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Meta-Analysis: Seasonal Variations in pH Concentration and Their Impact on River Water Quality

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Abstract: Water is a vital resource, yet its quality is increasingly affected by climate change and human activities. Seasonal variations, particularly between dry and rainy periods, may influence river water quality, with pH serving as a key chemical parameter. This study aimed to examine the effect of seasonal differences on river water pH levels using meta-analysis. The objective was to provide evidence of whether rainfall patterns significantly alter pH concentrations in tropical and subtropical regions. Relevant literature was collected from online databases using keywords such as "water pollution," "dry season," and "wet season." Out of more than 40 studies, four articles with complete seasonal pH data were selected. Data were processed using OpenMEE software with a random-effects model, and the log response ratio (lnRR) was applied to compare pH values between dry (control) and rainy (treatment) seasons. The analysis revealed no significant seasonal differences in pH levels. The overall effect size was weak (–0.758), with the 95% confidence interval crossing zero. Heterogeneity among studies was high (I^2 = 80.325%), yet subgroup analyses by region, climate, and location confirmed consistent results. In conclusion, river water pH in tropical and subtropical areas remains relatively stable across seasons, influenced by steady climate conditions, well-mixed water bodies, and consistent vegetation. Broader datasets, especially from Indonesia, are needed to validate these findings.

Keywords: Anthropogenic activities, meta-analysis, pH concentration, river water quality.

Introduction

Climate change has become a global issue that affects various aspects of life on Earth, particularly soil and water quality (Pinontoan et al., 2022). Indonesia, as a country with exceptionally high biodiversity, possesses vulnerable ecosystems where the impacts of climate change are strongly evident (Antarissubhi et al., 2023). Climate change is characterized by shifts in global climate patterns that lead to unpredictable weather conditions (Khotimah et al., 2022). This phenomenon occurs due to changes in climate variables, such as air temperature and rainfall, which take place consistently over a long period, around 50 to 100 years. In addition, climate change is influenced by unstable weather conditions, such as irregular rainfall, increasing storm frequency, extreme temperatures, and drastic shifts in wind direction (Kementerian Negara Lingkungan Hidup, 2004). Water is vital for life due to human and ecosystem dependence on sufficient and high-quality water resources (Mulyanti, 2022). To ensure the sustainability of water resources, it is important to wisely manage anthropogenic activities, promote sustainable practices, and adopt environmental protection policies that balance human needs with water resource conservation (J. Z. Khan & Zaheer, 2018; R. Khan et al., 2020; Margariti et al., 2019).

Water sources are a basic necessity for all life on Earth to sustain the survival of all living beings in the universe. Unpolluted water is essential for humans to meet daily needs, grow, and develop, as well as for all life processes, and is also crucial in other sectors such as industry, agriculture, and beyond (Rumaisa et al., 2019). The existence of springs is influenced by land conditions, soil types, and vegetation within catchment areas (Djunaedi, 2012). On Earth's surface, water is of great importance to all living organisms, including plants, animals, humans, and microorganisms. Life requires water as a fundamental necessity. However, if not available under proper conditions, water can also become a source of disaster (Fadila et al., 2023).

One of the most evident impacts of climate change is the decline in soil quality. Healthy soil serves as the foundation for agricultural activity and the sustainability of ecosystems. However, rising temperatures and erratic rainfall patterns accelerate erosion, pollution, and soil degradation (Hasan, 2025). In tropical regions of Indonesia, climate change has triggered soil fertility decline due to increased microbial activity and altered soil structure. This condition poses a serious threat to food security, particularly in rural areas heavily dependent on agriculture (Hariyanto, 2017; Supriyadi et al., 2021). Alongside soil, water as a source of life also faces major challenges due to climate change. Water quality in Indonesia is increasingly affected by rising temperatures and pollution, much of which comes from human activities. In urban areas, water sources often experience quality deterioration from domestic and industrial waste, exacerbated by extreme weather events. Consequently, the availability of clean water is declining, directly impacting public health and ecosystem sustainability (Mardizal & Rizal, 2024).

Various global efforts have been undertaken to secure the sustainability of water resources both now and in the future. These efforts are included in the focus of the United Nations Sustainable Development Goals (SDGs). Water resource issues involve both quality and quantity aspects. It is essential to address both simultaneously, as water quality and quantity are interrelated and influence one another. Poor water quality reduces the availability of safe water and can negatively impact human health and ecosystems. The pH parameter is one chemical indicator used to measure the acidity or alkalinity of water. Changes in pH can indicate pollution or disturbances in water resources. Healthy and natural water typically has a balanced pH, ranging from 6 to 8. River water originating from springs generally has very good quality. However, as it flows, it can accumulate many pollutants (Keraf, 2010). Water is a fundamental element for all biological activities and human life. Although considered one of the few natural resources that is always available, its existence remains limited because it depends on the continuously ongoing hydrological cycle. The amount of water on Earth has not increased significantly over time, leading to uneven distribution (Afiatun et al., 2018). The demand for water continues to grow alongside population growth, rising incomes, and the expansion of development activities that require water (Wulandari & Ilyas, 2019).

Several human activities affect water quality, including land-use change, domestic and industrial waste disposal, agricultural pollution, and construction activities. The intensity and type of anthropogenic activities can be influenced by climate and weather factors. Elevation, or altitude, is one of the physiographic factors that plays an important role in influencing climate, particularly rainfall and air temperature, while differences in elevation may affect variations in temperature and light intensity (Smith et al., 2023). The interaction between climate and weather changes and human activities can affect water quality (Gholizadeh et al., 2016; Guo et al., 2018; Hashem et al., 2021; Thu Minh et al., 2020; Xiao et al., 2020). During the rainy season, surface runoff increases and may carry more pollutants from agricultural or urban lands into water resources. Moreover, changes in rainfall patterns and water temperature caused by climate change can affect the physical and chemical quality of water.

Climate change can also influence plant growth patterns, fertilizer and pesticide use, as well as irrigation water needs. Industrial activities may likewise be affected by climate change, particularly in terms of water use in production processes and waste disposal. Overall, climate and weather factors can influence the intensity and types of anthropogenic activities related to water resources. Understanding the relationship between climate, weather, and human activities affecting water quality is crucial for sustainable water resource management. Sustainable natural resource management requires a balance between

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fulfilling human needs, improving social and economic welfare, and preserving environmental functions through environmentally friendly approaches to ensure the survival of future generations (Sabila S., 2020).

Research Methodes

Manuscript Selection

Using two boundary techniques, we gathered a variety of water contamination literature in order to concentrate the analysis on seasonal aspects. First, we applied a seasonal boundary, namely the rainy season and the dry season. Second, we applied a location boundary, focusing on urban and suburban areas. However, this method yielded more than 42 manuscripts covering both direct and indirect comparisons. Therefore, we narrowed the literature search by focusing specifically on the seasonal aspect.

To obtain manuscripts or literature, we accessed publication databases such as *search.proquest.com*. We used the keywords "water pollution," "dry season," "wet season," and "environment assessment." No restrictions were applied regarding publication year or research location, with the expectation that including temporal and spatial variations in the collected manuscripts would provide a solid data foundation for evaluating water pollution comparisons between the rainy and dry seasons.

In our literature search, we found many articles discussing water pollution; however, only a few studies compared pollution levels across different seasons. From the publication database, we identified 21 articles that reviewed water pollution during different seasons. Each study, however, employed different water pollution parameters such as pH, BOD, phosphate, nitrate, and others. Therefore, the first step we took was to inventory the most frequently discussed parameters across all articles. Three parameters were most commonly analyzed: nitrate, phosphate, and pH.

The second step was to check the completeness of the data presented in the articles, such as the number of samples, mean values, and standard deviation of each parameter during both the dry and rainy seasons. However, we encountered challenges with some articles that did not provide complete data, such as failing to state the number of samples or omitting standard deviation values. Some journals even reported data for only one season without including information for the other. The third step was to select parameters with complete data and a relatively large number of samples compared to other parameters. Based on these criteria, the pH parameter met the requirements and was chosen as the focus of our analysis.

After going through the selection stages described above, four articles met the criteria and were included in the analysis. The data from these four articles were mapped, coded, and analyzed. In this analysis, pH pollution levels during the dry season were considered the control group (c), while those during the rainy season were considered the treatment group (e). By dividing the data into these two groups, we were able to conduct a more in-depth comparison and analysis of differences in water pollution between the dry and rainy seasons. The following data were obtained from several journals and subsequently subjected to statistical meta-analysis.

Table 1. pH Characteristic Data

Study	Place	Region	Journal	Climate	Nc	Xc	SDc	Ne	Xe	SDe
1	Vietnam	Southeast Asia	MDPI	Subtropical	40	7.37	0.63	40	6.92	1.06
2	Malaysia	Southeast Asia	IOP Science	Tropical	3	7.37	0.2475	3	6.822	0.259
3	China	East Asia	ScienceDirect	Subtropical	30	7.58	0.29	30	7.68	0.31
4	China	East Asia	ScienceDirect	Subtropical	6	7.80	0.14	6	7.29	0.18
5	China	East Asia	MDPI	Tropical	26	8.62	0.16	26	8.51	0.15

Notes:
N = Sample;
X = Mean;
SD = Standard Deviation;
c = Control Data;
e = Experimental Data

Meta-Analysis

The selected data from 4 articles were processed using statistical meta-analysis with the OpenMEE software (Wallace et al., 2017), applying the Continuous Random Effects method. The log-transformed response ratio (effect size, lnRR) was used to quantify differences in pH levels between the rainy and dry seasons. The dry season served as the control variable, while the rainy season was considered the treatment variable. The following equation was used:

$$lnRR = \frac{X_t}{\ln(x)} \qquad \textbf{(1)}$$

Xe represents the mean pH concentration in the dry season, and Xc is the mean pH concentration in the rainy season. The variance of $ln\ RR$ is calculated using the following equation.

$$v = \frac{SD_t^2}{n_t X_t^2} + \frac{SD_c^2}{n_c X_c^2} \qquad \textbf{(2)}$$

The weighting of the effect size is calculated using the following equation.

$$ln\ RR = \frac{\sum ln\ RR_i\ x\ w_i}{\sum w_i} \qquad \textbf{(3)}$$

$$w_i = \frac{1}{v_i} \qquad \textbf{(4)}$$

$ln\ RR_i$ represents the effect size of data i, and wiw_iwi is its weight. Then, the 95% CI is calculated using the following equation.

$$95\%\text{CI} = \text{In RR} \pm 1.96SE_{lnRR} \qquad \textbf{(5)}$$

$$SE_{ln\ RR} = \sqrt{\frac{1}{\sum w_i}} \qquad \textbf{(6)}$$

$SE\overline{\overline{ln}}\overline{RR}$ denotes the standard error of $ln\ RR$. If the 95% CI intersects with zero, it indicates that the pH concentration in the rainy season does not differ significantly from that in the dry season.

Results and Discussion

The results of the analysis using standard meta-analysis indicate that the pH concentration between the control and treatment does not show a significant relationship. This is evident from the 95% confidence interval (CI), where the p-value is 0.045 or above 0.05, and based on the combined random-effect size value of -0.758, the relationship between control and treatment is considered weak.

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Continuous Random-Effects Model
Metric: Standardized Mean Difference
 Model Results
 Estimate   Lower bound   Upper bound   Std. error   p-Value
 -0.758       -1.498        -0.018        0.378       0.045

 Heterogeneity
 tau^2   Q(df=4)   Het. p-Value    I^2
 0.485   20.330     < 0.001       80.325
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Figure 1. Forest Plot

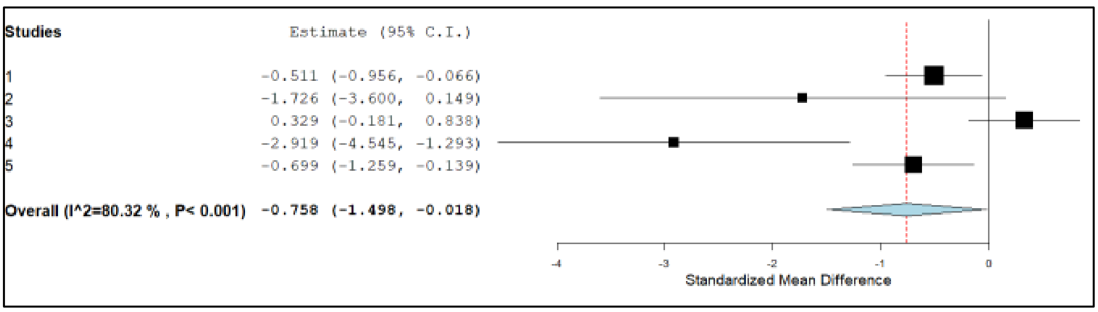

Figure 2. Forest Plot

The heterogeneity across the five studies shows varied results with an I² value of 80.325% and a heterogeneity p-value < 0.001. Furthermore, based on the forest plot, almost all studies indicate a negative effect size, with only Study 3 showing a positive effect size. This suggests that the majority of studies demonstrate better outcomes in the control group. Cumulative CI can be seen in Figure 2, while subgroup analyses are presented in Figures 3, 4, and 5.

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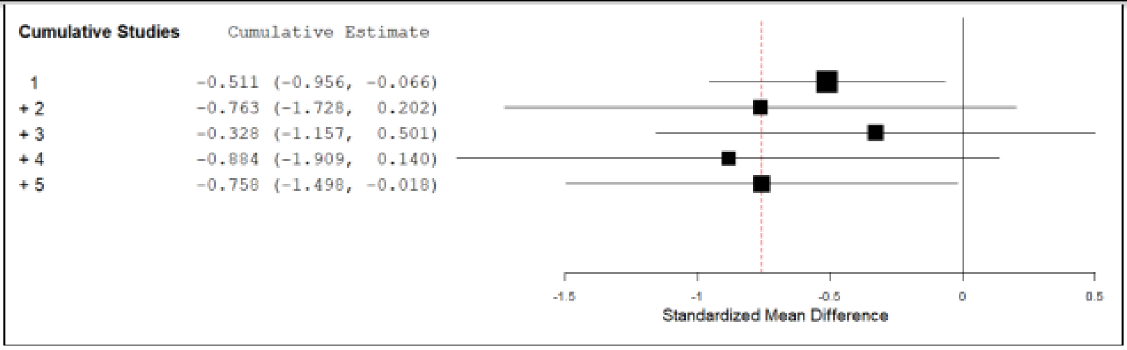

Figure 3. *Cumulative Forest Plot*

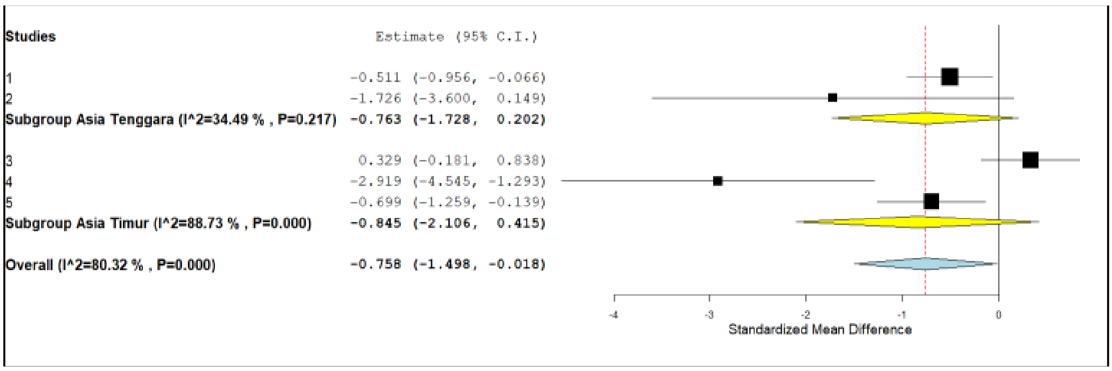

Figure 4. *Subgroup Forest Plot* by Continent/Region

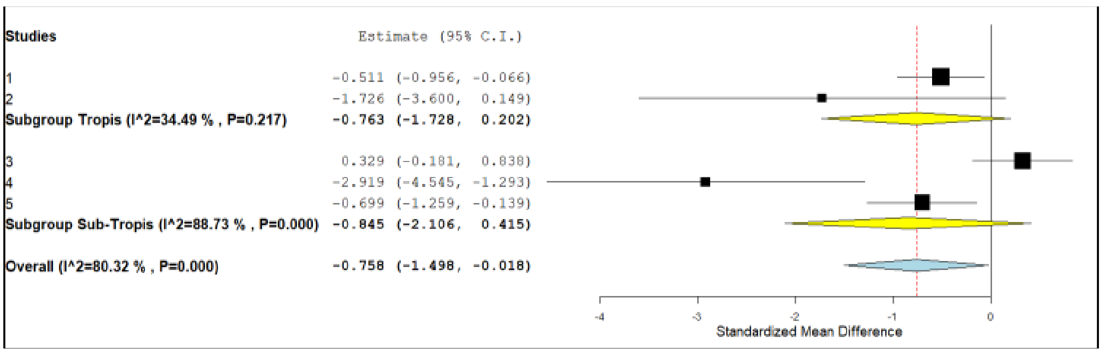

Figure 5. *Subgroup Forest Plot* by Climate

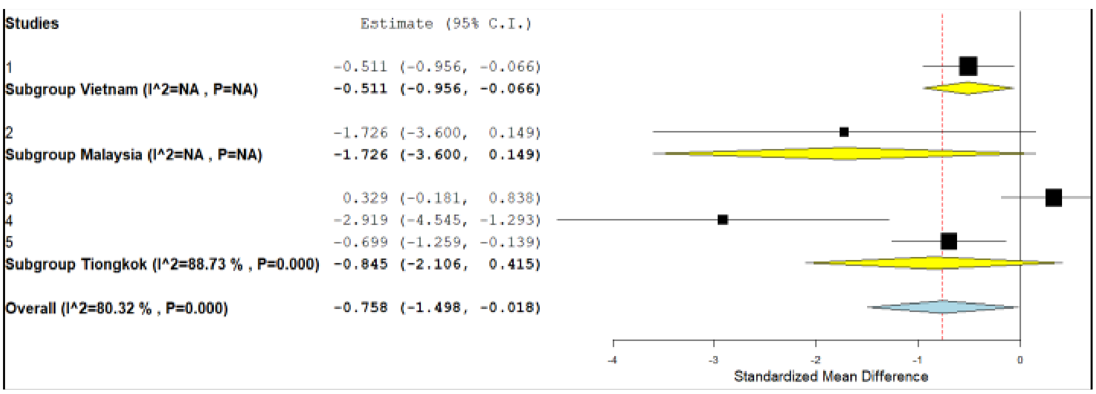

Figure 6. *Subgroup Forest Plot* by Location

Based on the effect sizes shown in Figures 3, 4, and 5 for each subgroup whether by Continent/Region, Climate, or Location there is no significant difference, as indicated by the 95%

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confidence interval (CI) in each subgroup intersecting the red line.

Conclusion

This study of the meta-analysis indicate that pH concentrations across different seasonal conditions do not differ significantly. This may occur because the climate in these regions is relatively stable throughout the year, meaning there are no major variations in temperature, rainfall, or other factors that could affect pH levels. The water bodies in these areas are relatively large and well-mixed, which means that any changes in pH tend to be distributed across wide areas, making them difficult to detect. Vegetation in these regions also remains relatively consistent throughout the year, resulting in a fairly constant release of organic matter into the water, which can also influence pH levels. To strengthen this conclusion, further studies incorporating additional data from other research or journals, including those focusing on conditions in Indonesia, are needed. However, since such articles have not yet been found, this remains a challenge.

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