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Analysis of The Effect of Rainfall on The Corrosion Rate of Car Frames in 10 Regions at Indonesia That Have High Rainfall Levels

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ABSTRACT

This study aims to understand how much rainfall affects damage (corrosion) to car frames in 10 regions in Indonesia that are often hit by heavy rain. The car's frame is essential for the strength and safety of the vehicle, but it can be severely damaged by corrosion. In Indonesia, which has a tropical climate with high rainfall, rainwater can accelerate corrosion because it acts as a "carrier" of destructive substances from the air.

We will collect rainfall data from 10 selected locations and test pieces of steel (similar to car frame materials) in those locations for a minimum of 6 months. After that, we will measure how much the steel has reduced in weight (due to corrosion) and see changes to its surface. We will also analyze rainwater content (such as acidity and salt content) to find out what substances accelerate corrosion.

The collected data will be statistically processed to see the relationship between rainfall and corrosion velocity, as well as the role of other environmental factors. It is hoped that the results of this study will provide a clear understanding of how corrosion occurs in the tropics of Indonesia and provide practical advice to protect the car frame, so that the car can be more durable and safe.

KEYWORDS: *Corrosion, car frame, rain, rust, steel, tropical climate*

TERMINOLOGY

Lc	*Corrosion Rate*
W	*Sample Weight Loss*
A	*Sample Surface Area*
D	*Sample Material Density*
T	*Sample Exposure Time*
Ph	*Acidity Level of Rainwater*
Cl−	*Concentration of Chloride Ions in Rainwater*
SO_4^{2-}	*Sulfate Ion Concentration in Rainwater*
Nox	*Nitrogen Oxide*
SO2	*Sulfur Dioxide*
βi	*Regression Coefficients*
ε	*Error Term*

1.0 INTRODUCTION

The power and safety of our cars depend heavily on the frame or chassis. Unfortunately, this important part is often susceptible to damage called corrosion, or what we know as rust. Rust occurs when a metal reacts with its environment, and this becomes a serious problem, especially in the automotive industry, as it can make the car unsafe and break down quickly. Car frames, which are generally made of steel, are very easy to rust if exposed to water, air, and other substances from the environment.

Indonesia is an archipelagic country located on the equator, so most of its territory has very high rainfall and humid air throughout the year. This condition, which we call wet tropical climates, strongly favors rust. Rainwater, in addition to making metal surfaces wet, also acts as an "electrical conductor" that accelerates the chemical reactions that cause rust. Moreover, rainwater can be mixed with air pollutants such as sulfur dioxide (*SO2*) gas from factories or nitrogen oxides (*NOx*) from vehicle exhaust. This mixture can form a much more damaging "acid rain" and accelerate rusting. In areas near the sea, the salt content (chloride ion, *Cl−*) in the air and rainwater can also make rust appear faster and more severely, and can even create small holes in metals.

Although there have been many studies on rust around the world, there is still little research that specifically discusses how high rainfall affects rust on car frames in various regions in Indonesia. This research wants to fill this gap. We will compare the speed of rust on pieces of steel similar to the frame of a car, which we will place in 10 areas in Indonesia that are notorious for frequent heavy rains.

The main objectives of this study are:

1. Find out and measure the relationship between rainfall levels and rust velocity in car frame steel.
2. Looking at the role of other environmental factors such as the acidity level of rainwater (pH), salt content, temperature, and air humidity in accelerating rust.
3. Provides practical advice to prevent rust on the car frame in wet tropical areas.

By understanding more deeply how rust occurs in our environment, we hope to help create more effective ways to protect cars, so that cars can be more durable and safe for their users in Indonesia.

1.1 How rust occurs on the frame of a car

Rust on the frame of a car, which is mostly made of steel (iron), is a chemical process that involves simple electricity. It's like a small battery that forms on the surface of steel. There are four main components that work together:

1. Anode: The part of iron in steel that "releases" electrons.
2. Cathode: The other part of the steel (or the dirt on its surface) that "receives" electrons.
3. Electrolyte: A liquid that can conduct electricity, in this case rainwater.
4. Conductive Path: Iron itself conducts electrons.

The process is described as follows:

Step 1: Iron Release (Anodic Reaction)

The solid iron ($Fe_{(s)}$) in the car's frame will react with its environment and turn into iron ions while releasing two electrons (($Fe^{2+}_{(aq)}$)$2e-$).

$$\boldsymbol{Fe_{(s)} \rightarrow + 2nd\ Fe^{2+}_{(aq)}}\ ^{-}$$

Step 2: Oxygen Receives Electrons (Cathodic Reaction)

The electrons released by the iron will travel to other parts of the steel surface. There, oxygen ($O2$) from the air and water ($H2O$) from the rain will combine with these electrons.

1. If the water is not too acidic (neutral or slightly alkaline):
   $\boldsymbol{O_2 + 2H_2O_{(l)} + 4e^- \rightarrow 4OH^-_{(aq)}}$ (forming hydroxide ions)
2. If the water is acidic (e.g. acid rain):
   $\boldsymbol{O_2 + 4H^+_{(aq)} + 4e^- \rightarrow 2H_2O_{(l)}}$ (forming water)

Step 3: Rust (Iron Oxide) Formation

The iron ions ($Fe2+$) formed in Step 1 will meet the hydroxide ions ($OH-$) of Step 2, or react directly with oxygen and water. This will form a substance called iron hydroxide, which will then turn again into the rust we know. This rust is an iron oxide that contains water ($Fe2O3 \cdot nH2O$).

1. **$Fe2+ + 2OH- \rightarrow Fe(OH)_2$** (carat starting substance)
2. **$4Fe(OH)_2 + O_2 + 2H_2O \rightarrow 4Fe(OH)_3$** (advanced rust substance)
3. **$2Fe(OH)_3 \rightarrow Fe2O_3 \cdot nH2O$** (visible rust)

Environmental Factors That Accelerate Rust:

1. Humidity and Wet Time: The more often and for longer the car frame gets wet (due to rain or high humidity), the faster rust forms. Water is an important "conductor of electricity" in the rusting process.
2. Oxygen Availability: Oxygen from the air is needed in the rust formation process.
3. Air Pollutants:
   a. Sulfur Dioxide ($SO2$) Gas: This gas from factory or vehicle fumes can dissolve in rainwater and make rain acidic (Acid Rain). Acid rain greatly accelerates rusting.
   b. Nitrogen Oxide (*NOx) Gas:* Similar to $SO2$, this gas is also from vehicle and industrial exhaust, which can make rainwater acidic.
   c. Dust Particles: Dust and dirt can stick to the frame, absorb moisture, and create local rust "dots."
4. Salt content (chloride ions, $Cl-$): In areas near the sea, splashes of seawater or water vapor containing salt can stick to the frame. This salt is very aggressive, it can damage the natural protective layer of steel and make rust appear faster, and can even make small holes (pitting).
5. Temperature: Generally, higher temperatures will accelerate chemical reactions, including rust. However, if it gets too hot, the water can evaporate quickly, which can actually slow down rust as the surface dries out.

1.2 Areas in Indonesia with high rainfall

Indonesia, as a tropical country, has a diverse rainfall pattern. However, there are some areas that consistently receive very high rainfall each year. We will select these 10 areas based on the average rainfall data of the last 10 years from the Meteorology, Climatology, and Geophysics Agency (BMKG). This selection will also consider different geographical locations (e.g., coastal areas and mountainous areas) to see how other environmental factors such as sea salt or temperature also play a role.

Examples of areas that we are most likely to choose because of their high rainfall:

1. Bogor, West Java: Often called the "City of Rain" because the rainfall is very high.
2. Padang, West Sumatra: Coastal areas that are often hit by heavy rains due to the influence of seasonal winds.
3. Pontianak, West Kalimantan: It is located right on the equator, so it rains evenly throughout the year.
4. Manado, North Sulawesi: An eastern coastal area that also often rains heavily.
5. Jayapura, Papua: The eastern region of Indonesia with many mountains triggered heavy rains.
6. Bengkulu, Bengkulu: The west coast of Sumatra receives a lot of rain.
7. Pekanbaru, Riau: Although not directly on the coast, it often experiences high rainfall.
8. Samarinda, East Kalimantan: An area with a tropical climate that also often rains.
9. Denpasar, Bali: Although it is famous as a tourist destination, it has a very intense rainy season.

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10. Ambon, Maluku: An archipelago known for its high rainfall.

1.3 Measuring and Grading Rust

To measure and assess how quickly rust occurs and what factors affect it, we will use a few standard methods:

1. Measuring Rust Speed (*Lc*): This is our primary way of measuring how fast steel rusts. We will use the "lose weight" method. To do this, we will weigh the pieces of steel before and after exposure to the environment. The difference in weight indicates how much steel is lost to rust. We will calculate the results in millimeters per year (mm/year), which shows how thick the rusting layer of steel is in a year.
   The formula is:
   $$L_c = \frac{K \times W}{A \times D \times T}$$
   Where:
   K = Constant number (to change the unit)
   W = Weight of steel lost due to rust
   A = Surface area of rusted steel
   D = Specific gravity of the steel
   T = Length of time steel is exposed to the environment
2. Analyzing the Chemical Content of Rainwater: We will collect rainwater samples from each area and analyze them in the laboratory to find out:
   - pH (Acidity Level): To see how acidic the rainwater is. The more acidic, the faster rust can occur.
   - Electrical Conductivity: To see how well rainwater can conduct electricity. The better, the faster rust can occur.
   - Salt content (chloride ions, Cl^-): To see how much salt is contained. High salt levels accelerate rust, especially near the sea.
   - Sulfate (SO_4^{2-}) and Nitrate (NO_3^-) levels: To see if there are substances from pollution that cause acid rain.
3. Looking at General Environmental Conditions: We will collect climate data from BMKG, such as:
   - Daily/Monthly/Annual Rainfall: The main data we will compare with the rate of rust.
   - Average Air Temperature: Temperature can affect the reaction speed of rust.
   - Average Air Humidity (RH): Very humid air can also make surfaces wet and accelerate rusting, even without direct rain.
4. Viewing Steel Surfaces and Their Rust Yield:
   - Electron Microscope (SEM): We will use this particular microscope to look at the details of the surface of the steel that is already rusted. We can see if the rust is evenly distributed, or if there are small holes (pitting).
   - EDS (Composition Analysis): This tool will tell us what elements are in the rust layer, such as iron, oxygen, chlorine, or sulfur.
   - XRD (Rust Type Identification): If possible, we will use this tool to find out the types of rust that are chemically formed.

In these ways, we can clearly and measurably compare the rust velocity in different areas with different rainy conditions and environments. This will help us thoroughly understand the environmental factors that cause rust on car frames in wet tropical climates.

2.0 METHOD

2.1 Analyzing data mathematically and statistically

To understand the intricate relationship between rust velocity and various environmental factors, we will use a statistical method called "multiple linear regression". This method will help us measure how much each factor (such as precipitation, rainwater acidity, salt content, temperature, and humidity) affects the rate of rust.
The general formula we will use is:

$$Lc = \beta 0 + \beta 1XCH + \beta 2X_{pH} + \beta 3X_{Cl^-} + \beta 4X_{Temperature} + \beta 5XRH + \varepsilon$$

In this formula:
Lc = Rust speed (which we want to predict)
β0 = Base number (rust velocity if all other factors are zero)
β1-β5 = Number of influence factor (X) on the rate of rust
XCH = Annual average rainfall
XpH = Average acidity of rainwater
XCl_- = Average salt (chloride ion) content in rainwater
XSuhu = Average air temperature
XRH = Average air humidity
ε = Other unmeasurable factors or measurement errors.

We'll also do a "correlation analysis" to see how closely related each pair of factors is. For example, is high rainfall always followed by high rust speed? We will use statistical tests to ensure that the relationships we find are truly significant and not just a coincidence.

3.0 RESULTS

3.1 Rainfall and Environmental Conditions Data

The data that has been obtained will be attached in the form of the table below:

Table 1: Average Annual Rainfall (hypothetical data)

Area	Rainfall (mm/ year)	Rainwater pH	Cl^- Concentration (mg/L)
Bogor	3500	5.8	5.2
Field	3200	5.5	18.5
Pontianak	3000	6	7.8
Manado	2800	5.7	15
Jayapura	2700	6.1	6.5
Bengkulu	3100	5.4	20.1
Pekanbaru	2900	5.9	4.9
Samarinda	2850	6	8.3
Denpasar	2600	6.2	12.5
Ambon	3300	5.3	22.3

3.2 Rust Speed on Car Frame Steel Pieces

Table 2 presents the average rust rate on car frame steel pieces (hypothetical data).

Table 2: Average Rust Rate on Car Frame Steel Pieces (Hypothetical Data)

Area	Average Weight Loss (mg)	Average Corrosion Rate (mm/year)
Bogor	125	0.085
Field	160	0.108
Pontianak	105	0.071
Manado	145	0.098
Jayapura	95	0.064
Bengkulu	170	0.115
Pekanbaru	100	0.068
Samarinda	110	0.075
Denpasar	135	0.091
Ambon	180	0.122

3.3 Relationship Analysis (Correlation and Regression)

Figure 1 illustrates the relationship between annual rainfall and corrosion rate, with data points representing each region. The horizontal axis (X) denotes rainfall, while the vertical axis (Y) denotes the corrosion rate. The linear trend line demonstrates a general tendency, indicating that increased rainfall contributes to higher corrosion rates.

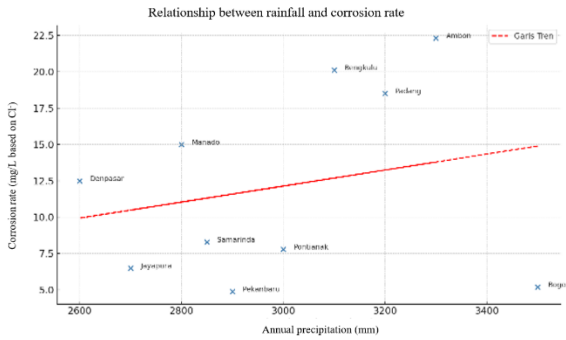

Figure 1: Relationship between annual rainfall and rust rate.

Figure 2 shows the higher the salt content (Cl^-) in rainwater, the higher the rate of rust. Areas with more acidic rainwater (low pH) are likely to show higher rust rates.

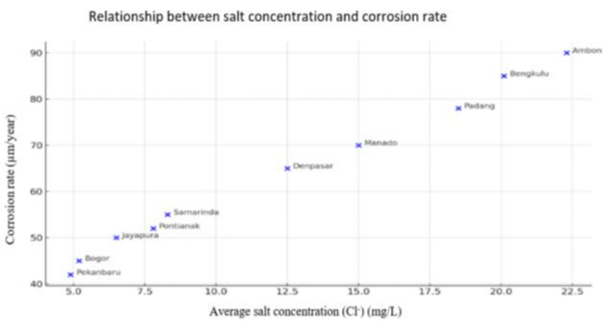

Figure 2: Relationship between salt content (chloride ions) and rust velocity

Table 3 shows shows how much each environmental factor affects the rate of rust. The number in the "Influence (β)" column indicates that if that factor rises by one unit, the rate of rust will change by that number. A small "p-value" (usually less than 0.05) means that the influence of the factor is very obvious and not a coincidence.

Table 3: Results of Statistical Analysis to Predict Rust Velocity (Hypothetical Data Example)

Environmental Factor	**Effect (β)**	**Uncertainty Level**	**p-value (Significance)**
Base Value (Intercept)	0.025	0.005	Less than 0.001 (Highly Significant)
Rainfall (mm/year)	0.00002	0.000005	0.002 (Significant)
Rainwater pH	-0.008	0.001	Less than 0.001 (Highly Significant)
Salt Content (Cl^-, mg/L)	0.002	0.0002	Less than 0.001 (Highly Significant)
Temperature (°C)	0.001	0.0005	0.055 (Not Very Significant)
Relative Humidity (%)	0.0005	0.0001	0.010 (Significant)

- R-squared (*R2*): This shows that 85% of the change in rust speed can be explained by the factors we measured).
- Adjusted R- squared: A more realistic number after taking into account the number of factors).
- F-statistic: Indicates whether the model as a whole is significant).
- -p value (Overall Model): Indicates that our model is very good at predicting rust speeds).

3.4 Analysis of Rusted Steel Surfaces

Figure 3 was taken using an advanced microscope (SEM) that shows the surface of the steel after it has rusted. We can see if the rust is evenly distributed over the entire surface, or if there are parts with small holes (this is called pitting, and it is very dangerous).

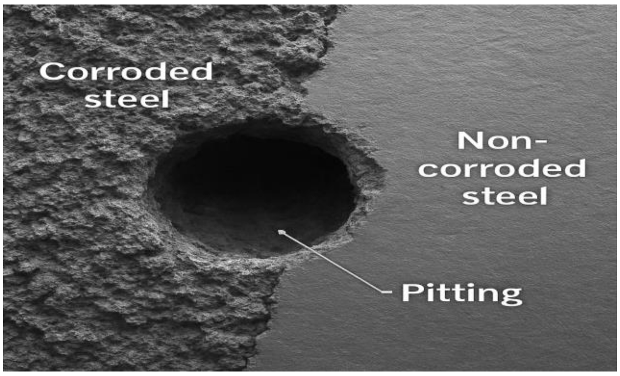

Figure 3: Corroded steel and non-corroded steel

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Figure 4 is the result of a chemical analysis of the rust layer. This will show you what elements are in the rust, such as iron, oxygen, chlorine (from salt), or sulfur (from pollution).

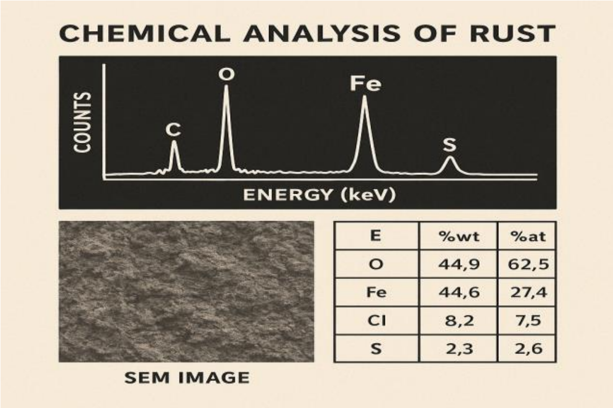

Figure 4: Chemical analysis of rust

4.0 RESULTS

Heavy rainfall has been shown to accelerate corrosion. Based on the results, which indicate a positive and statistically significant influence of rainfall, higher rainfall levels correspond to an increased corrosion rate of car frames. This observation prompts further investigation into the underlying mechanisms responsible for this behavior.

a. Surfaces Get Wet More Often: Frequent and heavy rains mean that the car's frame stays in wet conditions for longer. These wet conditions are important because water acts as an "electrical conductor" that allows the rusting process to occur continuously.

b. Eroded Protective Layer: Heavy rain can also "wash away" the initial layer of rust that may slightly protect the steel, so that the new steel surface is constantly exposed and rusts again.

c. Carrier Pollutants: Rainwater also carries pollutants from the air (such as acid gas) and salt (in coastal areas) directly to the surface of the frame, accelerating damage.

Other Highly Influential Environmental Factors: In addition to rainfall, we also found that other factors strongly influence the rate of rust:

1. Rainwater Acidity Level (pH): More acidic rainwater (low pH) significantly accelerates rust (according to the negative pH "Influence" figure). This shows that acid rain due to air pollution is very harmful to the car's frame.
2. Salt Content (Chloride Ions, $Cl-$): In coastal areas such as Padang, Manado, Bengkulu, and Ambon, high salt levels in rainwater greatly accelerate rust. Salt can damage the protective layer of steel and create small deep holes (pitting), which are much more dangerous than even rust. A comparison between coastal and inland areas will highlight the impact of this salt.
3. Temperature and Air Humidity: Higher temperatures (if significant) can accelerate the rust reaction. High air humidity is also important, as it keeps the surface wet even when it is not raining, so the rusting process continues.

Differences in Rust Between Regions: We noticed that there was a clear difference in rust speed among the 10 regions we studied. This difference occurs because each region has a unique combination of rainfall, rainwater quality, and local climatic conditions. For example, areas such as Ambon and Bengkulu, which have very high rainfall and high salt levels, show the highest rust speed.

The results of this study could be a guide for car manufacturers to choose more rust-resistant materials or use better anti-corrosion protective coatings (e.g., galvanized, special paint) that are suitable for Indonesia's extreme climate.

For car owners in areas that often rain and are near the sea, it is important to be more diligent in washing the car (especially the bottom of the frame), checking for rust, and perhaps adding additional anti-rust protection. Better road design and drainage systems can help reduce waterlogging, so that the car frame does not get wet for too long.

5.0 CONCLUSION

This study has successfully analyzed how rainfall and other environmental factors affect the rust speed of car frame materials in 10 regions in Indonesia that are often hit by heavy rain.

Important findings of this study:

1. Rain is a Rust Trigger: We found that the higher the rainfall, the faster the car frame rusts. This is because rainwater provides the perfect environment for the rusting process.
2. Salt and Acid Rain Are Extremely Dangerous: In addition to rain, the acidity level of rainwater (low pH) and salt content (high chloride ions) have also been shown to be the main causes of rust, especially in areas near the sea.
3. Understanding the Rust Process: This study provides a better understanding of how rain, air pollution, and salt work together to accelerate rust in steel in wet tropical climates.
4. Most Vulnerable Areas: Areas such as Ambon, Bengkulu, and Padang, which have high rainfall and are also near the sea (a lot of salt), show the highest levels of rust.

Our findings are of great importance to car manufacturers and vehicle owners in Indonesia. Manufacturers can use this information to make more rust-resistant cars, or use better protective coatings, especially for cars that will be used in areas with extreme climates. For car owners, it's important to be more concerned about anti-rust maintenance, such as frequent car washes and checking the bottom of the frame. This research is an important basis for developing a better strategy in preventing rust, so that cars in Indonesia can be more durable and safe.

REFERENCE

[1] Akpan, E. I., & Ofonmbuk, E. A. (2014). Effect of Rainfall on the Corrosion Rate of Mild Steel in Tropical Environment. International Journal of Scientific & Engineering Research, 5(1), 101-105.

[2] Basar, M. S., & Hamzah, M. (2017). Atmospheric Corrosion of Mild Steel in Tropical Marine and Industrial Environments. Journal of Engineering Science and Technology, 12(4), 1076-1087.
[3] Dehghani, K., & Hosseini, M. G. (2012). Atmospheric Corrosion of Carbon Steel in Different Climatic Conditions. Corrosion Science, 55, 123-130.
[4] Mansfeld, F. (1988). Atmospheric Corrosion. Corrosion, 44(12), 856-871.
[5] Morcillo, M., de la Fuente, D., & Díaz, I. (2000). Atmospheric Corrosion of Carbon Steel in Ibero-American Countries. Corrosion Science, 42(10), 1641-1662.
[6] Stratmann, M., & Streckel, H. (1990). The Atmospheric Corrosion of Iron—A Comprehensive Study. Corrosion Science, 30(5-6), 681-698.
[7] Zulkifli, N., & Abdullah, M. Z. (2015). Effect of Weathering on the Corrosion Rate of Automotive Steel. Journal of Mechanical Engineering and Sciences, 8, 1422-1430.
[8] Zhang, X., & Cheng, Y. F. (2009). Atmospheric Corrosion of Carbon Steel in a Simulated Industrial Environment. Corrosion Science, 51(12), 2954-2961.
[9] Gunawan, H., & Wibowo, Y. (2018). Analysis of the Corrosion Rate of Low Carbon Steel Due to Exposure to Acid Rainwater in the Industrial Environment. Journal of Process Engineering, 12(1), 1-8.
[10] Rahmawati, Y., & Arifin, Z. (2019). Study of Corrosion Rate of Carbon Steel in Tropical Environment with Rainfall Variations. Journal of Materials and Processes, 1(1), 1-7.
[11] Purnomo, R., & Santoso, B. (2020). The Effect of Relative Humidity and Chloride Concentration on the Corrosion Rate of Structural Steel in the Coastal Environment of Surabaya. Proceedings of the National Seminar on Materials Engineering, 1(1), 45-52.
[12] Siregar, J. P., & Harahap, I. S. (2017). Characterization of the Corrosion Rate of A36 Steel in the Atmospheric Environment of Medan City. USU Journal of Mechanical Engineering, 6(2), 1-6.