



## Exploring the link between Atmospheric conditions and Acid rain prevalence: a 12-year study at Juanda International Airport, Sidoarjo, Indonesia.

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### Abstract

Acid rain is a pressing environmental concern, posing severe threats to the well-being of various forms of life. Our research sought to evaluate the acidity level of rainwater at Juanda International Airport, attempting to correlate it with weather parameters. We analyzed a span of twelve years, inspecting the relationship of rainwater pH with upper atmospheric conditions, specifically focusing on air temperature and humidity. Utilizing a statistical approach enabled us to draw meaningful conclusions from the extensive data at hand. Our analysis revealed that a significant 40% of the rain data fell under the acid rain category, demonstrating the alarming prevalence of the phenomenon in the region. A fascinating insight uncovered through our study was the existence of a correlation between the pH level of the rainwater and the air temperature and humidity values, particularly in zones where rain clouds tend to develop. This finding amplifies our understanding of the intricate relationships between acid rain formation and atmospheric conditions. We posit that weather parameters like temperature and humidity may have an integral role in acid rain production, thereby influencing the ecosystem's balance. Continued research in this realm can potentially help in creating better predictive models and in devising effective strategies for combating the devastating effects of acid rain.

## 1. Introduction

Condensation, crucial to the formation of rain, typically requires a nucleus such as dust grains for water vapor to cling to, consequently forming larger particles that descend as rain [1]. During this transformation, the vapor interacts with different atmospheric particles, absorbing various gases and pollutants. This absorption of pollutants could result in acid rain, a phenomenon that has been thoroughly investigated in urban settings [2]. Although rainwater generally has a pH around 5.6, under certain conditions, this value can fall below 5.6, indicative of acidity and potential acid rain [3].

The formation of acid rain occurs when atmospheric water vapor interacts with particulates and gases produced from the combustion of fuel and natural processes. Water vapor ( $H_2O$ ) interacting with Carbon Dioxide ( $CO_2$ ) and Carbon Monoxide ( $CO$ ) yields weak carbonic acid ( $H_2CO_3$ ) (Whardani et al., 2015). On the other hand, the combination of water vapor with gases like Hydrogen Sulfide ( $H_2S$ ) and Sulfur Oxide ( $SO_2$ ), which originate from sulfur combustion or heating, produces strong sulfuric acid ( $H_2SO_4$ ) [4]. Clearly, pollutants from human and natural sources that enter the atmosphere have a considerable impact on the type of rainfall.

The dispersion of pollutants in the atmosphere is dependent on factors like air temperature and humidity [5]. Changes in air temperature can lead to pollutants being trapped in the lower atmosphere, while higher humidity can enable pollutants to settle and be incorporated into water droplets, leading to the formation of larger particles [6].

Acid rain poses significant environmental and health concerns, affecting everything from human health to the structural integrity of built environments and the mechanical properties of materials such as

asphalt [2], [7-9]. The Juanda International Airport, approximately 20 km from Surabaya City and 3 km west of the Madura Strait waters, has a geographical location that influences local rain formation. Paweka (2017) suggests that the chemical mix in rainwater, resulting from both fuel combustion in urban areas and natural oceanic processes, significantly determines its quality [10]. This study aims to understand the interplay between atmospheric dynamics — specifically air temperature and humidity at the 850 hPa, 700 hPa, and 500 hPa layers — and the acidity, or pH, of rainwater around Juanda International Airport.

## 2. Methodology

The research was conducted in the Sedati District, situated within the Sidoarjo Regency, an area characterized by its unique climatic and atmospheric conditions [2], [11]. The selected measuring station for this study is located three meters above sea level, providing a representative sampling location to ensure the accuracy of the recorded data [5]. The study adopted a systematic approach, focusing on the collection and analysis of rainwater quality, temperature, and humidity data within the Juanda International Airport area [9]. The time frame for the data collection spanned twelve years, from 2010 to 2021. This extensive timeline was chosen to capture a comprehensive understanding of potential atmospheric variations and trends [6].

The temperature and humidity data were meticulously gathered from different atmospheric layers: 850 hPa, 700 hPa, and 500 hPa, representing the low, middle, and high atmospheric layers respectively. This stratified approach offers a holistic overview of the atmospheric dynamics at different altitudes [12], [13]. Rainwater quality data was sourced from the Air Quality Database (DBKU) of the Meteorology, Climatology, and Geophysics Agency (BMKG). The data in this database includes biweekly sampling data collected from an Automatic RainWater Sampler (ARWS) tool, providing a reliable and consistent source of information for our analysis [14].

The research methodology followed a structured process. First, daily upper-air data was collected and processed into a graphical format to visually represent the information. This data was then analyzed descriptively to derive monthly averages, trends, and patterns [4], [15].

$$\mu = \frac{\sum_{i=1}^N X_i}{N}$$

Where:  $\mu$  is mean,  $X$  is the data,  $N$  is number of data

Lastly, a correlation analysis was carried out to establish a relationship between upper air conditions, specifically air temperature and humidity, and the pH level of the collected rainwater [1], [16-17]. The correlation formula used is as follows:

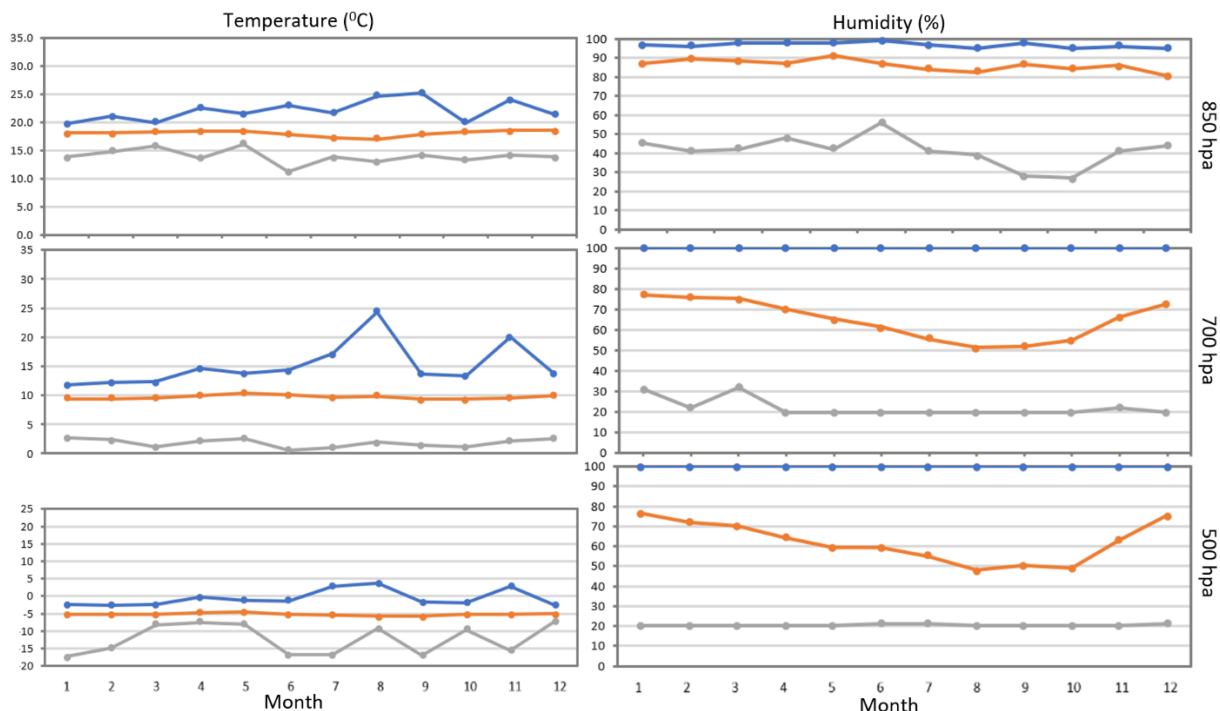
$$r_{xy} = \frac{n \sum XY - \sum X \sum Y}{\sqrt{n \sum X^2 - (\sum X)^2} \sqrt{n \sum Y^2 - (\sum Y)^2}}$$

Where:  $r_{xy}$  is correlation coefficient,  $x$  is independent variabel  $X$ ,  $y$  is Dependent Variabel  $Y$ , and  $n$  is the number of data. This analysis is crucial for understanding how atmospheric conditions influence rainwater quality [8].

## 3. Results and discussions

### 3.1 Air Temperature and Air Humidity

A comprehensive analysis of monthly air temperature at the atmospheric pressure levels of 850 hPa, 700 hpa, and 500 hPa, utilizing data spanning from January 2010 to December 2021. The resulting data is visually represented in the subsequent figures.

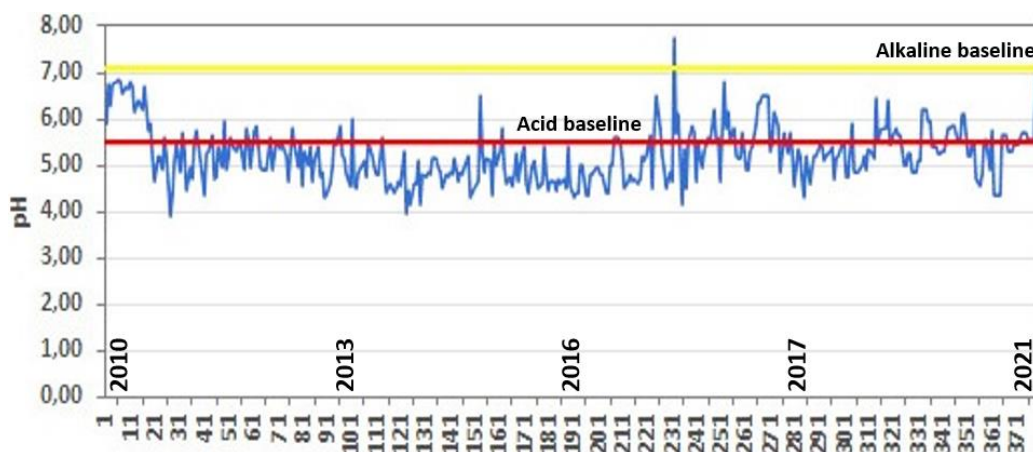


**Figure 1.** The monthly temperature (left) and humidity (right) from 2010 to 2021 on the various atmosphere pressure layers.

Figure 1 (upper section) displays data at the 850 hPa layer. The findings reveal that the peak air temperature occurs in September, registering at 25.2°C. Conversely, the lowest temperature is encountered in October and June, measured at 11.2°C. In terms of humidity, the maximum levels, pegged at 99%, are recorded in January, February, April, May, June, November, and December. October experiences the lowest humidity, dropping to 27%.

The middle part of Figure 1 reveals data for the 700 hPa layer. Here, the maximum air temperature is discovered in August, reaching up to 24°C. June, on the other hand, records the lowest air temperature at 1°C. As for humidity, the maximum level of 100% is a constant throughout all months. However, the minimum air humidity, which stands at 20%, is observed between April and October.

Finally, the data distribution at the 500 hPa layer is depicted in the lower part of Figure 1. It indicates that the highest air temperature, 4°C, is found in August, while the lowest temperature, 14.9°C, is reported in both October and December. Maximum air humidity maintains a steady 100% throughout the year, while a minimum humidity level of 20% is recorded each month, with the average from June to October being lower than that of November to May.



**Figure 2.** The rainwater acidity time series in 2010-2021

**Table 1.** The category of the rainwater pH

pH	Category	Data distribution (%)
> 7	normal	0.1
6.1 – 7	Tend to Neutral	4.4
5.6 – 6	Ideal	7.1
4.1 – 5.5	Acid	40
3 – 4	High Acid	0.4
< 3	Extreme Acid	0

### 3.2 Rainwater Quality

The acidity level (pH) of rainwater at Juanda International Airport exhibits a range from 3.89 to 7.71. The dispersion of the pH data for rainwater is graphically illustrated in Figure 2. Further categorization, based on the guidelines set forth by the Meteorology, Climatology, and Geophysics Agency (BMKG), allows us to classify the acidity level (pH) of the collected rainwater, as demonstrated in Table 1.

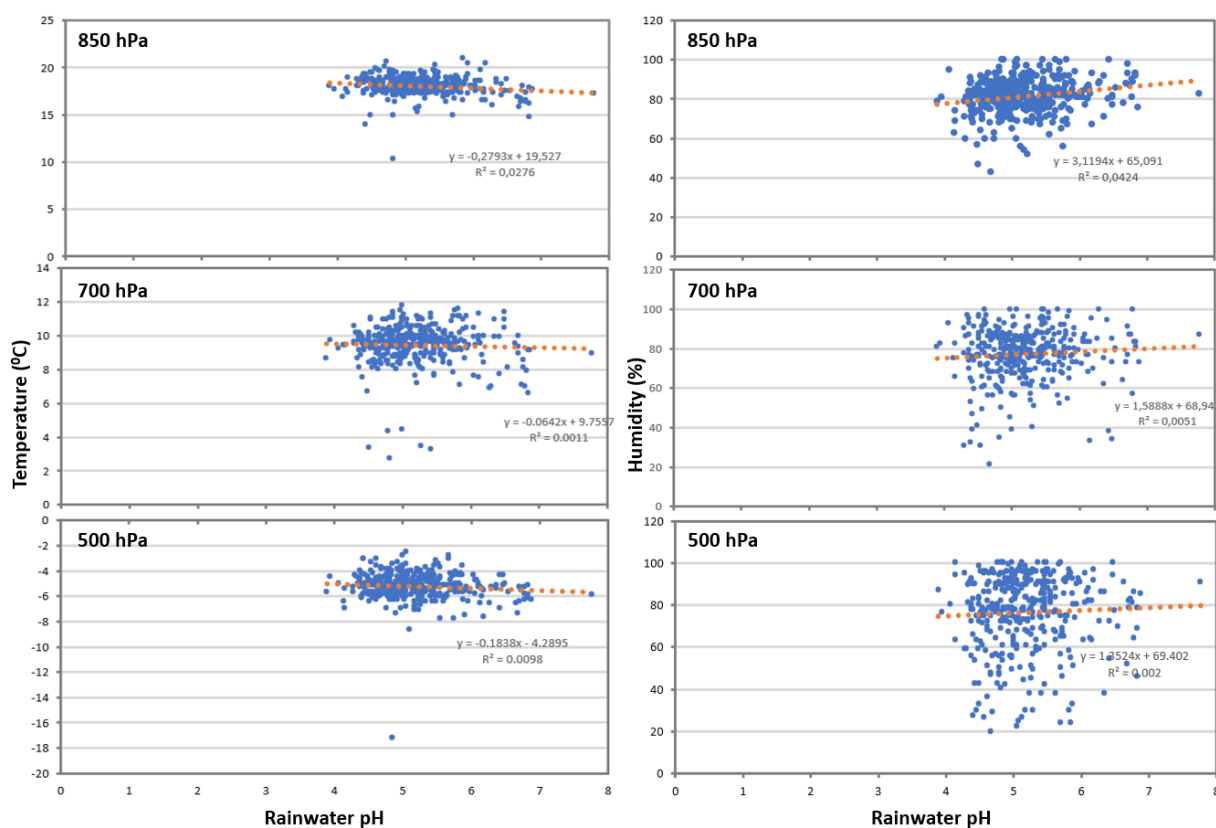
Table 1 indicates that a significant portion of rainwater, constituting 40% of the total data, falls within the pH range of 4.1 to 5.5, placing it under the acid rain category. This implies that rainwater at Juanda International Airport predominantly falls under the acid rain category. The reason for such lower pH values can be attributed to the location of the rainwater collection site, which is in proximity to the airport runway and relatively near the Madura Strait.

These geographical features inevitably impact the quality of rainwater in the area. Emissions from aircraft fuel combustion and marine chemicals have the potential to contaminate the atmospheric composition where rainfall originates. Notably, Carbon dioxide ( $\text{CO}_2$ ) and Carbon monoxide (CO) react with water vapor ( $\text{H}_2\text{O}$ ) mixed with other evaporated compounds to form carbonic acid ( $\text{H}_2\text{CO}_3$ ), categorized as a weak acid. Moreover, gases produced from the combustion or heating of sulfur, such as Hydrogen Sulfide ( $\text{H}_2\text{S}$ ) and Sulfur Oxide ( $\text{SO}_2$ ), react with water vapor to form Sulfuric Acid ( $\text{H}_2\text{SO}_4$ ), which is categorized as a strong acid [2]. The peak incidences of acid rain were notably recorded in the years 2016 and 2021.

### 3.3 The Relationship of Air Temperature and Humidity with the pH of Rainwater

An analysis of the relationship between the air temperature at an altitude of 850 hPa and the pH of rainwater reveals a distribution pattern with a negative inclination, as depicted in Figure 3 (upper left section). This indicates that a decrease in air temperature corresponds to an increase in the pH of rainwater, and vice versa. The correlation coefficient for the air temperature and rainwater pH is measured at -0.2793. Figure 3 (upper right) presents a scatterplot demonstrating the correlation between air humidity at 850 hPa and the pH of rainwater. Interestingly, the distribution pattern exhibits a positive trend, suggesting that an increase in air humidity coincides with a rise in the pH concentration of rainwater, and the inverse is also true. The correlation coefficient here is reported as 3.1194. Figure 3 (middle section) portrays the situation at an altitude of 700 hPa. The distribution pattern of the relationship between air temperature and rainwater pH appears to have a negative trend, with a correlation value of -0.0642. A scatterplot illustrating the correlation between air humidity and rainwater pH exhibits a positive distribution trend, with a correlation value of 1.5888. Finally, Figure 3 (lower section) represents a scatterplot depicting the correlation between air temperature, humidity, and the pH of rainwater at an altitude of 500 hPa.

Here, the relationship between air temperature and rainwater pH continues to show a negative distribution pattern, with a correlation value of -0.1838. However, the scatterplot demonstrating the correlation between air humidity and rainwater pH reveals a distribution pattern tending towards a low or non-existent correlation. This implies that, at an altitude of 500 hPa, air humidity does not significantly influence the pH of rainwater.



**Figure 3.** The scatterplot that showing relationship of pH vs temperature (left) and pH vs humidity (right) from 2010 to 2021 on the various atmosphere pressure layers.

Delving into this multifaceted discourse, a fitting point of departure would be exploring the chemistry and quality of rainwater, as rigorously scrutinized by [2] in Palu and [15] in Bekasi. Both of these insightful studies illuminate the intricate makeup of rainwater in these specific regions, thereby establishing a firm groundwork for deeper discussions on potential sources and subsequent effects of acid rain. Complementing these studies, comprehensive assessments on acid rain's properties, potential origins, and their interactions with distinctive environmental elements, conducted by [3-4], [17], offer an enriched perspective. These meticulous analyses pave the way towards understanding the considerable contribution of industrial operations, fuel burning, and the content of atmospheric gases in the evolution of rainwater's acidity.

When considering the wider implications of acid rain, it is fundamentally crucial to examine its effects on a wide spectrum of materials and structures. This significance is strongly underscored by the works of [7] and [8]. These studies unravel the destructive potential of acid rain, which includes the degradation of the mechanical properties of asphalt and the corrosion of stainless steel rebars embedded in concrete – both of which are crucial constituents of urban infrastructure. Adding to this, the crucial role of weather forecasting and nowcasting in alleviating the environmental pollution impacts on sectors like aviation is convincingly demonstrated by [5] and [12]. Advanced predictive methodologies, as advocated by these studies, can facilitate the anticipation of severe weather phenomena, including those exacerbated by pollution, thereby enabling efficient planning and response mechanisms. Expanding the perspective, understanding how climate variations such as rainfall patterns affect ecosystems is of fundamental significance. This crucial link is effectively highlighted by [13], enabling a more comprehensive view of the interplay among climate change, acid rain, and ecosystems.

Finally, interjecting an economic and human-centric viewpoint into this dialogue, studies by [11] and [16] focus on the economic adaptations to environmental changes and the collective environmental impacts borne from human activities. These investigations underscore the profound socio-economic facets of environmental pollution and accentuate the dire need for sustainable practices to mitigate these impacts.

**Table 2.** Association between atmospheric dynamics (temperature and humidity) and the pH of rainwater

The Relationship of Rainwater pH with		Atmospheric Dynamics	
		Temperature	Humidity
Layer (hPa)	850	-0.2793	31.194
	700	-0.0642	15.888
	500	-0.1838	

#### 4. Conclusion

Our study reveals that the rainfall recorded at Juanda International Airport significantly falls into the acid rain category, constituting approximately 40% of total occurrences, with an acidity level (pH) ranging between 4.1 and 5. This highlights a concerning environmental aspect that warrants further attention. The atmospheric dynamics, namely air temperature and humidity, have a noticeable effect on the pH level of the rainwater. Air temperature presents a negative correlation, whereas air humidity exhibits a positive correlation with the pH of rainwater. Interestingly, the correlation values are more conspicuous at the upper atmospheric strata, specifically at the 700 hPa layer for air temperature and the 850 hPa layer for air humidity. These layers are crucial as they serve as the primary formation zones for convective clouds, which are the primary cause of rainfall. Our findings underscore the intricate relationship between atmospheric conditions and rainwater acidity, a subject deserving further in-depth research and understanding.

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