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Models of the Effects of Ultraviolet Exposure, Temperature, and Humidity on the Quantity of Microplastics in Indoor Air

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ABSTRACT

Microplastics are a new pollutant in the air, but the determination of the maximum limit of their existence has not been set in regulations. Microplastics found in the air of building spaces are made from plastic waste. The presence of microplastics in the air is influenced by physical environmental factors. Inhaling microplastics can have a detrimental impact on lung tissue. The research aims to create a mathematical model of the effect of ultraviolet exposure, temperature, and humidity on the quantity of microplastics in indoor air. Mathematical models can be used to predict the quantity of microplastics in the air. The type of research is a true experiment with a posttest-only control group design. Air samples are taken daily for 60 days by the passive method by taking dustfall. The parameters measured include the quantity of microplastics, ultraviolet intensity, temperature, and air humidity. Microplastic examination by visual method using a 40-fold magnification binocular microscope. Analysis of the mathematical model of the effect of ultraviolet exposure, temperature, and humidity on the quantity of microplastics in the form of time series data using linear regression. The results of data analysis show that the effect of the panel regression estimation model, in accordance with the empirical data, is the Fixed Effect Model (FEM). The conclusion based on the results of the study shows that physical environmental factors have an influence on the quantity of microplastics in the air, whose existence can be predicted using FEM modeling that has been made.

Keywords: Modeling; predictors; microplastics; air.

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INTRODUCTION

The annual manufacturing of plastics keeps rising. Global plastic manufacturing surpassed 330 million tons in 2013. In the next 50 years, there will likely be a 100-fold rise in the manufacture of plastic. This is consistent with the growing amount of plastic garbage being used. Plastic trash growth is strongly correlated with rising plastic consumption. Up to 10% of garbage made of plastic comes from human activity(1). One polymer that is hard for the environment to break down is plastic. The 3R program, which stands for reduce, reuse, and recycle, is used to manage plastic trash(2). Polyethylene, polypropylene, polyvinyl chloride, polyethylene terephthalate, polyurethane, and polystyrene are the plastic materials that produce the greatest garbage. The nature of plastic makes it difficult for the environment to break it down, which leads to an accumulation of plastic garbage(3).

Polymeric materials, such as plastic, are created at specific temperatures and pressures. Three categories make up the classification of plastics: elastomers, thermosets, and thermoplastics (4). When plastic is exposed to external stimuli, it can decompose into smaller pieces. Environmental elements such as temperature, humidity, UV light, air pressure, friction, oxidation, hydrolysis, and microbe activity can all have an impact on how big plastic particles get(5). Changes in the size of plastics into particles measuring 0,1 µm-5 mm are called microplastics. Since there isn't a common term for microplastics worldwide, they are occasionally referred to as fragment beads, spherule films, microbeads, and microfibres(4,6). Among the new contaminants in the environment is the existence of microplastics. Microplastics can be found in soil, wastewater, food, air, water, and drinking water (7).

The breakdown and fragmentation of plastic polymers results in the formation of microplastics. Plastics break down and fragment due to mechanical, chemical, and biological factors. Primary and secondary microplastics are the two types of sources of microplastic pollution. Primary microplastics, such as granules for cosmetics, medications, and facial exfoliation, are purposefully created to be beneficial to people. Secondary microplastics are produced when polymers naturally break down into tiny particles. Microplastics are often categorized based on their morphological characteristics, which include dimensions, hue, and form. One aspect that determines the extent of detrimental impacts on organisms is size morphology. Microplastics have the capacity to release chemicals rapidly due to their huge surface area to volume ratio(4).

In many nations and continents, it has been discovered that both indoor and outdoor air contains microplastics. The air of Paris, France, was discovered to contain microplastics, ranging in size from 1 to 60 particles per square meter(8). The quantity of microplastics in the air in houses in the city of Sydney, Australia is 22-6169 particles/m^2/day(9). Microplastics as many as 3,82 particles/m^3 were found in the air of office buildings in Surabaya, Indonesia(10). In the Chinese city of Shanghai, microplastics were found as much as 1,2-11,48 N/m^3(11). Apart from the influence of environmental factors, the presence of microplastics in indoor air is also determined by several factors, including the use of plastic furniture and residential density(8), the activities of building occupants(10), and room ventilation(11).

Attention should be paid to airborne microplastic contamination. Human exposure to microplastics is thought to have detrimental effects on health, particularly on the respiratory system. Thirty-three microplastic particles in polyethylene (PE) and polyprophylene (PP) smaller than 5.5 microns were detected in human lung tissue. Out of the 20 tissue samples, the microplastics were discovered in 13 lung tissue samples(12). When microplastics enter the respiratory system, lung tissue will be harmed and function will be compromised. It is necessary to estimate the relationship between the use of plastic waste-based structures and the airborne presence of microplastics, taking into account a variety of environmental conditions. This is why using structures made of plastic trash requires careful thought and evaluation of how it may affect locals' health.

METHOD

The research was conducted in Banyumas Regency, Central Java Province, Indonesia. This study uses a control group that is only used for the posttest and is an example of a real experiment. Temperature, air humidity, and UV light intensity were the study's independent variable. The amount of microplastics in space air is the dependent variable. The weight of plastic garbage and the building's volume served as the study's control variables. This research has been ethical approval with ethical number No. 994/EA/F.XXIII.38/2024 issued by Health Research Ethics Commitee Ministry of Health Semarang Health Polytechnic. For 60 days, samples of microplastic are collected every day. Dust falls were sampled once every twenty-four hours. Samples of the dust fall were collected at the base of a 1 m^3 model of a structure constructed entirely of plastic garbage. Placing bricks and paving blocks produced from recycled plastic trash together creates the small building. The leftover plastic is shredded and combined with sand and cement to make bricks and paving blocks. The ratio of volume 1 cement to 2 sand to 3 plastic waste is used to make bricks and paving block. For a full day, little structures constructed from plastic trash are subjected to UV light. The dust fall sampling was done actively with a vacuum equipped with a 0.3 µm HEPA filter. Following the vacuum cleaner sample collection, a liter of aquades is used to rinse the HEPA filter until it is clean. Next, 90 cm diameter, 2.5 µm pore Whatman filter paper is used to filter the water from the HEPA filter rinse. A binocular microscope with a 100-fold magnification was then utilized to examine the Whatman filter that had been used for filtering. Calculate the particle of microplastics in the filter paper. The visual method, which involves examining microplastics under a microscope, is another name for it. Temperature and air humidity measurements were carried out using a thermohygrometer with a temperature unit of °C while humidity with a unit of %. UV intensity is measured using a UV meter with $mwatt/cm^2$ units.

Analysis utilizing linear regression to determine how temperature, UV intensity, and air humidity affect the amount of microplastics in the air. The goal of the regression analysis is to create a model that illustrates how temperature, humidity, and UV intensity relate to the amount of microplastics. This study used two cross sections, namely the treatment and control groups, and 60 time series of longitudinal data. Regression analysis starts with estimating the longitudinal data regression model and moves on to traditional assumption testing. Conducting a regression model feasibility test with the F, T, and determination coefficients is the final step. The Common Effect Model (CEM) and Fixed Effect Model (FEM) models are used in the data regression model estimation. Chow test is used for model effect testing. Multicollinearity, normality, and heterokedasticity assumptions were made in order to conduct the classical assumption test. The Jarque Bera test provides insight into the normalcy assumption test. The Glejser Test is used to test the assumptions of heterokedasticity.

RESULT

Microplastic levels, ultraviolet intensity, temperature, and humidity in the air

The measurement of microplastic, ultraviolet, temperature, and air humidity levels was carried out for 60 days described in the table 1

Table 1. Results of measurements of microplastic levels, ultraviolet intensity, temperature, and air humidity for 60 days in the air of buildings made from plastic waste

Sample		MPs Levels (particle/m^3/day)	UV (mwatt/cm^2)	Temperature (°C)	Humidity (%)
Treatment	Mean±SD	38,78±9,78	0,32±0,15	25,86±0,91	73,23±6,63
	Minimum	26	0,20	23,80	58
	Maximum	72	1	27,70	83
Control	Mean±SD	22±3,99	0,02±0,02	25,29±1,05	72,98±6,11
	Minimum	11	0,01	22,10	59
	Maximum	28	0,07	27,50	83

Source: Primary Data, 2024

Based on table 1, it shows that the level of microplastics in the control is lower than in the treatment. The humidity temperature, and ultraviolet intensity of the two samples did not differ significantly, as the two samples were located in adjacent locations.

The influence of temperature, humidity, and ultraviolet on the levels of microplastics in the air was analyzed using linear regression shown in table 2. Uji normalitas data menggunakan uji Kolmogorov Smirnov diperoleh nilai signifikansi 0,200 > α 0,05

Table 2. Analysis of the influence of temperature, humidity, and ultraviolet on the levels of microplastics in the air of buildings based on plastic waste

Variable	B	Sig (2-tailed)
UV	45,157	0,001
Temperature	-0,236	0,399
Humidity	-0,154	0,001

Based on table 5, it is explained that humidity and ultraviolet intensity affect the level of microplastics in the air of buildings made from plastic waste. Air temperature does not significantly affect the level of microplastics in the air.

Selection of regression models

The following table shows the results of the chow test that was used to identify the independent effects in the regression estimation model for longitudinal data:

Table 4. Chow test results of the effect of ultraviolet exposure, temperature, and humidity on the quantity of microplastics in the air of buildings made from plastic waste

Effects Test	Statistic	d.f.	Prob.
Cross-section F	14.450926	(1,115)	0.0002
Cross-section Chi-square	14.204367	1	0.0002

The outcome is that the Chi-Square statistic is 40.843644 with a p-value of 0.0426, as seen in the above table. H0 was discarded because the test findings revealed a p-value < level of significance (α=5%). Consequently, the Fixed Effect Model (FEM) is the result of the panel regression estimation model that matches the empirical data.

Classical Assumption Test

It was carried out through tests of multicollinearity assumptions, normality assumptions, and heteroscedasticity assumptions

Assumption of Multicollinearity

The results of the correlation test can be seen in the following table:

Table 5. Results of the correlation test on the effect of ultraviolet exposure, temperature, and humidity on the quantity of microplastics in the air of buildings made from plastic waste

Variable	Temperature	Humidity	UV
Temperature	1	-0.04287	0.17279
Humidity	-0.04287	1	-0.01378
UV	0.17279	-0.01378	1

It is evident from the data in Table 5 that all associations involving independent variables result in a correlation value less than 0,99. Therefore, there are no signs of multicollinearity in the regression model that was created. in order to satisfy the multicollinearity assumption.

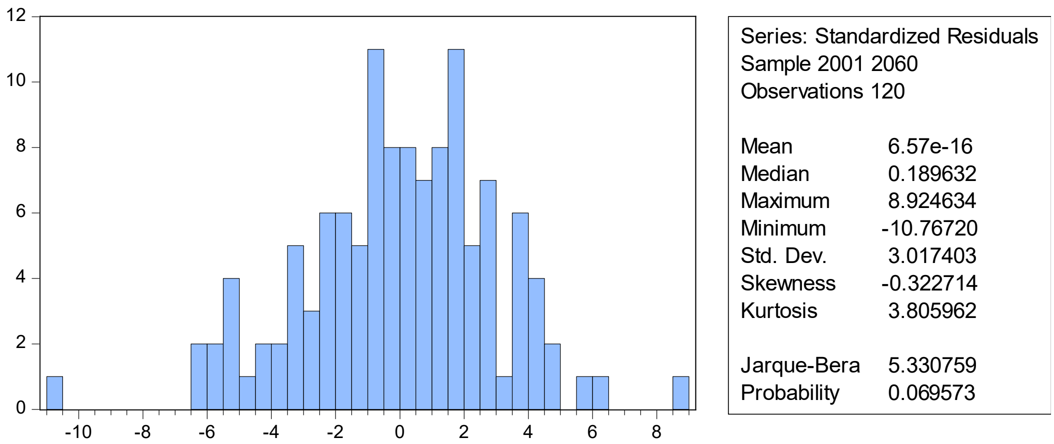

Figure 1. Results of Testing Assumptions of Normality Through Jarque Bera Effect of Ultraviolet Exposure, Temperature, and Humidity on the Quantity of Microplastics in the Air

Assumptions of Normality

The following graphic displays the findings of the normalcy assumption test using the Bera-Jarque: The normality assumption test produced a Jarque-Bera statistic of 5,330759 with a p-value of 0,069573, based on the results shown in the preceding figure. Results indicate that the p-value is greater than the significance level (α=5%). As a result, it is determined that the residual is regularly distributed. Shows in Figure 1.

Asumsi Heteroskedastisitas

The following table displays the findings of the Glejser Test-based heterokedasticity assumption test:

Table 6. Test results of the heteroskedasticity assumption of the effect of ultraviolet exposure, temperature, and humidity on the quantity of microplastics in the air of buildings made from plastic waste

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	4.638209	4.746387	0.977208	0.3305
Temperature	-0.127632	0.164803	-0.774453	0.4403
Humidity	0.007020	0.025333	0.277104	0.7822
UV	1.408295	1.233591	1.141623	0.2560

The results of the heteroscedasticity assumption test showed that all independent variables produced p-values> *levels of significance* (α=0.05). Thus, the assumption of heteroscedasticity is fulfilled.

Best Regression Model Estimation

The following table displays the findings from applying the Fixed Effect Model (FEM) to investigate the effects of temperature, humidity, and UV on microplastic quantras.

Table 7. Test results of the influence of temperature, humidity, and ultraviolet Against the quantity of microplastics in the air of buildings made from plastic waste

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	28.61857	7.853766	3.643929	0.0004
Temperature	0.024911	0.272696	0.091349	0.9274
Humidity	-0.142658	0.041918	-3.403285	0.0009
UV	51.63173	2.041202	25.29477	0.0000
Fixed Effects (Cross)				
_Control—C	1.898089			
_Treatment—C	-1.898089			
Effects Specification				
Cross-section fixed (dummy variables)				
R-squared	0.935980	Mean dependent var		30.39167
Adjusted R-squared	0.933753	S.D. dependent var		11.24016
S.E. of regression	2.893038	Akaike info criterion		5.003265
Sum squared resid	962.5122	Schwarz criterion		5.119411
Log likelihood	-295.1959	Hannan-Quinn criterion.		5.050433
F-statistic	420.3295	Durbin-Watson stat		2.306417
Prob(F-statistic)	0.000000			

The regression equations from the results of the regression analysis estimation using *the Fixed Effect Model* (FEM) for each group are:

Microplastic_Control = 1.898089 + 28.61857 + 0.024911*Temperature_Control - 0.142658*Humidity_ Control + 51.63173*UV_ Control

Microplastic_Treatment = -1.898089 + 28.61857 + 0.024911* Temperature_Treatment - 0.142658* Humidity_Treatment + 51.63173*UV_ Treatment

There are two regression equations for two groups, namely the control group and the treatment. The same coefficients for both groups showed that the influence of independent variables on microplastics was assumed to be consistent between the control and treatment groups, but the initial values differed due to the fixed effect. The temperature coefficient of +0.024911 means that for every 1 °C increase in temperature then the microplastic content increases by 0.024911 particles assuming other variables are constant. The moisture coefficient of -0.142658 means that for every 1% increase in humidity the microplastic content decreases by 0.142658 particles. The ultraviolet coefficient of +51.63173 means that for every 1 mwatt/cm2 increase in ultraviolet microplastic levels, the microplastic content increases by 51.63173 particles. The fixed effects of each group showed an average difference between the control group and the treatment that was not explained by the other variables. The fixed effect of the control group was -1.898089 and the treatment group of +1.898089 meant that there was a fundamental difference in the microplastic levels between the two groups even though the other variables were the same. There was a fixed effect between the control and treatment groups, as shown by the difference in constant values.

Coefficient of Determination

The contribution of temperature, humidity, and UV influences to microplastic levels can be determined by the determination coefficient (R2) of 0,935980 or 93,5980%. This indicates that a very high temperature, humidity, and UV of 93,5980% can account for 93,598 percent of the variance in the microplastic content data; the remaining 93,598 percent can be attributed to the contribution of other independent factors not covered in this study.

Simultaneous Hypothesis Testing

Simultaneous hypothesis testing results in a value of Fcal = 420,3295 with *a p value* of 0,00000. The test results showed *p value* < *level of significance* (α=5%). This means that there is a significant simultaneous effect of temperature, humidity, and UV on microplastic levels.

Testing Partial Hypothesis

The results of the partial test of each independent variable are as follows:

1. Test on the effect of temperature on the quantity of microplastics

   Testing the hypothesis of the influence of temperature variables resulted in a calculated t value of 0,091349 with *a p value* of 0,9274. The test results showed a *p value* (0,9274) > *level of significance* (α=5%), which means that there was no significant influence of temperature on microplastic levels.
2. Test on the effect of moisture on the quantity of microplastics

Testing the humidity effect hypothesis resulted in a calculated t value of -3,403285 with *a p value* of 0,0009. The test results showed a *p value* (0,0009) < *level of significance* (α=5%), which means that there is a significant influence of moisture on microplastic levels. When viewed from the β2 regression coefficient in the humidity variable with a negative value of -0,142658, it indicates that humidity has a negative effect on microplastic levels. This means that the higher the humidity, the lower the microplastic levels.

3. Test of the effect of UV on the quantity of microplastics

   Testing the UV influence hypothesis produced a t-value of -25,29477 with *a p-value* of 0,0000. The test results showed a *p value* (0,0000) < *level of significance* (α=5%), which means that there is a significant influence of UV on microplastic levels. When viewed from the β3 regression coefficient in the UV variable with a positive value of 51,63173, it indicates that UV has a positive effect on microplastic levels. This means that the higher the UV, the higher the microplastic levels.

DISCUSSION

Microplastic particles can come from various sources, including plastic degradation, synthetic fibers from clothing, dust, and debris from damaged plastic products (13–15). Previous research has shown the presence of microplastics in the air, both indoors and outdoors (8,16). Microplastics in the air are found mainly in urban areas close to pollution sources such as traffic-congested highways and the textile industry (17). Factors that affect the presence of microplastics in the air include emission sources, human activities, environmental factors, population density, geographical and topographic factors, weathering rates and plastic degradation. Environmental factors are the main factors in the formation and spread of microplastics in the air (18).

This study demonstrates that temperature, humidity, and UV light are environmental factors that affect the amount of microplastics in the air. In accordance with study by Susanto et al., which revealed that a month's worth of exposure to UV light can cause polymer bonds to split, resulting in physical changes in the polymer such as surface fractures. The amount of cracks in the plastic polymer will rise with the length of time it is exposed to UV light. Plastic flakes turn into microplastics as a result of increased polymer surface breaking. Apart from UV exposure, other physical elements like temperature and humidity also play a role in the development of microplastics(19).

In this study, the microplastics in the air of buildings made from plastic waste found were ≥2.5 μm in size for 60 days. Microplastics in the air have also been identified in the air of space in various cities and countries. The presence of microplastics was identified in the apartment space of the city of Paris, France(8), in the air of the city of Sydney, Australia(9), in the air of homes and offices in the city of Shanghai, China(11), in the air of the office building of the city of Surabaya, Indonesia(10). The presence of microplastics in the air in the space is influenced by several factors, including the use of plastic furniture, the activities of building occupants, residential solids, and the presence of air ventilation(8–11).

The people who occupy the building will be at risk of inhaling microplastics due to their presence in the air. Inhalation exposure to microplastics causes buildup in the respiratory system. The size of the inhaled microplastic particles determines how much microplastic accumulates in lung tissue. Particles ranging in size from 0.1 to 10 µm have the potential to harm lung tissue. Microplastics less than 5 µm are likely to land on the nose, nasopharynx, trachea, and bronchial branches. During respiration, microplastics smaller than 0,5 µm will be discharged once again. Lung tissue with microplastics has cytotoxic and inflammatory effects. Exposure to microplastics raises the risk of developing chronic obstructive pulmonary disease. In the meantime, the lungs' protective barrier may be damaged by the low concentration of microplastics in lung tissue, raising the risk of lung disease(20).

The lung tissue of humans contains microplastics. Thirteen out of twenty lung tissue samples had microplastic polymers of polyethylene (PE) and polypropylene (PP) with fibers between 8.12 and 16.8 µm and sizes less than 5.5 µm. Thirty-three polymer particles and four fibers were the amount of microplastics found in human lung tissue samples(12). The presence of microplastics in lung tissue has the potential to cause acute and chronic inflammation(21). The ability of microplastics to survive and bioaccumulate in biological tissues determines their hazardous consequences. When the diameter of microplastic particles decreases and exposure is prolonged, bioaccumulation will increase(22).

Microplastics that enter the bodies of living beings will result in damage at the molecular and cellular levels in the organs of the body. Exposure to microplastics through inhalation can damage the reproductive organs at the cellular level. Exposure to PE and PVC microplastics at a dose of 15 mg/m^3 for 28 days resulted in a decrease in SOD enzymes and an increase in MDA metabolites in the ovaries of test animals (23). Exposure to PS microplastics for four weeks at a dose of 0.01 mg/kg body weight resulted in a decrease in SOD, CAT, and GPx in lung tissue (24). Exposure to PP microplastics of 2 and 10 mg/m^3 for four weeks resulted in inflammation that could potentially cause lung tissue damage (25). Mammals' gastrointestinal epithelium can be penetrated by microplastics with a diameter of less than 130 µm, which can subsequently enter the blood and lymphatic circulation systems and cause systemic effects. The liver, kidneys, lungs, intestines, and pancreas are just a few of the organs that microplastics with a diameter of less than 20 µm can enter. Membranes and system barriers of different kinds can be breached by microplastics having a diameter of less than 10 µm. The components of the chemical compounds that make up the particles also affect how harmful microplastics are(12,26).

CONCLUSIONS AND RECOMMENDATIONS

The study's findings indicate that physical aspects of the environment, including humidity, temperature, and ultraviolet light, have an impact on the amount of microplastics in the air. The Fixed Effect Model (FEM) model derived from the study's findings can be used to forecast the amount of microplastics in the air that are smaller than 2,5 microns and are influenced by physical factors. Occupiers of buildings constructed from plastic trash may be more susceptible to microplastic exposure. Persistent inhalation of microplastics will cause detrimental impacts on the lung tissue's cellular composition. Rethinking the use of structures constructed of plastic waste is necessary to prevent lung tissue harm. To identify and create predictors for microplastics with a particle size of less than 2,5 microns, more studies must be conducted using filter paper with reduced pore sizes.

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