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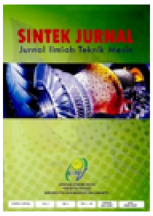

EXPERIMENTAL ANALYSIS OF CLIMATE PARAMETERS EFFECT ON STRUCTURAL STEEL ATMOSPHERIC CORROSION RATE IN MEDAN CITY ENVIRONMENT

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ABSTRACT

This study aims to explore the important role of weather parameters i.e. humidity, rainfall, temperature, and wind speed on the corrosion rate in the Medan City atmospheric environment. Three forms of material with low carbon steel type were prepared in this investigation. The exploration process was conducted for six months starting from June to December 2023, in the open area of the Engineering Faculty, Universitas Muhammadiyah Sumatera Utara. Corrosion rate assessment is carried out monthly using the weight loss method and climate parameter data is obtained from the Medan City Meteorology and Geophysics Agency (BMKG). The dimensions, initial preparation, data collection, post-test material preparation, and corrosion rate calculations refer to the ASTM G1 and G50 standards. Regression analysis and Pearson correlation explain the relationship between corrosion rate and climate parameters. The investigation showed that the corrosion rate fluctuated monthly from 0.1 to 0.5 mpy. By referring to corrosion resistance data on metal materials, it was found that the corrosion level was in the good resistance category "outstanding". Based on the regression analysis results, humidity, local temperature, and rainfall play an important role in the atmospheric corrosion rate in Medan City. The percentage of closeness between variables is ± 98% and the standard deviation is ± 0.0001. Further development is needed to determine other parameters that also play an important role in atmospheric corrosion rate and forming a random forest model for predicting future corrosion rates.

Keywords: low carbon steel; atmospheric corrosion; corrosion rate; climate parameters; Medan City

ABSTRAK

Penelitian ini bertujuan untuk mengetahui peran penting parameter cuaca yaitu kelembaban, curah hujan, suhu, dan kecepatan angin terhadap laju korosi di lingkungan atmosfer Kota Medan. Tiga bentuk material dengan tipe baja karbon rendah disiapkan dalam penelitian ini. Proses eksplorasi dilakukan selama enam bulan mulai bulan Juni sampai dengan Desember 2023, di area terbuka Fakultas Teknik Universitas Muhammadiyah Sumatera Utara. Penilaian laju korosi dilakukan setiap bulan dengan metode weight loss dan data parameter iklim diperoleh dari Badan Meteorologi dan Geofisika (BMKG) Kota Medan. Dimensi, persiapan awal, pengambilan data, persiapan material pasca uji, dan perhitungan laju korosi mengacu pada standar ASTM G1 dan G50. Analisis regresi dan korelasi Pearson menjelaskan hubungan antara laju korosi dan parameter iklim. Penelitian menunjukkan bahwa laju korosi berfluktuasi setiap bulan dari 0,1 sampai dengan 0,5 mpy. Dengan mengacu pada data ketahanan korosi pada material logam, didapatkan bahwa tingkat korosi berada pada kategori ketahanan baik "luar biasa". Berdasarkan hasil analisis regresi, kelembaban, suhu setempat, dan curah hujan memegang peranan penting terhadap laju korosi atmosfer di Kota Medan. Persentase kedekatan antar variabel sebesar ± 98% dan simpangan baku sebesar ± 0,0001. Perlu dilakukan pengembangan lebih lanjut untuk mengetahui parameter lain yang juga memegang peranan penting terhadap laju korosi atmosfer dan membentuk model random forest untuk memprediksi laju korosi di masa mendatang.

***Kata Kunci**: baja karbon rendah; korosi atmosferik; laju korosi; parameter cuaca; Kota Medan*

1. Introduction

Medan City is the third-largest metropolitan area in Indonesia, characterized by extensive infrastructure development to support its economic growth. Key advancements include urban infrastructure expansion, the development of industrial zones, and the enhancement of the Belawan container port [1,2]. These initiatives heavily rely on carbon steel due to its low cost, favorable properties, and versatility [3].

Medan City's topography, located near the Indian Ocean, coupled with its tropical climate and proximity to industrial areas, accelerates atmospheric corrosion [4]. This phenomenon poses a significant concern as it disrupts infrastructure development and may lead to long-term negative impacts [5]. Atmospheric corrosion, fundamentally, is the degradation of metal quality (Fe) caused by interactions with the local environment [6-8]. Various climatic factors, including temperature, humidity, and chloride deposition, play critical roles in this process [9,10].

Simillion et al. [11] emphasize the complex correlation between climate variables, their effects on material properties, and atmospheric corrosion resistance. Further studies support that the intricate relationship between climate and corrosion significantly influences the structure and formation of corrosion products on material surfaces [12,13]. Corrosion-induced damage to infrastructure materials can reduce their mechanical strength, ultimately leading to potential structural failure if left unmonitored [14].

Preventing atmospheric corrosion requires early and comprehensive intervention. Key measures include providing accurate information on the corrosion resistance of materials and identifying dominant factors that contribute to corrosion. Such insights enable effective initial planning to mitigate corrosion risks during infrastructure development [15-17].

Investigations into atmospheric corrosion in Medan City's environment have yielded important findings. In 2019, Syifaul et al. [18] examined the corrosion resistance of elbow and square infrastructure materials in the city's industrial zones. Their findings revealed significant variations in corrosion rates across five exposure stations, with the highest rates observed near waste storage areas due to airborne waste particles dispersed by wind. Despite these localized variations, the overall corrosion resistance was classified as "Good," and a corrosivity map for the industrial areas was successfully developed.

In 2021, Affandi et al. [19] studied the corrosion resistance of infrastructure materials in Medan City's coastal areas. Their research classified the materials' resistance as Outstanding, with average corrosion rates ranging from 0.22 to 0.42 mpy. A corrosivity map of the coastal regions was also created. However, these studies primarily focused on the corrosion resistance of materials in industrial and coastal zones, without analyzing the influence of climatic factors on corrosion rates.

To address this gap, this study aims to examine the effects of weather parameters humidity, rainfall, temperature, and wind speed on atmospheric corrosion rates in the Medan City environment. This research seeks to contribute to the development of a comprehensive atmospheric corrosion database for the region, which is essential for informed infrastructure planning and management.

2. Methods

Location and Materials

This investigation was conducted in the open area of the Faculty of Engineering, Universitas Muhammadiyah Sumatera Utara, spanning six months from June 2023 to December 2023. The location was carefully selected based on several key considerations to ensure the study's reliability and relevance. These factors included the secure placement of test materials, proximity to the coastline, adjacency to Medan City's industrial zones, and centrality to the urban area. Such a location was chosen to provide a representative environment that captures the combined effects of marine, industrial, and urban atmospheric conditions. Additionally, the selected site facilitated seamless data collection and monitoring throughout the investigation period, thereby ensuring accuracy and consistency in the recorded parameters. The detailed layout of the research location is depicted in Figure 1.

For this study, four distinct forms of structural steel reinforcing steel, rectangular plates, and elbow sections were prepared as test materials. These shapes were selected due to their prevalent use in infrastructure, particularly in buildings and industrial facilities where exposure to atmospheric conditions is a critical consideration. By focusing on these forms, the investigation aimed to provide insights into the corrosion behavior of commonly utilized structural components in real-world applications. Such an approach ensures that the findings are directly applicable to engineering practices and can inform material selection and design decisions.

The test materials were composed of low-carbon steel, a widely used material in construction due to its cost-effectiveness and mechanical properties. Prior to the experiment, material composition was verified using

Optical Emission Spectroscopy (OES) to ensure consistency and accuracy in the study. This analysis confirmed the suitability of the steel samples for the intended investigation, providing a reliable foundation for evaluating the corrosion rates under varying atmospheric conditions. The use of standardized material and forms underscores the methodological rigor of the study, enhancing the reliability of the results obtained.

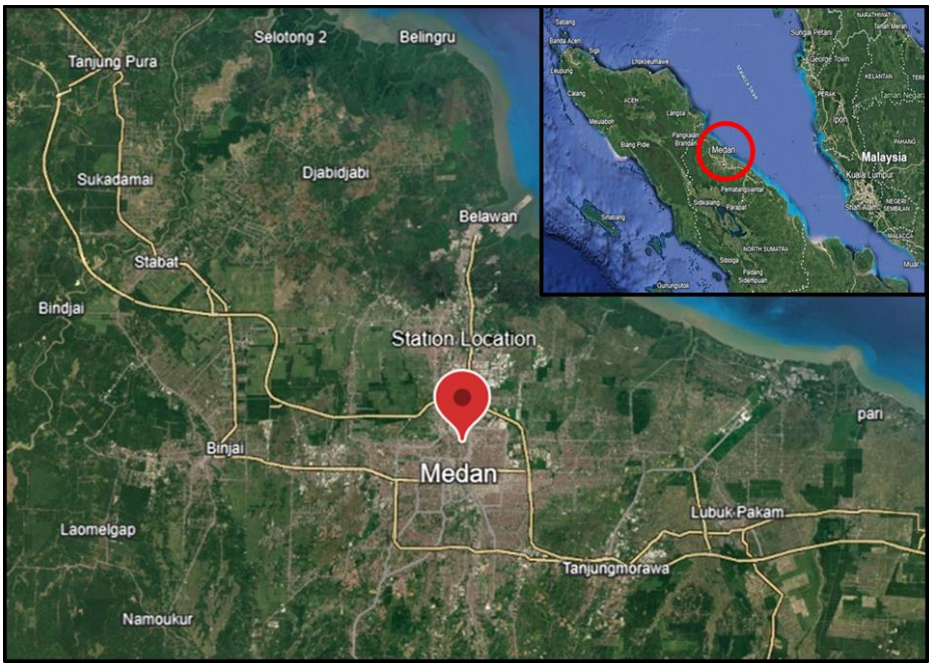
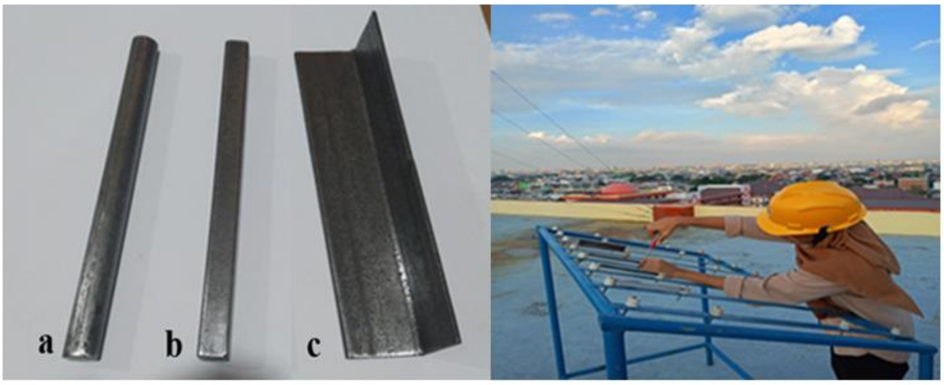


Figure 1. Station Location

All preparation of this investigation's test materials refers to ASTM G-50 [20,21]. The shapes of the test materials can be seen in Figure 2 A, and the results of the test material composition can be seen in Table 1. A series of test material preparations were carried out to ensure the accuracy of the results in this study. The initial stage before the test material is exposed is cleaning using a steel brush with acetone solution to ensure the surface of the test material is clean. After the cleaning process is complete, the test material is weighed using a high-precision digital scale to determine its initial weight. This process was conducted according to the ASTM G-1 [22,23]. Furthermore, the test material is exposed to the atmospheric environment using a test rack with plastic isolator supports. This aims to prevent the interaction between test material to other materials that can cause local galvanic corrosion [24]. The testing rack used in this investigation is shown in Figure 2 B.

Table 1. Material Composition Test Results

Fe	C	Si	Mn	P	S	Fe	Ni
96,6	0,189	0,046	1,18	0,019	0,013	0,047	1,7



(A) (B)

Figure 2. Test Materials: (A) reinforcing (a), rectangular (b), elbow (c), and (B) test rack

Data Collection and Atmospheric Corrosion Rate Calculation

The corrosion rate analysis was conducted using the weight loss method, the test materials had been exposed for 1 month and were cleaned from dust using a steel brush and acetone solution. After that, the test materials were weighed to determine their final weight. Data was collected using a high-precision digital scale with a precision of 0.001 mg. The data collection processes also refer to ASTM G-1 [22,25].

The calculation of atmospheric corrosion rate is based on Equation 1, and the corrosion rate constant values are shown in Table 2.

$$Corrotion\ Rate = K.W/A.T.D \qquad (1)$$

Corrosion Rate (mpy) where:
K = Conversion Factor (3.45×10^6)
W = Weight Loss (grams)
A = Surface Area (cm^2)
T = Exposure Time (hours)
D = Density of the test material (g/cm^3)

Table 2. Corrosion Rate Constant Value

corrosion rate unit	*K* Value
Mils per Year (mpy)	3.45×10^6
Millimeter per year (mm/y)	8.76×10^4
Gram per square meter per hour ($g/m^2.h$)	100 10^4 x D

Regression and Pearson Correlation Analysis

The relationship between each weather parameter and the corrosion rate is observed through regression analysis by referring to equation 2. Furthermore, to observe the correlation of all data, a Pearson correlation analysis is carried out by referring to equation 3. The required weather parameter data include rainfall, humidity, temperature, and wind speed. Data collection is carried out monthly from Medan City climate reports on the Meteorology, Climatology, and Geophysics Agency (BMKG) website.

$$\dot{y} = b_0 + b_1 x \qquad (2)$$

$\dot{y}$ is the dependent variable where:
x = the Independent variable
b_0 = the Intercept or constant term
b_1 = the Regression coefficient or slope

$$r = \frac{\sum_{i=1}^{n}(X_i - \dot{X})(Y_i - \dot{Y})}{\sqrt{\sum_{i=1}^{n}(X_i - \dot{X})^2 \sum_{i=1}^{n}(Y_i - \dot{Y})^2}} \qquad (3)$$

r is the Pearson correlation where:
X_i = the Individual values of variables X
Y_i = the Individual values of variables Y
$\dot{Y}$ = the average (mean) of variable Y
$\dot{X}$ = the average (mean) of variable X

3. Results and Discussion

Weather Parameter Data

The recapitulation of weather parameter data from BMKG is presented in Figures 3 (A) to (D), providing a comprehensive overview of the climatic conditions during the study period. The data highlights consistently high humidity levels, with monthly averages of 78.93%, 79.96%, 84.8%, 77.7%, 78.95%, and 83.1%, respectively. Such elevated humidity is a crucial factor contributing to the accelerated corrosion process, as it facilitates the formation of an electrolyte layer on the steel surface, thereby promoting electrochemical reactions. The consistently high relative humidity observed aligns with the tropical climate characteristics of Medan City.

In terms of rainfall, significant fluctuations were observed, with recorded values of 2.81 mm, 5.95 mm, 14.15 mm, 1.68 mm, 2.91 mm, and 9.84 mm across the first to sixth months of exposure. Notably, the highest rainfall occurred during the 3rd and 6th months, suggesting potential periods of heightened corrosion activity due to prolonged wetness on exposed steel surfaces. These fluctuations in rainfall underscore the dynamic climatic conditions of the study area, which could have a considerable impact on the progression and variability of corrosion rates over time.

Temperature data showed a stable trend during the study, with monthly averages ranging from 27.6°C to 28.96°C, indicating its secondary role compared to humidity and rainfall in influencing corrosion rates. Wind speed varied moderately between 2.28 m/s and 2.91 m/s, potentially affecting the dispersion of corrosive agents like chlorides and sulfates. These findings highlight the interplay of weather parameters, particularly the significant roles of humidity and rainfall, in accelerating atmospheric corrosion of structural steel in Medan City's environment. Together, the data provide valuable insights into the climatic factors influencing steel degradation in tropical urban conditions.

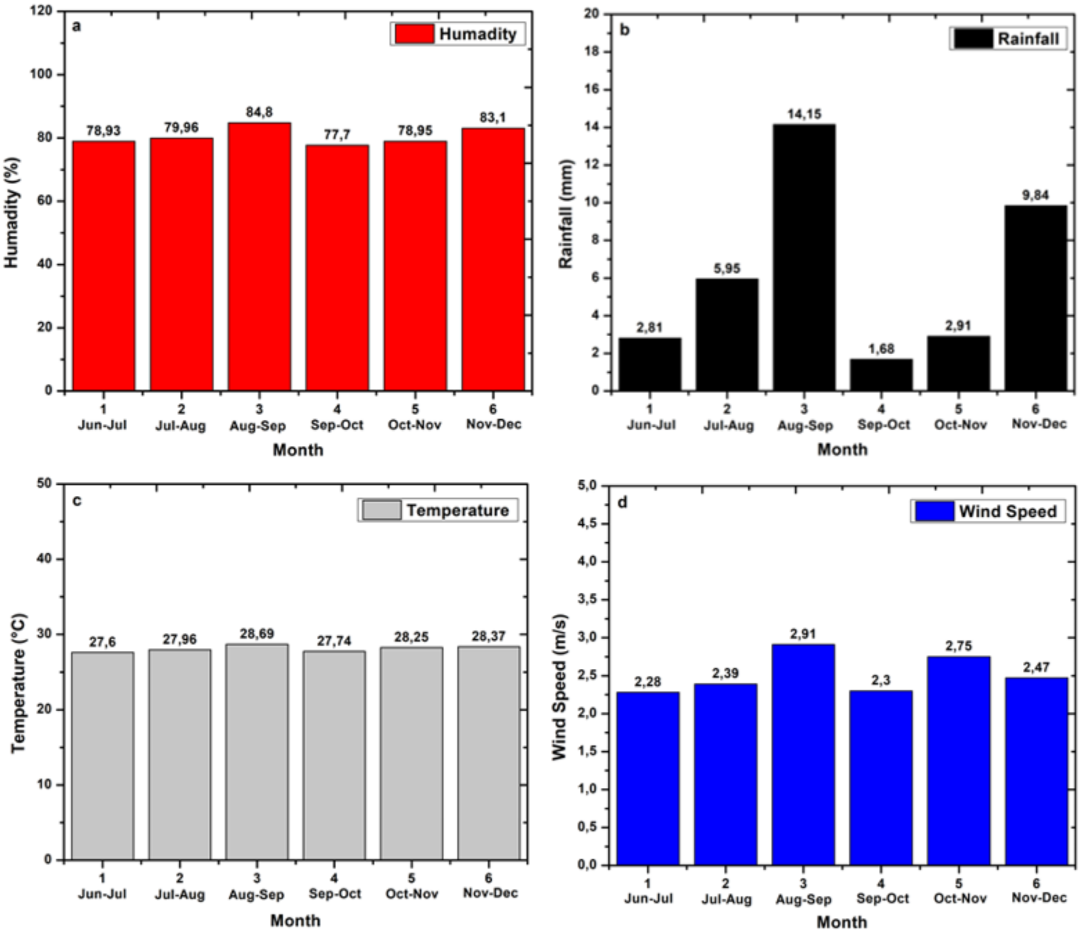


Figure 3. Climate Parameter Data; (A) Humidity, (B) Rainfall, (C) Temperature, and (D) Windspeed.

Table 3. The relative corrosion resistance of a metal to the corrosion rate.

Relative Corrosion Resistance	**Approximate Metric Equivalent**	
	mpy	**mm/year**
Outstanding	< 1	<0.02
Excellent	1–5	0.02–0.1
Good	5–20	0.1–0.5
Fair	20–50	0.5–1
Poor	50–200	1–5
Unacceptable	200+	5+

Atmospheric Corrosion Rate

The atmospheric corrosion rate occurring during the 6-month exposure period is calculated using Equation (1). The calculation results show that the corrosion rate occurring each month has a fluctuating trend. The highest corrosion rates occurred in the third and sixth months, with average corrosion rates of 0.548 mpy and 0.461 mpy, respectively. Meanwhile, in the first, second, fourth, and fifth months, the corrosion rates ranged from 0.1 mpy to 0.2 mpy. The monthly corrosion rate data for each material are shown in Figure 4. Referring to the relative corrosion resistance of metal materials, the corrosion rate is categorized as “outstanding”. This indicates that the material is quite resistant to atmospheric corrosion attacks [21]. The relative corrosion values based on the corrosion rates are shown in Table 3.

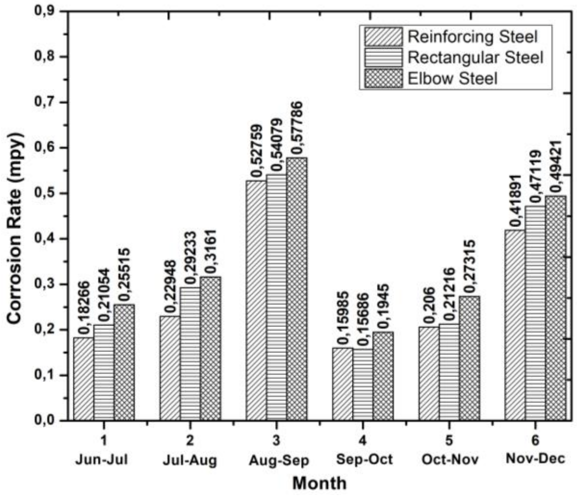
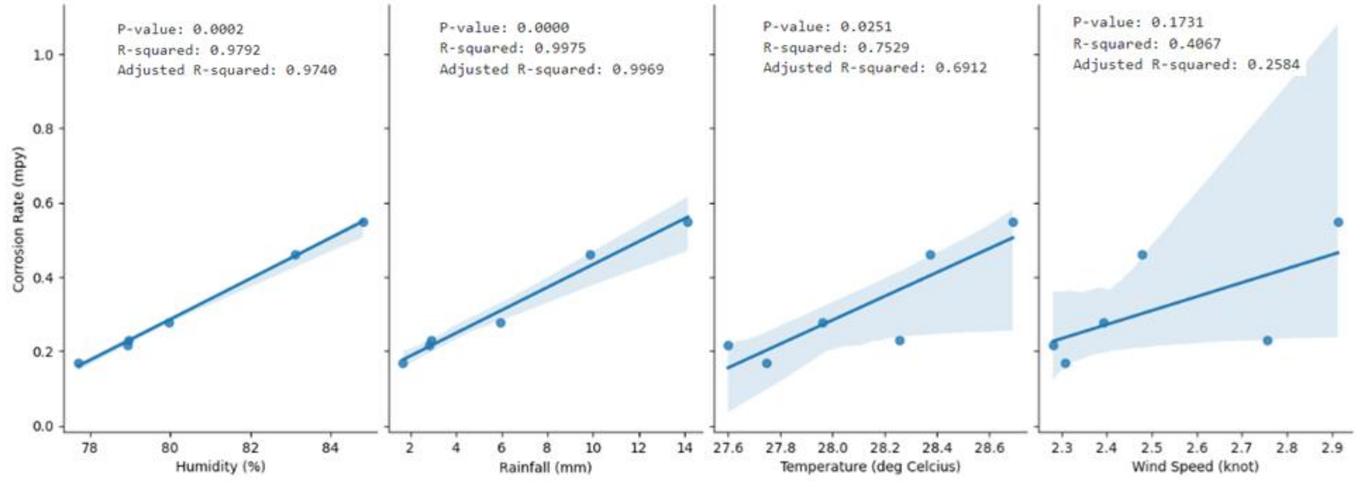


Figure 4. Corrosion Rate of the Exposure Results.

Relationship Between Corrosion and Weather Parameters

After the weight loss data summary is complete and calculated, the data is made into the subject for regression analysis, followed by Equation (2). The relationship between weather variables and the corrosion rate is observed based on the standard deviation (s), coefficient of determination (R-Sq), and significance (P) data. The desired data error is 5% or equal to 0.05. The smaller the S and p values produced in the analysis, the more accurately the model represents the response. Meanwhile, R-Sq is the percentage of variation in the response to observe the percentage of relationships. Furthermore, the data is re-analyzed to observe the correlation of each data poured into the heatmap. The correlation of each data is observed based on the Pearson correlation coefficient (r), when r is equal to 1 it has a positive correlation, r is equal to -1 it has a perfect negative correlation and if r is equal to 0 then it does not have a linear correlation. The regression analysis results of weather parameters on the corrosion rate are shown in Figures 5 and Table 4. Furthermore, the Pearson correlation test result in Figure 6.



(A) (B) (C) (D)

Figure 5. Corrosion Regression Plot against; (A) humidity, (B) rainfall, (C) temperature, and (D) wind speed.

Table 4. Regression analysis data of weather parameters on corrosion rate

Variable	S	R-Sq	R-Sq(Adj)	P/Reg
Humidity	0,0084458	99,8%	99,7%	0,000
Rainfall	0,0244602	97,9%	97,4%	0,000
Temperature	0,0843365	75,3%	69,1%	0,025
Wind Speed	0,130684	40,7%	25,8%	0,173

Refer to the analysis results attached in Table 4. Humidity and rainfall parameters are important players and have a significant impact on the corrosion rate in the Medan City environment. The relationship between the two climate parameters on the corrosion rate (R-sq) is ± 97% with (S) 0.008 – 0.02 and (P) 0.000. Furthermore, the results of the analysis show that local temperature has a relationship but is not very significant compared to humidity and rainfall. This can be observed from the close relationship between local temperature and corrosion rate of 75% with (S) 0.08 and (P) 0.025. The results of this analysis still describe a good pattern because the standard deviation and significance values between data are below the error value. This also shows that the corrosion rate that occurs is also caused by the local environmental temperature. Contradictory results occurred for the wind speed parameter. The relationship between windspeed and the corrosion rate is only (Rsq) 40.7% with (S) 0.130684 and (P) 0.173. The values (S) and (P) exceed the specified error value threshold. These results indicate that wind speed parameters do not have much impact on the corrosion rate in the Medan City environment. This is in line with previous research reports where Time of wetness (TOW) greatly contributes to the electrolyte medium which triggers electrochemical reactions and oxygen diffusion which causes corrosion [26-28].

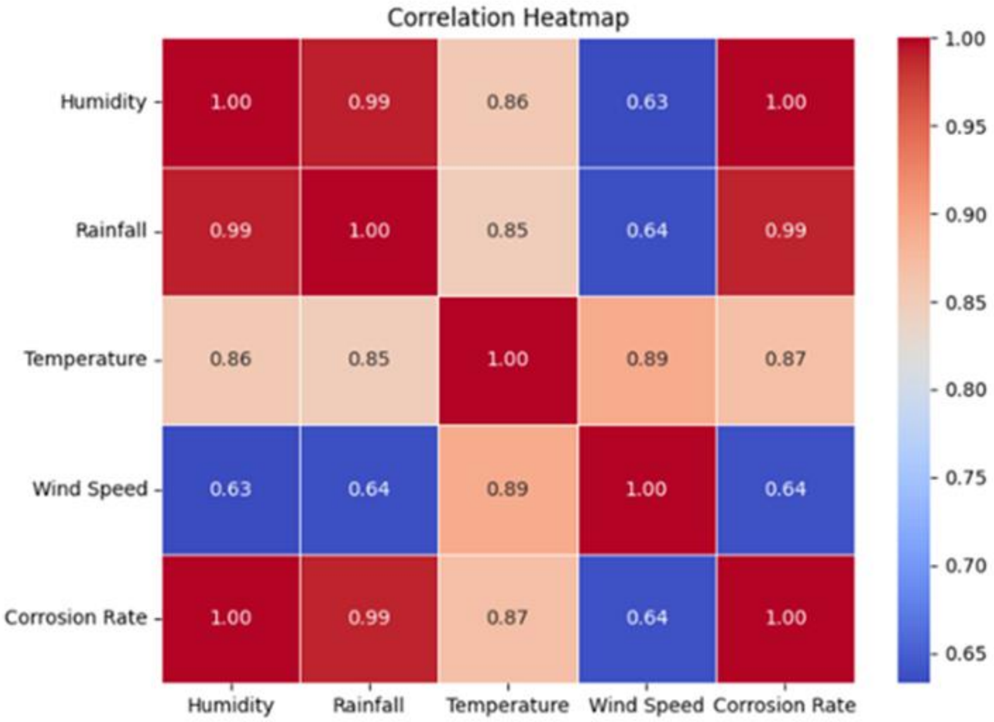


Figure 6. Pearson Correlation Results

The person correlation analysis results show that the humidity parameter has the highest correlation with the corrosion rate, with a correlation coefficient (r) value 1. This illustrates that humidity has a significant effect on the corrosion rate in the Medan City environment. The analysis continued with rainfall and temperature. The analysis results also show a significant influence of these two climate parameters on the corrosion rate with a percentage (r) 0.99 – 0.86. Based on the analysis results, these two parameters also determine the humidity that occurs. Different results are shown in the wind speed parameter. The analysis results show a weak correlation on the corrosion rate with a percentage (r) 0.64. Even though it has an influence, the impact is very weak compared to other parameters. These results can be used as a reference for handling construction materials in both industry and urban infrastructure regarding the atmospheric corrosion rate which is influenced by several local climate parameters.

4. Conclusion

This study successfully investigated the influence of weather parameters on atmospheric corrosion in the Medan City environment over a six-month exposure period. The results classified the corrosion rate as Outstanding across all tested material forms, highlighting the resilience of the selected low-carbon steel under tropical conditions. Observations revealed that humidity, rainfall, and temperature significantly contribute to the corrosion process, with a strong interdependence between these parameters.

To enhance the understanding of atmospheric corrosion, further studies are recommended over a longer exposure period, preferably exceeding one year, to evaluate the consistency of findings. Additionally, future research should explore other potential factors influencing corrosion rates, such as air particulate composition, including chlorides and sulfates. Incorporating advanced predictive techniques, such as random forest models, is also proposed to improve the accuracy of corrosion rate forecasting under diverse environmental conditions. These efforts will strengthen the applicability of findings in real-world infrastructure management and material design.

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