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Indoor air quality and the resident's health complaints after eruption of Mount Sinabung, Indonesia

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Abstract

The purpose of this study was to measure the concentration of exposure to indoor particulate matter (PM_1, $PM_{2.5}$, PM_{10}), CO_2, RH, and temperature and to evaluate public health complaints due to volcanic ash after the eruption of Mount Sinabung. A correlation analytic was assessed with a cross sectional approach at Payung, Gurukinayan and Perbesi villages from April to July 2021. The level of particles (PM_1, $PM_{2.5}$, PM_{10}), CO_2, temperature and humidity were measured by the AS-LUNG type 0019 instrument, Academia Sinica, Taiwan. Respondents' health complaints were evaluated by interviewing respondents using questionnaires. The Mann Whitney U test was used to analyze the differences levels of particles in the area zone. Multivariate analysis of covariance (MANCOVA) was used to evaluate the effect between the concentrations of particulate matter exposure on respondents' health complaints. The results showed that the mean concentration of exposure to PM_1, $PM_{2.5}$, PM_{10} in Perbesi and Gurukinayan villages was above maximum level required by Indonesia indoor air quality guideline No. 1077 while CO_2 was still below the maximum level required. According bivariate test, there was a significant difference in particle concentration between three villages (p-value = 0.00) and in particle concentration between area zone (p-value = 0.00). The MANCOVA test showed that exposure to PM_1, $PM_{2.5}$, PM_{10}, CO_2, RH, and temperature has an effect on eye complaints (p-value <0.05), exposure to PM_1, $PM_{2.5}$, PM_{10}, and RH (p-value <0.05) has an effect on respiratory complaints, and exposure to PM10 (p-value <0.05) has an effect on skin diseases.

Keyword :
Exposure, particulate matter, health complaints, eruption, ashes

1 Introduction

Mount Sinabung is one of the Stratovolcano Mountains located in Karo Regency, about 25 miles from Lake Toba on Sumatra Island, North Sumatra, Indonesia (Gunawan et al., 2019; Afnimar et al., 2022). Mount Sinabung is one of two active volcanoes, one of which is Mount Sibayak (Tampubolon et al., 2022; Prasetyo et al., 2018). The peak of Mount Sinabung has a height of 2,460 m or about 8071 feet (Program, 2021). Sinabung volcano experienced its first confirmed Holocene eruptions during August and September 2010 (Primulyana et al., 2019). A new eruptive phase began continuing into mid-2018 where the volcano remained calm from September 2013 (Lowenstern et al., 2022). The growth and destruction of the dome resulted in block avalanches, multiple explosions with clumps of ash, and lethal pyroclastic flows during that period. After a lull in activity from September 2018 to April 2019, explosions occurred again during May and June 2019 (Lerner et al., 2022). The frequent eruptions of the Sinabung volcano led to hundreds of block avalanches and dozens of ash-laden explosions reported every month during March to mid-May 2021.

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The status of the mountain is still on alert to this day so that the rise and fall of volcanic activity causes problems for local refugees by evacuating people from their homes to refugee camps (Barclay et al., 2019). This is what causes a very large distribution of ashes in Karo Regency so that it can result in the possibility of high concentrations of dust particles in residential areas which can have a negative impact on public health such as respiratory complaints, so people are advised to wear masks when leaving the house. Each burst of volcanic ash will produce very high concentrations of particulate matter in a very short time and can cause very fine particles to float in the air for quite a long time (Pearson and Brooker, 2020). This can cause health problems for people living in the area around the radius of the volcanic eruption because volcanic ash contains very bad chemical compounds that can threaten humans such as silica dioxide (SiO_2) 54%, aluminum oxide (Al_2O_3) 18.37%, ferri oxide (Fe_2O_3) 18,59%, and potassium oxide (CaO) (Oudin, Carlsen, Forsberg, & Johansson, 2013). In addition, volcanoes generally also emit water vapor (H_2O), carbon dioxide (CO_2), sulfur dioxide (SO_2),hydrochloric acid (HCl), hydrofluoric acid (HF) and others into the atmosphere (Bubach et al., 2020).

Several studies have investigated whether volcanic ash from mountains may increase pollutant concentrations, so that it can affect health, especially the acute respiratory system such as asthma and brief effects of exposure (Zabert et al., 2020). An editorial study also said an increase the number of patients who came to the emergency department during ash fall occurred with respiratory complaints, such as cardiovascular effects, upper and lower respiratory tract, and eye complaints were the most significant to exposure (Mueller et al., 2020). A study from the British West Indies found that concentrations of volcanic ash in the air increase in parts of the island closest to the volcano during the monsoons dry and are at increased risk of mild silicosis disease which is often exposed to high exposure to volcanic ash (Searl et al., 2002). A study found that there is a positive relationship between exposure to volcanic ash from the eruption of Mount Etna in 2002 and the acute health effects on residents of Catania (Lombardo et al., 2013). Other findings also provide evidence that a long duration of exposure to high ambient levels of ash particles inhaled from the volcano adversely affects the respiratory health of children in Montserrat (Forbes et al., 2003).

Due to the thick dust that is visible on the roofs of houses, yards and even terraces of people's houses around Mount Sinabung and research references on health hazards from volcanic eruptions, the objective of this study was to measure the concentration of exposure to indoor particulate matter (PM_1, $PM_{2.5}$, PM_{10}), CO_2, RH, and temperature and to evaluate public health complaints due to volcanic ash after the eruption of Mount Sinabung.

2 Materials and method

2.1 Study design

This study used a cross sectional design to evaluate the air quality measurement in the house by measuring the concentration of particulate matter (PM) and health complaints of its occupants. This research was conducted in Payung, Gurukinayan, and Perbesi Village. Payung and Gurukinayan have a close distance to the red zone and Perbesi is far from the red zone. This research was conducted from April to July 2021. The research population was the total number of households residing in Perbesi, Payung and Gurukinayan Village that have been exposed to Mount Sinabung ashes. The total sample in this study was 60 households, including 25 houses from Payung, 25 houses from Perbesi and 10 houses from Gurukinayan (many of whom fled from the village). The sampling technique was purposive sampling by measuring the concentration of particles in the house.

2.2 Air quality measurement

Indoor air quality was measured with direct reading instrument (AS-LUNG type 0019, Academia Sinica Taiwan) to measure the concentration of dust particles (PM_1, $PM_{2.5}$, PM_{10}), CO_2, temperature, and humidity. The instrument was set and calibrated to record the total exposure to dust particles. Parameter measurement takes 10 minutes in one house then the results of the instrument measurements can be downloaded after finish conducting the samples. The results of environmental parameter were reported as median, interquartile and ranges. Other characteristics of the building, type of ventilation, and use of pesticides in the house were carried out by questionnaire interviews.

2.3 Data collection

Data was collected by interviewing residents using a questionnaire about demographic data, job characteristics, health complaints, and previous respondents' medical history. The contents of the questionnaire were quoted from previous research and translated into Indonesia language (Tarigan et al., 2017). Interviews and filling out questionnaire sheets were carried out by researchers along with measurements of particles exposure in residents' house.

2.4 Data categorization

The measurement of particulate matter concentration in the air was expressed in units of g/m^3. According to the guidelines for indoor air quality (Indonesia, 2011), the quality standard for exposure to dust particles for $PM_{2.5}$ should be $<35\mu g/m^3$ while for PM_{10} should be $<70\mu g/m^3$ in 24 h. If the average measurement of the dust particles concentration in the house is above the values of 35 g/m_3 and 70 g/m^3, then the indoor air quality is above the required limit.

Health complaints that occurred due to the eruption of Mount Sinabung felt by the community can be evaluated from symptoms of eye disease, symptoms of respiratory disease, symptoms of skin diseases measured ordinals with the categories never (0%), rarely (1-25%), sometimes (26-50%), often (51-75%), always (76-100%). Multivariate analysis calculated the percentage (%) of residents who experienced health symptoms from ordinal data. Symptoms of health complaints were divided into the presence of complaints or no complaints. Respondent complaints were defined when the percentage of health symptoms reached >26%, while no respondent complaints were defined when the number of health symptom presentations was <25%.

2.5 Statistical analysis

Microsoft Excel and SPSS (Version 20) were used for data processing and statistical analysis. Univariate analysis was intended to determine the frequency distribution of each dependent variable and independent variable. Prior to the analysis, data was tested whether the data were normally distributed or not. If the results of the normality statistical test get a p-value≤0.05, the variable data is not normally distributed and vice versa p-value ≥0.05, then the variable data is normally distributed. Bivariate analysis with Kruskal Wallis was used to analyze differences in dust particle concentrations between villages and Mann Whitney U test was used to analyze differences in dust particle concentrations between risk zones. Multivariate analysis of covariance (MANCOVA) was used to evaluate the health impact of respondents on exposure to dust particles. An interchangeable covariance model was used to adjust the correlation between respondents. P value < 0.05 was considered statistically significant.

This research has been approved by the Review Board of the Health Research Ethics Committee of Prima Indonesia University with No.012/KEPK/UNPRI/I/2021. All respondents received informed consent about the study prior to conducting interviews.

3 Results and discussion

3.1 Risk zone

The environmental parameters were measured for 2 days, on May 14th and 15th, 2021. Meanwhile, the air measurements were carried out starting at 9 am to 5 pm. From Table 1, it can be seen that Payung and Gurukinayan are villages in the red zone of the eruption of Mount Sinabung, while Perbesi is a safe zone from the eruption of Mount Sinabung. The total samples of the particles in the air at the time of the study were from 60 houses; 25 samples were from 25 houses in Payung and Perbesi Villages, while only 10 samples were from 10 houses in Gurukinayan as many houses had been deserted.

Table 1 Number of samples and regional overview

Avenue	Number of samples	Area (km^2)	Risk zone	Sampling date
Payung	25	8.80	Red zone	14 Mei 2021
Gurukinayan	10	11.30	Red zone	14 Mei 2021
Perbesi	25	17	Safe zone	15 Mei 2021

Table 2 shows that the majority of the respondents were female (66.7%), the category of body mass index was normal (56.7%), the education level was high school (48.3%), and the occupations were majorly farmers (63.3%). In addition to this, it was also obtained that most of the farmers planted and grew maize and tangerine.

Table 2 Frequency distribution of respondents characteristics (n=60)

Respondents Characteristics	Frequency	Percentage (%)
Gender		
Male	20	33,3
Female	40	66,7
Body Mass Index		
Underweight	2	3,3
Normal	34	56,7
Overweight	19	31,7
Obese	5	8,3
Education		
Uneducated	3	5,0
Primary school	5	8,3
Secondary school	14	23,3
High school	29	48,3
University	9	15,0
Occupation		
Farmer	38	63,3
Government Officer	3	5,0
Employee	2	3,3
Others	17	28,3

3.2 Overview of particulate matter

The exposure concentration to PM_1, $PM_{2.5}$, PM_{10}, and CO_2 in Gurukinayan and Perbesi was greater than the threshold limit values according to the Indonesia indoor air quality guideline number 1077/Menkes/PER/V/2011, while Payung was still at a safe level. The concentration of the particle exposure in Perbesi, which is far from the location of the eruption, was higher than that in Payung and Gurukinayan Villages, which are in the red zones. It shows that the concentration of particulate matter in the safe zone had higher concentrations of PM_1, $PM_{2.5}$, PM_{10}, and CO_2 compared to that in the red zone. The results from Kruskal Wallis test found a significant difference in exposure to particulate matter due to volcanic ash from Mount Sinabung among the three villages in Karo Regency (p-value = 0.00). Meanwhile, in terms of risk zones, the results from Mann Whitney test showed that there was a significant difference in the concentrations of particulate matter exposure in Karo Regency (p-value = 0.00).

Table 3 Comparison of particulate matter by village and risk zones after the eruption of Mount Sinabung (Data presented is mean (standard deviation), *Kruskal Wallis test, **Man Whitney Test)

Parameters/ Village	Payung	Gurukinayan (n=10)	Perbesi (n=25)	P-value*	P-value**
PM_1 ($\mu g/m^3$)	16.34 (22.50)	46 (38.23)	103.28 (67.66)	.00	.00
$PM_{2.5}$ ($\mu g/m^3$)	24.09 (34.19)	151.11 (307.49)	185.03 (158.22)	.00	.00
PM_{10} ($\mu g/m^3$)	28.68 (40.72)	322.35 (803.80)	235.31 (216.74)	.00	.00
CO_2 (ppm)	428.80 (41.48)	427.90 (28.26)	483.77 (23.28)	.00	.00
Temperature (°C)	30.20 (0.62)	28.03 (1.44)	29.12 (0.65)	.00	.01
RH (%)	51.53 (3.01)	55.6 (4.4)	61.51 (1.95)	.00	.00

Table 4 showed that there was a relationship between exposure to PM_1, $PM_{2.5}$, PM_{10}, and CO_2, temperature, and humidity (p-value <0.05) with eye health complaints after the eruption of Mount Sinabung. The regression coefficient of determination shows a value of 0.477, which means that the PM_1 variable is able to explain variations in eye health complaints by 47.7%. The regression coefficient of determination shows a value of 0.407, which means that the $PM_{2.5}$ variable is able to explain variations in eye health complaints by 40.7%. The regression coefficient of determination shows a value of 0.383, which means that the PM10 variable is able to explain variations in eye health complaints to the residents after eruption in Karo Regency by 38.3% and so for the next variable.

The results in Table 4 also showed that there was a relationship between exposure to PM_1, $PM_{2.5}$, PM_{10}, CO_2, and humidity (p-value <0.05) with respiratory health complaints after the eruption of Mount Sinabung. The regression coefficient of determination shows a value of 0.152, which means that the PM_1 variable is able to explain variations in respiratory health complaints after eruption by 15.2%. The regression coefficient of determination shows a value of 0.144, which means that the $PM_{2.5}$ variable is able to explain the variation of respiratory health complaints after eruption by 14.4%. The regression coefficient of determination shows a value of 0.133, which means that the PM10 variable is able to explain variations in respiratory health complaints to the residents after eruption in Karo Regency by 13.3% and so for the next variable.

Table 4 Relationship of particulate matter exposure to health complaints after the eruption of Mounts Sinabung

Parameters	Eyes complaints		
	R^2	**F**	**p-value**
PM_1	.477	52.949	.000
$PM_{2.5}$	.407	39.769	.000
PM_{10}	.383	35.982	.000
CO_2	.258	20.190	.000
Temp	.097	6.216	.016
RH	.315	3.165	.000
Parameters	**Respiratory complaints**		
	R^2	**F**	**p-value**
PM_1	.152	10.413	.002
$PM_{2.5}$	.144	9.779	.003
PM_{10}	.133	8.908	.004
CO_2	.078	4.911	.031
Temp	.011	.629	.431
RH	.097	6.231	.015
Parameters	**Skin complaints**		
	R^2	**F**	**p-value**
PM_1	.090	5.763	.020
$PM_{2.5}$	.063	3.867	.054
PM_{10}	.054	3.341	.073
CO_2	.075	4.725	.034
Temp	.035	2.134	.149
RH	.052	3.165	.080

The table above also shows that there was a relationship between PM_1 and CO_2 exposure (p-value <0.05) with skin health complaints after the eruption of Mount Sinabung. The regression coefficient of determination shows a value of 0.090 which means that the PM_1 variable is able to explain variations in skin health complaints after eruption by 9% and the regression determination coefficient shows a value of 0.075 which means that the CO_2 variable is able to explain variations in skin health complaints to the residents after eruption in Karo Regency by 7.5%.

Based on the results of the General Linear Model (GLM) test in Table 5, it can be seen that there was an effect of exposure to PM_1, $PM_{2.5}$, and PM_{10} on eye health complaints (b= 0.054, b= 0.143, b=

-0.113.), there was an effect of exposure to $PM_{2.5}$ and PM_{10} on respiratory health complaints (b=-0.190 and b=0.133), and there was an effect of exposure to $PM_{2.5}$ and PM_{10} on skin health complaints (b=-0.161 and b=-0.116) after the eruption of Mount Sinabung to the community.

Table 5 Effect of particulate matter exposure on eye complaints, respiratory complaints, and skin complaints after the eruption of Mount Sinabung

parameters	eyes complaints	
	b	*p-value*
constanta	7.991	.000
PM_1	.054	.022
$PM_{2.5}$	.143	.008
PM_{10}	-.113	.002
parameters	**respiratory complaints**	
	b	***p-value***
constanta	18.705	.000
$PM_{2.5}$	-.190	.011
PM_{10}	.133	.017
parameters	**skin complaints**	
constanta	7.521	.000
$PM_{2.5}$	.161	.008
PM_{10}	-.116	.010

This study showed that indoor air exposure to dust particles after the eruption of Mount Sinabung was above the required threshold value according to indonesia indoor air sanitation and who indoor air quality guideline. The $PM_{2.5}$ concentrations with a 24-hour average measurement should not exceed a value of $35\mu/m^3$ and the concentration of PM_{10} with a 24-hour average measurement should not exceed a value of $70\mu g/m^3$. The results showed that the concentration of PM_{10} in gurukinayan village was $322\mu g/m^3$ compared to Payung Village which was only $28\mu g/m^3$. The concentration of $PM_{2.5}$ exposure in Gurukinayan ($151\mu g/m^3$) and Perbesi ($185\mu g/m^3$) were much higher than Payung Village which was only $24\mu g/m^3$. In Perbesi Village, PM_1 exposure concentration was four times higher ($103\mu g/m^3$) compared to Payung Village (16 g/m^3). This means that the concentration of dust particle exposure in Perbesi Village has a much higher level than other villages. It can be seen that the concentration of exposure to PM_1 was above the concentration of exposure to $PM_{2.5}$ according to guidelines for indoor air sanitation.

There was no set threshold value for PM_1 exposure in indonesia, so we compared it with $PM_{2.5}$ concentrations because previous researchers have found that high concentrations of $PM_{2.5}$ in the room can cause very bad respiratory effects for humans, as well as on the other hand, with high concentrations of PM_1 in the room, because PM_1 has a very small diameter, it can even be smaller than <1 micron (blanco-becerra et al., 2014; lau and he, 2017; lombardo et al., 2013). This study was in line with research conducted in the united states on volcanic eruptions from mount kilauea that the levels of ambient and indoor dust particles due to volcanic ash pollution are above the required threshold value from the who recommendations for indoor air quality guidelines (longo, 2009). Research conducted in iceland also stated that the main particle concern is the potential for future icelandic volcanic eruptions to produce fine volcanic ash that is very easily inhaled and can increase the ambient concentration of particulate matter in the air (damby et al., 2017). A study conducted in two patagonian cities also found that a significant increase in the perception of volcanic ash exposure was reported 14% in Bariloche City vs. 6% in cipolletti city ($p<0.05$) (zabert et al., 2020).

The results of this study found that among three villages produced CO_2 gas concentration value in the room which was below the threshold value according to Indonesia indoor air quality guideline, which was 1000 ppm in 8 h. The results of this study were not in line with research conducted in Portugal on the dangers of indoor CO_2 gas in volcanic environments, that the lethal concentration of indoor CO_2 gas is higher than the vol% measured in each shelter in Furnas Village, an area close to the eruption of mount furnas. Danger levels of CO_2 concentrations are detected not only underground floor but also on the ground floor (viveiros et al., 2016). Research on the Japanese Island of Miyakejima found that the eruption of Mount Oyama increased the concentration of SO_2 gas measured at 6 monitoring stations annually from 2006-2011 and consequently increased the prevalence of symptoms of cough, throat irritation, runny nose, and eye irritation even though the adult population on miyakejima island did not show a decrease in lung function at SO_2 levels (kochi et al., 2017). The low concentration of CO_2 gas in the resident's homes may be due to the very short air quality measurement, which was about 10 minutes per house and the instrument used was not a specific tool for measuring CO_2 gas alone.

The particulate concentrations among three places were also different which is higher at Perbesi. Perbesi Village is far from the eruption but resulting very high particulate. this may be due to wind, weather conditions and humidity (pering, 2010). In addition, the factors that influence the distribution of volcanic ash include wind, humidity, weather conditions, and deposition. wind parameters that affect the distribution of volcanic ash are wind speed and direction (poulidis et al., 2018). The distribution of volcanic ash can also is affected by humidity conditions during an eruption. according to the study, humidity plays an important role in the deposition of volcanic ash in the air. low humidity conditions can cause the range of volcanic ash to be closer to the mountain or it can be said that the deposition of volcanic ash will occur around the mountain. however, humid environmental conditions especially in the tropics, condensation of water vapor retained in the eruption plume is expected to increase convection, increasing the height of the eruption column to several kilometers above dry air altitude.

This study shows that there was a relationship among exposure to indoor PM_1 , $PM_{2.5}$, PM_{10}, CO_2 , temperature, and humidity (p-value <0.05) with eye health complaints such as red, watery and itchy eyes due to irritation after the eruption. This study also showed that there was a relationship among exposure to PM_1 , $PM_{2.5}$, PM_{10}, CO_2 , and humidity (p-value <0.05) with respiratory health complaints such as cough, shortness of breath and dry throat after the eruption. there was significant relationship among the concentration of PM_1 and CO_2 and skin health complaints such as red, itchy and dry skin on the occupants of the house after the eruption of Mount Sinabung. This study is in line with research conducted in uruguay on exposure to dust particles after the volcanic eruption of Mount Puyehue found that every 10 mg/m^3 increase in PM_{10} exposure to volcanic ash during the third trimester in pregnant women living near the mountain was associated with a higher likelihood of premature birth (balsa et al., 2016).

This study is also in line with the previous research that there was a significant relationship between exposure to volcanic ash and cough, dry throat, rhinorrhea, congestion, wheezing, eye irritation, and bronchitis diagnosed and thirty-five percent of informants feel that their health is affected by the eruption, especially in smokers and those suffering from chronic respiratory diseases (longo, 2009). Research conducted by tam resulted in different concentrations of SO_2 , $PM_{2.5}$ and acid particles in four different ash measurement areas during the eruption of mount kilauea and epidemiologically, chronic exposure to acid particles was significantly associated with increased coughing and possibly decreased lung function in school-age children on the island of hawaii, but not significantly in asthma or bronchitis (tam et al., 2016). A study conducted in the azores archipelago, an area of active volcanoes located in the atlantic ocean, found that there was an association of volcanic air pollution with respiratory disease, retrostitis, and obstructive defects (copd) in humans living in volcanically active areas (linhares et al., 2015).

This study has several research limitations. First, the number of samples studied in each village is very small from the existing population because many people are still in the evacuation area, especially the residents of Gurukinayan Village. Therefore, we only evaluated the impact of indoor dust pollution on as many as 60 inhabited houses on the health of the population thus limiting the generalizability of our results. However, the adverse effects of exposure to volcanic ash particles on post-eruption respiratory, eye and skin health are very clear. second, we used self-reported questionnaires to evaluate community-perceived environmental and health parameters. thus, bias and social pressure may have resulted in symptoms of misclassification or underreporting. Finally, the measurement time for indoor air particles in this study was very short, around 10 minutes in each houses, so it is not very valid for the amount of concentration produced for the standard threshold value according to the minister of health of the Republic of Indonesia number 1077/MENKES/PER/V/2011 about indoor air quality, which is 8 h or 24 h of measurement. Therefore, further research should be carried out longitudinally on the exposure to volcanic ash particles and the health risks in large groups.

4 Conclusion

The aim of this study was to measure exposure consentrations of indoor particulate matter (PM_1, $PM_{2,5}$ and PM_{10}), CO_2, RH, and temperature and to evaluate public health complaints due to volcanic ash after the eruption of Mount Sinabung. Exposure concentrations of PM_1, $PM_{2,5}$ and PM_{10} in Gurukinayan and Perbesi were above the required threshold value by the Minister of Health of the Republic of Indonesia regulation number 1077/MENKES/PER/V/2011 concerning guidelines for indoor air sanitation, while in Payung was still at a safe level. There was a significant difference in the concentration of particulate matter exposure among three villages, and in the concentration of particulate matter exposure between the risk zones after the eruption of Mount Sinabung. There was an effect of exposure to particulate matter from volcanic ash in the house on eye complaints, respiratory complaints, and skin complaints to the residential after the eruption. Thus, people are required to take precautions by wearing masks when leaving the house and always cleaning the dust from the eruption of Mount Sinabung inside their homes every day and increasing air exchange by opening adequate ventilation when there is no eruption. People who are living in the red zone must also evacuate to a safer place so that they are not to be affected worse. Further studies are also needed to further evaluate the health effects of the population in large longitudinal cohorts.

Declaration of competing interest

The authors declare no known competing interests that could have influenced the work reported in this paper.

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