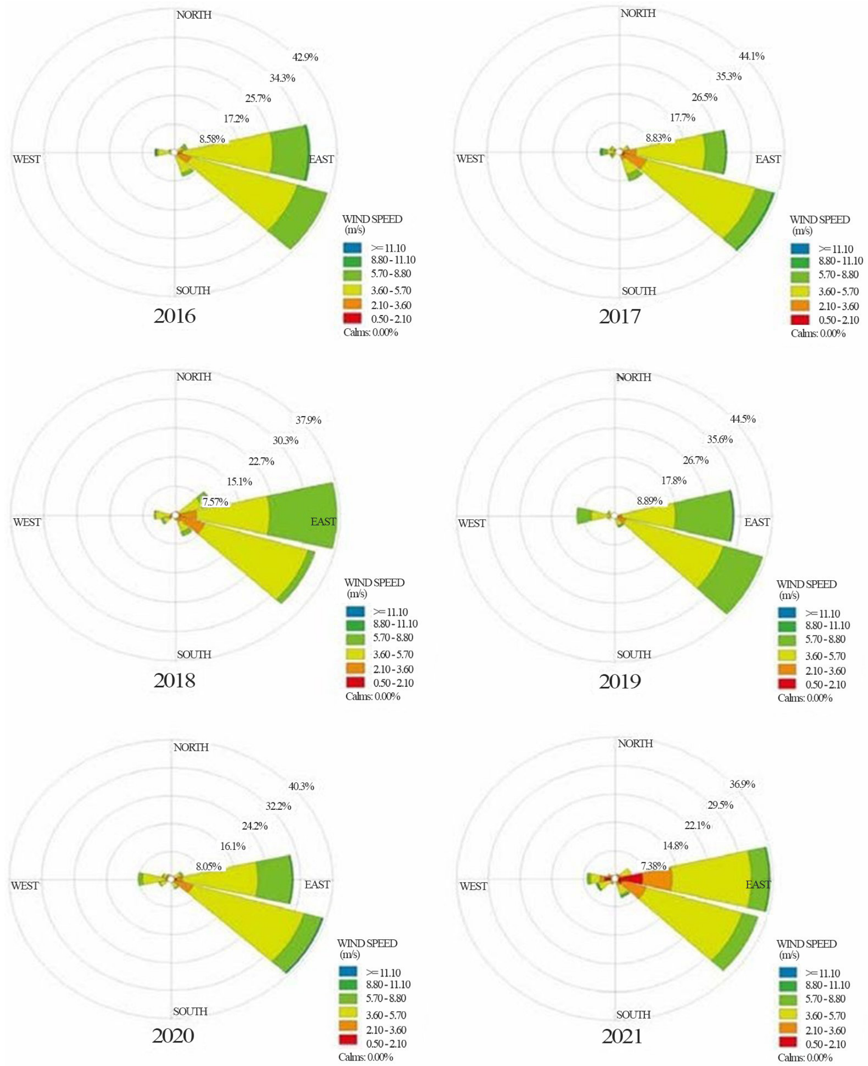

Figure 1. Annual wind rose around the Pangkep cement plant complex in 2016-2021.

of cement from the last century (Figure 2) (Bakhtyar et al., 2017), but the cement production is growing worldwide due to the economic growth, notably in developing countries.

The following is the concentration and risk assessment at 18 stations in 6 sub-districts of Pangkep Regency, Indonesia, presented in Table 2

The higher production growth of cement, the bigger CO_2 emissions are increasing too. According to An et al. (2019) the new technology of Carbon capture and storage is the most feasible option to reduce the acidification and acid rain in water resources, as its known that turbidity, heat increase and other health impacts are critical concerns that children and adults have experience.

3.3. Monte Carlo Simulation

The Monte Carlo Simulation (MCS) model is an advanced, a sophisticated and have a high validity method that result exact precise number or risk point forecast. The association

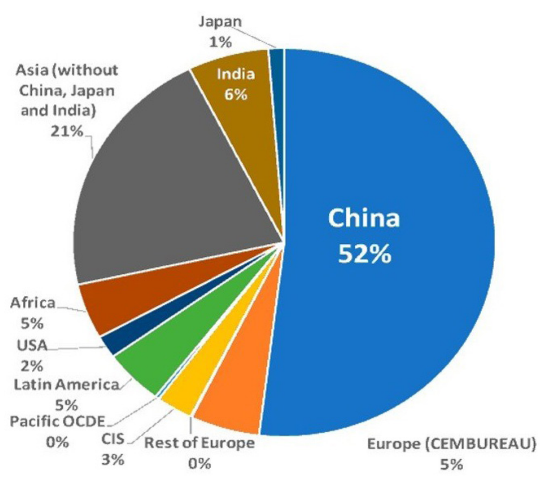

Figure 2. Cement production in some countries.

Table 2. Concentration of CO_2, Risks Assessment and the Location for 18 stations in Six Districts in Pangkep Regency, Indonesia

No	Study Areas	CO_2 Concentration µg/m³	HQ Inhalation Risks Assessment (CO_2)		Locations	
			Adult	Child	Southern	Eastern
1	Bontoa dist.1	143.23	5.232	0.225	04 ° 48'07.9 "	119 ° 35'44.0"
2	Bontoa dist.2	152.92	7.063	0.350	04 ° 48'04.9 "	119 ° 35'23.0"
3	Bontoa dist.3	141.18	1.194	0.343	04 ° 48'11.9 "	119 ° 35'17.0"
4	Taraweang dist.1	108.31	4.345	0.498	04 ° 46'37.9 "	119 ° 36'08.5"
5	Taraweang dist.2	120.22	3.043	0.122	04 ° 46'32.9 "	119 ° 36'07.5"
6	Taraweang dist.3	110.15	6.878	0.321	04 ° 46'28.9 "	119 ° 36'09.5"
7	Taqwa mosq dist.1	123.22	7.642	0.234	04 ° 47'08.0 "	119 ° 36'29.5"
8	Taqwa mosq dist.2	129.67	6.456	0.497	04 ° 47'06.0 "	119 ° 36'26.5"
9	Taqwa mosq dist.3	122.17	7.548	0.434	04 ° 47'02.0 "	119 ° 36'18.5"
10	Biringere dist.1	110.19	5.251	0.164	04 ° 46'43.6 "	119 ° 36'50.6"
11	Biringere distr.2	99.77	4.432	0.267	04 ° 46'39.6 "	119 ° 36'43.6"
12	Biringere dist.3	89.67	5.263	0.782	04 ° 46'35.6 "	119 ° 36'37.6"
13	Kampung sela dist.1	91.23	3.261	0.413	04 ° 46'47.0 "	119 ° 37'40.7"
14	Kampung sela dist.2	96.85	1.416	0.345	04 ° 46'43.0 "	119 ° 37'37.7"
15	Kampung sela dist.3	99.68	2.564	0.032	04 ° 46'39.0 "	119 ° 37'29.7"
16	Mangilu dist.1	102.15	2.678	0.242	04 ° 47'48.3 "	119 ° 38'22.3"
17	Mangilu dist.2	99.28	1.759	0.412	04 ° 47'45.3 "	119 ° 38'17.3"
18	Mangilu dist.3	87.73	2.181	0.346	04 ° 47'40.3 "	119 ° 38'13.3"

HQ = Hazard Quotient.

between the exposure frequency and health or ecological impact determine the probability risk of health or ecological effect according to the observed levels of exposure and characterizes the uncertainty factor associated with the estimated risk.

The application of MCS on this study assuring the assessment of factors uncertainty related to the estimated risk is well identified as a probability distribution to estimate risk or the exposure. It evolving huge numbers of random from some distribution of specified theoretical probability and can investigate the variables that most sensitive leading to health risk. The simulation study is operated by ORACLE inc software, (Crystal ball version 11.1.2) in Microsoft Excel 2019, USA (Mallongi et al., 2023; Ratna et al., 2023; Goudarzi et al., 2018).

3.4. HQ adult and children

Based on the Monte Carlo Simulation (MCS) results, in Figure 3, the probability of cancer risk occurrence at the 5th and 95th percentiles among adult communities were 0.83 and 1.53 that indicated low cancer risks. The percentiles for children had 388, respectively, that show a potential of cancer risks occurrence. This due to the children exposure duration for children more frequently as they play more out their home. Those condition indicating that CO_2 exposure in the Pangkep regency population has a low risk of cancer

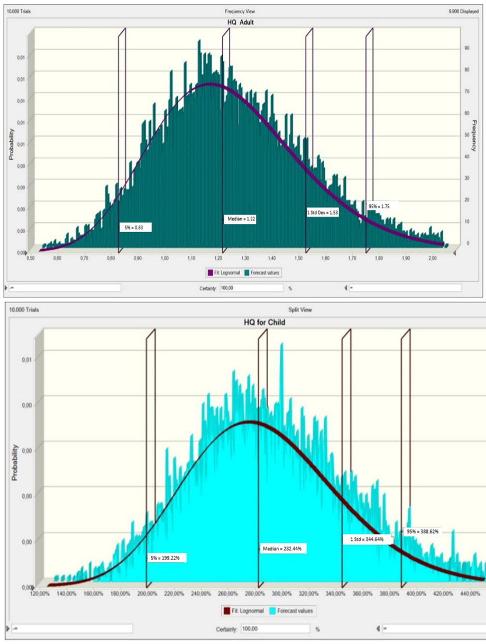

Figure 3. The Predicted probability of CO_2 risks for adult **(a)** and children **(b)** population in the area of Cement Plant, Pangkep Regency, Indonesia.

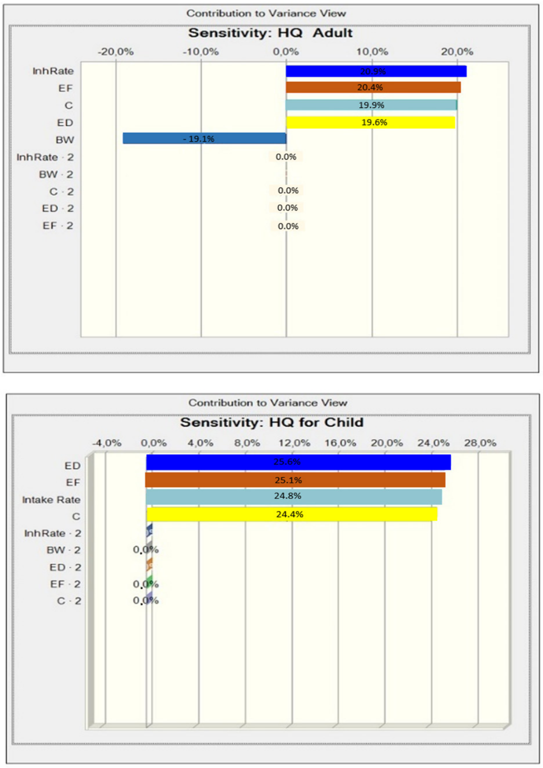

Figure 4. (a) Adult and (b) child HQ Sensitivity.

for adults which was contrast to children that have higher possibility to be risks. This also show that the greater of CO_2 value, the greater potential health risk to be suffered to communities both adults and children

According to the sensitivity chart in Figure 4a, exposure frequency (EF) of CO (20.4%) and inhalation rate (IR) were the two most important factors for escalating health issues in adults. In contrast, in children the exposure duration (ED) of CO (25.6%) and EF (25.1%) made the largest contributions. This indicates that exposure to CO pollution and their concentration had the greatest influence on people's ability to acquire negative health impacts.

Therefore, the best-suited scenarios concentrate on minimizing inhalation rates and exposure times on the site, as well as on routinely monitoring industrial emissions close to residential areas. This shows that the likelihood that inhabitants may be at risk increases as the frequency of discrete exposure occurrences increases. As a result, both kids and adults should limit their activities and use protective gear to reduce their interaction with air CO pollution that may include hazardous compounds. Body weight (BW) made a negative contribution, indicating that it had little impact and may be disregarded.

4. Conclusion

Adults are not at risk from the CO2 magnitude, but children are. Therefore, it is imperative to reduce exposure frequency and CO2 levels in the vicinity of schools for youngsters. Children and adults should reduce their activities and use protection to decrease their contact with the air CO pollution that possibly contains harmful materials.

4.1. Paper context

This participatory research project conducted jointly with the local communities leader and school in assisting the data collection and method of sampling collection. Research aimed investigate the magnitude of CO2 concentration out side the cement Plant such as in front of communities' house and in the near by school children. Then this study also assessed the potential risks suffered from CO inhalation both to adults and children, here we develop health risks assessment risk calculation model that prepared by EPA. At the end this research applied Monte Carlo Simulation (MCS) to estimate the various risks factors with its numeric value and set the sensitivity level of each parameter to indicated which parameter gave the highest contribution the Risk occurrence due to CO emission inhalation. Data gathered for this manuscript can be retrieved by contacting the corresponding authors.

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Ethics and consent

Ethical approval for the study was granted by the Faculty of Public Health, University Muhammadiyah Jakarta (No: 10.712.B/KEPK-FKMUMJ/X/2022) .

References

AN, J., MIDDLETON, R.S. and LI, Y., 2019. Environmental performance analysis of cement reduction with CO_2 capture and storage technology in a life-cycle perspective. *Sustainability (Basel)*, vol. 11, no. 9, pp. 2626. http://dx.doi.org/10.3390/su11092626.

ASTUTI, R.D.P., MALLONGI, A., AMIRUDDIN, R., HATTA, M. and RAUF, A.U., 2021. Risk identifcation of heavy metals in well water surrounds watershed area of Pangkajene, Indonesia. *Gaceta Sanitaria*, vol. 35, suppl. 1, pp. S33-S37. http://dx.doi.org/10.1016/j.gaceta.2020.12.010. PMid:33832621.

BADAN METEOROLOGI KLIMATOLOGI, DAN GEOFISIKA – BMKG, 2023 [viewed 3 January 2023]. Available from: https://www.bmkg.go.id/en.html

BAKHTYAR, B., KACEMI, T. and NAWAZ, M.A., 2017. A review on carbon emission in Malaysian cement industry. *International Journal of Energy Economics and Policy*, vol. 7, no. 3, pp. 282-286.

BARKER, D.J., TURNER, S.A., NAPIER-MOORE, P.A., CLARK, M. and DAVISON, J.E., 2009. CO2 capture in the cement industry. *Energy Procedia*, vol. 1, no. 1, pp. 87-94. http://dx.doi.org/10.1016/j.egypro.2009.01.014.

BENHELAL, E., RAFIEI, A. and SHAMSAEI, E., 2012. Green cement production : potential and achievments. *International Journal of Chemical Engineering and Applications*, vol. 3, no. 6, pp. 407-409. http://dx.doi.org/10.7763/IJCEA.2012.V3.229.

BLAMEY, J., ANTHONY, E.J., WANG, J. and FENNELL, P.S., 2010. The calcium looping cycle for large-scale CO_2 capture. *Progress in Energy and Combustion Science*, vol. 36, no. 2, pp. 260-279. http://dx.doi.org/10.1016/j.pecs.2009.10.001.

BODEN, T., MARLAND, G. and ANDRES, B., 2011. *Global CO2 emissions from fossil-fuel burning, cement manufacture, and gas flaring: 1751e2008. Carbon dioxideinformation analysis Center, Oak Ridge National Laboratory* [online]. Oak Ridge, Tenessee: U.S. Department of Energy's (DOE). [viewed 3 January 2023]. Available from: https://data.ess-dive.lbl.gov/datasets/doi:10.3334/CDIAC/00001_V2017

ERNYASIH, M.A., DAUD, A., PALUTTURI, S., STANG, S., THAHA, A.R., IBRAHIM, E. and AL MADHOUN, W., 2023. Health risk assesment through probabilistic sensitivity analysis of carbon monoxide and fine particulate transportation exposure. *Glob. J. Environ. Sci. Manag.*, vol. 9, no. 4, pp. 1-18.

GARDARSDOTTIR, S.O., DE LENA, E., ROMANO, M., ROUSSANALY, S., VOLDSUND, M., PÉREZ-CALVO, J.-F., BERSTAD, D., FU, C., ANANTHARAMAN, R., SUTTER, D., GAZZANI, M., MAZZOTTI, M. and CINTI, G., 2019. Comparison of technologies for CO_2 capture from cement production – Part 2: cost analysis. *Energies*, vol. 12, no. 3, pp. 542. http://dx.doi.org/10.3390/en12030542.

GOUDARZI, G., ALAVI, N., GERAVANDI, S., IDANI, E., BEHROOZ, H.R.A., BABAEI, A.A., ALAMDARI, F.A., DOBARADARAN, S., FARHADI, M. and MOHAMMADI, M.J., 2018. Health risk assessment on human exposed to heavy metals in the ambient air PM10 in Ahvaz, southwest Iran. *International Journal of Biometeorology*, vol. 62, no. 6, pp. 1075-1083. http://dx.doi.org/10.1007/s00484-018-1510-x. PMid:29464337.

HEGERLAND, G., PANDE, J.O., HAUGEN, H.A., ELDRUP, N., TOKHEIM, L.A. and HATLEVIK, L.M., 2006. Capture of CO2 from a cement plant–technical possibilities and economical estimates. In: *Proceedings of the 8th international Conference on Greenhouse Gas Control Technologies*, 2006, Trondhein, Norway. USA: Elsevier Science Ltd, pp. 1-5.

KOMPAS.COM, 2018 [viewed 23 December 2022]. *Inilah Penghasil CO2 Terbesar yang Sering Tak Kita Sadari* [online]. Indonesia: Kompas.com. Available from: https://sains.kompas.com/read/2018/12/18/185138623/inilah-penghasil-co2-terbesar-yang-sering-tak-kita-sadari?page=all

LIAO, S., WANG, D., REN, T. and LIU, X., 2022. Heterogeneity and decomposition analysis of manufacturing carbon dioxide emissions in China's post-industrial innovative megacity Shenzhen. *International Journal of Environmental Research and Public Health*, vol. 19, no. 23, pp. 15529. http://dx.doi.org/10.3390/ijerph192315529. PMid:36497606.

LIN, B. and OUYANG, X., 2014. Analysis of energy-related CO2 (carbon dioxide) emissions and reduction potential in the Chinese non-metallic mineral products industry. *Energy*, vol. 68, pp. 688-697. http://dx.doi.org/10.1016/j.energy.2014.01.069.

LIN, B., MOUBARAK, M. and OUYANG, X., 2014. Carbon dioxide emissions and growth of the manufacturing sector: evidence for China. *Energy*, vol. 76, no. C, pp. 830-837. http://dx.doi.org/10.1016/j.energy.2014.08.082.

LIU, J., YANG, Q., ZHANG, Y., SUN, W. and XU, Y., 2019. Analysis of CO2 emissions in China's manufacturing industry based on extended logarithmic mean division index decomposition. *Sustainability*, vol. 11, no. 1, pp. 226. http://dx.doi.org/10.3390/su11010226.

MA, X., SUN, L., HU, G. and JI, J., 2016. Decomposition of China's manufacturing carbon emission factors-based on the study of internal structure changes in manufacturing industry. *Modern Management Science*, no. 10, pp. 64-66. http://dx.doi.org/10.3969/j.issn.1007-368X.2016.10.021.

MALLONGI, A., RAUF, A.U., ASTUTI, R.D.P., PALUTTURI, S. and ISHAK, H., 2023. Ecological and human health implications of mercury contamination in the coastal water. Global J. Environ. *Sci. Manage.*, vol. 9, no. 2, pp. 1-14. http://dx.doi.org/10.22034/gjesm.2023.02.06.

MALLONGI, A., RAUF, A.U., DAUD, A., HATTA, M., AL-MADHOUN, W., AMIRUDDIN, R., STANG, S., WAHYU, A. and ASTUTI, R.D.P., 2022. Health risk assessment of potentially toxic elements in Maros karst groundwater: a Monte Carlo simulation approach. *Geomatics, Natural Hazards & Risk*, vol. 13, no. 1, pp. 338-363. http://dx.doi.org/10.1080/19475705.2022.2027528.

MI, Z., WEI, Y.-M., WANG, B., MENG, J., LIU, Z., SHAN, Y., LIU, J. and GUAN, D., 2017. Socioeconomic impact assessment of China's CO2 emissions peak prior to 2030. *Journal of Cleaner Production*, vol. 142, pp. 2227-2236. http://dx.doi.org/10.1016/j.jclepro.2016.11.055.

MILLARD, S.P., 2002. *Environmental Stats for S-Plus®: user's manual for version 2.0*. 2nd ed. New York: Springer. Monte Carlo simulation and risk assessment., cap. 9, pp. 173-174. http://dx.doi.org/10.1007/978-1-4613-0043-4_9.

MITCHELL, L.E., LIN, J.C., BOWLING, D.R., PATAKI, D.E., STRONG, C., SCHAUER, A.J., BARES, R., BUSH, S.E., STEPHENS, B.B., MENDOZA, D., MALLIA, D., HOLLAND, L., GURNEY, K.R. and EHLERINGER, J.R., 2018. Long-term urban carbon dioxide observations reveal spatial and temporal dynamics related to urban characteristics and growth. *Proceedings of the National Academy of Sciences of the United States of America*, vol. 115, no. 12, pp. 2912-2917. http://dx.doi.org/10.1073/pnas.1702393115 PMid:29507190.

MUN, M., CHO, H., KWON, J., KIM, K. and KIM, R., 2017. Investigation of the CO2 sequestration by indirect aqueous carbonation of waste cement. *American Journal of Climate Change*, vol. 6, no. 1, pp. 132-150. http://dx.doi.org/10.4236/ajcc.2017.61008.

NATIONAL DEVELOPMENT AND REFORM COMMISSION OF CHINA, 2022 [viewed 21 December 2022]. *Enhanced actions on climate change: China's intended nationally determined contributions*. Available from:

QADEER, A., SAQIB, Z.A., AJMAL, Z., XING, C., KHALIL, S.K., USMAN, M., HUANG, Y., BASHIR, S., AHMAD, Z., AHMED, S., THEBO, K.H. and LIU, M., 2019. Concentrations, pollution indices and health risk assessment of heavy metals in road dust from two urbanized cities of Pakistan: comparing two sampling methods for heavy metals concentration. *Sustainable Cities and Society*, vol. 53, pp. 101959. https://doi.org/10.1016/j.scs.2019.101959.

RATNA, D.P.A., MALLONGI, A., AMIRUDDIN, R., HATTA, M. and RAUF, A.U., 2023. Hexavalent chromium contamination in groundwater and its implication to human health: a Monte Carlo model approach in Indonesia. *Sustainable Water Resources Management*, vol. 9, no. 1, pp. 22. http://dx.doi.org/10.1007/s40899-022-00806-x.

RAUF, A.U., MALLONGI, A., DAUD, A., HATTA, M., AL-MADHOUN, W., AMIRUDDIN, R., RAHMAN, S.A., WAHYU, A. and ASTUTI, R.D.P., 2021. Community health risk assessment of total suspended particulates near a cement plant in Maros Regency, Indonesia. *Journal of Health & Pollution*, vol. 11, no. 30, pp. 210616. http://dx.doi.org/10.5696/2156-9614-11.30.210616. PMid:34268002.

REN, S., YIN, H. and CHEN, X., 2014. Using LMDI to analyze the decoupling of carbon dioxide emissions by China's manufacturing industry. *Environmental Development*, vol. 9, pp. 61-75. http://dx.doi.org/10.1016/j.envdev.2013.11.003.

REPUBLIK INDONESIA, 2023 [viewed 3 January 2023]. *Komitmen Global dan Aksi Lokal Iklim Indonesia* [online]. Available from: https://www.menlhk.go.id/site/single_post/5211/komitmen-global-dan-aksi-lokal-iklim-indonesia

RODGERS, L., 2018 [viewed 23 December 2022]. *Perubahan iklim: Inilah penghasil emisi CO2 terbesar yang mungkin tak Anda sadari* [online]. Indonesia: BBC. Available from: https://www.bbc.com/indonesia/majalah-46591036

ROSE, A. and CASLER, S., 1996. Input–output structural decomposition analysis: a critical appraisal. *Economic Systems Research*, vol. 8, no. 1, pp. 33-62. http://dx.doi.org/10.1080/09535319600000003.

SHAO, S., ZHANG, X. and ZHAO, X., 2017. Empirical decomposition and peaking pathway of carbon dioxide emissions of China's manufacturing sector-generalized divisia index method and dynamic scenario analysis. *China Ind. Econ.*, vol. 3, pp. 44-63.

THE STATE COUNCIL THE PEOPLE'S REPUBLIC OF CHINA, 2016 [viewed 23 December 2022]. *13th Five-Year Comprehensive Work Plan for Energy Conservation and Emission Reduction* [online]. Beijing: The State Council the People's Republic of China. Available from: https://www.fao.org/faolex/results/details/en/c/LEX-FAOC175032/

UNITED NATION FRAME OF CONVENTION ON CLIMATE CHANGE - UNFCCC, 2019 [viewed 5 January 2023]. *Climate action and support trends* [online]. USA: UNFCCC. Available from: https://unfccc.int/sites/default/files/resource /Climate_Action_Support_Trends_2019.pdf

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY - USEPA. 2002 [viewed 3 January 2023]. *Supplemental guidance for developing soil screening levels for superfund sites, office of emergency and remedial response* [online]. Washington: USEPA. Available from: https://nepis.epa.gov/Exe/ZyPDF.cgi/91003IJK.PDF?Dockey=91003IJK.PDF

XU, Y., XU, K. and HU, Y., 2011. Driving factors and decoupling effect of carbon emissions: evidence from China's. *Research in Statistics*, vol. 28, pp. 55-61.

ZHOU, P. and ANG, B.W., 2008. Decomposition of aggregate CO2 emissions: a production-theoretical approach. *Energy Economics*, vol. 30, no. 3, pp. 1054-1067. http://dx.doi.org/10.1016/j.eneco.2007.10.005.