JURNAL KESEHATAN LINGKUNGAN
JURNAL DAN APLIKASI TEKNIK KESEHATAN LINGKUNGAN

ISSN 1829-9407 (Print)
ISSN 2581-0898 (Online)

Volume 23, No.1, January 2026 ; Page: 25-34; DOI: https://doi.org/10.31964/jkl.v23i1.1103

Original Research

IMPACT OF WEATHER VARIABILITY ON EMERGENCY MEDICAL SERVICE ACTIVITY IN SEMARANG CITY

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Article Info

Article history:

Received December 19, 2025
Revised January 15, 2025
Accepted January 27, 2025

Keywords:

Weather variability
Emergency medical services
Extreme temperature
Relative humidity
Rainfall

ABSTRACT

Impact of Weather Variability on Emergency Medical Service Activity in Semarang City. *Weather variability influences the occurrence of medical emergencies that require rapid response, particularly in urban areas with high population density. This study aimed to analyze the effects of temperature, relative humidity, and rainfall on the number of daily PSC 119 calls in Semarang City. An ecological time-series design was applied using daily call records and meteorological data collected over 365 days in 2024, analyzed with a Distributed Lag Non-linear Model combined with quasi-Poisson regression to estimate risks across lag periods. The results show that both low and high temperatures substantially increased the risk of PSC 119 calls compared with the reference temperature. Moderate humidity was associated with higher risk, while very high humidity demonstrated a protective effect. Rainfall, particularly no-rain to light-rain conditions, also contributed to increased call frequency. Most weather-related effects occurred within 0–3 days, indicating an acute pattern of influence. These findings highlight the importance of integrating weather prediction into emergency preparedness systems to support workforce planning, resource allocation, and operational response. Further studies incorporating call-type classifications and additional environmental variables are recommended to improve understanding of weather-related emergency service demand.*

INTRODUCTION

Climate change has emerged as a major global health issue due to its impact on environmental stability and its role in increasing the risk of various health disorders [(1)]. Rising global temperatures, shifts in rainfall patterns, and the increasing frequency of extreme weather events, such as heatwaves and high-intensity precipitation, have been associated with adverse health outcomes [(2)]. The World Health Organization (WHO) emphasizes that exposure to extreme temperatures can elevate the risk of cardiovascular diseases, respiratory disorders, dehydration, and heat exhaustion, all of which may require emergency medical care. In addition, the World Health Organization (WHO) and the Intergovernmental Panel on Climate Change (IPCC) have explained that the health impacts of climate change may occur through both direct pathways, such as exposure to extreme heat, and indirect pathways

mediated by changes in environmental quality, including air and water quality, as well as shifts in vector-borne disease patterns [3][4].

In Indonesia, the Ministry of Health has reported that exposure to high temperature and humidity may trigger hypertension, ischemic heart disease, and cerebrovascular disorders, particularly among vulnerable populations [5]. This issue becomes increasingly relevant in urban areas experiencing rising temperatures due to rapid urbanization. The urban heat island (UHI) phenomenon results in higher air temperatures in cities compared with surrounding areas, thereby amplifying health risks during periods of extreme heat [6].

International evidence further supports the association between extreme weather conditions and increased demand for emergency medical services. Systematic reviews have demonstrated that both extreme heat and cold are consistently associated with increased ambulance dispatches and emergency medical service utilization across multiple regions [7][8]. A study conducted in Australia reported that heatwaves were associated with a 12.68% increase in ambulance calls, particularly among vulnerable populations and communities with lower socioeconomic status [9]. Similarly, a study in China found that exposure to extreme temperatures, both hot and cold, significantly increased the risk of ambulance calls within 24 hours after exposure, with relative risks (RR) of 1.172 during extreme heat and 1.175 during extreme cold conditions [10].

In Indonesia, daily weather fluctuations have become increasingly unpredictable due to rapid urbanization and climate change [11]. The Indonesian Agency for Meteorology, Climatology, and Geophysics (BMKG) reported that 2024 was among the hottest years of the past decade, marked by an increase in consecutive extreme heat days [12]. This condition intensifies thermal stress in urban areas such as Semarang, a city characterized by a pronounced urban heat island (UHI) effect and high population density [13].

Semarang City also has a relatively high prevalence of cardiovascular diseases, which further increases the potential for emergency events during periods of extreme weather [14]. According to the 2021 Central Java Provincial Health Profile, the number of hypertension cases in Semarang City reached 67,101, with a prevalence of 19.56%, one of the highest in the province [15]. This high burden of hypertension increases the likelihood of medical emergencies, particularly during extreme weather conditions that may precipitate hospitalization or death due to heart attack, stroke, or acute cardiovascular decompensation [16]. These conditions may place an additional burden on emergency medical services, particularly the Public Safety Center (PSC) 119, which operates as part of the Integrated Emergency Medical Service System (Sistem Penanggulangan Gawat Darurat Terpadu, SPGDT).

PSC 119 serves as the central command for emergency response, managing a wide range of calls, including medical transportation, emergency homecare services, medical emergencies, traffic accidents, and non-emergency incidents [17]. In dynamic urban settings such as Semarang, weather variability may influence the volume of PSC 119 calls, as several health conditions are sensitive to changes in temperature and humidity, while rainfall and extreme weather events increase the risk of injuries and accidents [18]. Therefore, understanding the relationship between weather factors and emergency service demand is essential to support preparedness, fleet planning, and the effectiveness of rapid response systems.

Despite substantial global evidence linking weather conditions to increased emergency calls, no study in Indonesia has quantified the non-linear and short-term lagged effects of multiple weather variables on emergency medical service demand, particularly using PSC 119 data. Most Indonesian research has focused on the effects of weather on specific diseases, such as infectious diseases or dengue fever, with relatively limited attention to impacts on emergency care systems. Moreover, no studies have specifically examined how temperature, humidity, and rainfall influence PSC 119 call patterns, particularly in Semarang City. In addition, local studies employing a Distributed Lag Non-linear Model (DLNM) approach are lacking, even

though this method is highly relevant for capturing non-linear relationships and delayed effects of environmental exposures on health outcomes.

Therefore, robust scientific evidence is needed to elucidate the impact of weather variability on PSC 119 activities in Semarang, both for epidemiological purposes and for operational planning of emergency services. Based on these gaps, this study aims to analyze the effects of temperature, humidity, and rainfall on the number of PSC 119 calls using a time-series approach with a Distributed Lag Non-linear Model (DLNM), in order to characterize the non-linear associations and lagged effects within the urban population of Semarang City.

MATERIALS AND RESEARCH METHODS

This study employed an observational design with an ecological time-series approach to examine the effects of weather variability on the number of Public Safety Center (PSC) 119 service calls in Semarang City from January to December 2024. This design was selected because it is appropriate for evaluating temporal associations between time-varying environmental exposures and acute health events at the population level.

The first stage of the study involved the collection of daily secondary data. Data on the number of PSC 119 calls were obtained from the Semarang City Health Office and included all calls recorded each day, encompassing medical emergencies, traffic accidents, and other emergency incidents. These data were used as the dependent variable. Daily meteorological data, including mean air temperature (°C), relative humidity (%), and rainfall (mm), were obtained from the Indonesian Agency for Meteorology, Climatology, and Geophysics (BMKG), Semarang Climatology Station, and were treated as exposure variables.

In the subsequent stage, data cleaning and synchronization were conducted based on calendar dates to ensure consistency between PSC 119 call records and meteorological data. Incomplete or inconsistent observations were assessed and managed according to standard time-series analytical procedures. As the study used aggregated daily data without individual identifiers, ethical approval for individual participants was not required.

Weather variables were treated as non-linear exposures with the potential to exert both immediate and delayed effects on acute health outcomes. The ecological time-series design evaluates day-to-day variations within the same population, thereby inherently controlling for time-invariant confounding factors. To minimize confounding by long-term trends and seasonal patterns, the analysis focused on short-term lag effects ranging from 0 to 3 days, capturing acute responses to weather variability rather than gradual temporal changes. Accordingly, the estimated associations primarily reflect the immediate impacts of weather conditions on emergency service demand. Given the one-year study period, the analysis was not intended to estimate long-term trends but to assess short-term fluctuations in PSC 119 call volume associated with daily weather variability.

To quantify these relationships, a Distributed Lag Non-linear Model (DLNM) was applied. This modeling framework enables the assessment of non-linear exposure–response relationships while simultaneously estimating short-term lagged effects. Cross-basis functions were constructed for each weather variable using natural cubic splines to flexibly model exposure–response associations across different levels of exposure.

The reference temperature was set at 29°C, corresponding to the average daily temperature during the study period and representing typical thermal conditions in Semarang City. The lag period was defined as 0–3 days, based on epidemiological evidence suggesting that the health effects of weather exposures generally occur within a few days after exposure. Exposure levels for temperature, relative humidity, and rainfall were selected based on the distribution of daily observations to represent both commonly observed and extreme weather conditions.

Model estimation was conducted using quasi-Poisson regression to account for the count nature of the outcome variable and to address potential overdispersion. The results were expressed as relative risks (RRs) with 95% confidence intervals to quantify the magnitude of

associations between weather exposures and PSC 119 call volume. All statistical analyses were performed using R software version 4.x, employing the dlnm package, which is widely used in environmental epidemiology research.

RESEARCH RESULTS AND DISCUSSION

Descriptive Statistics

From January to December 2024, substantial day-to-day variability was observed in the number of PSC 119 calls in Semarang City. The average number of calls was 68.86 cases per day (SD 29.21), with a range of 17–137 calls. Daily air temperature ranged from 25.9°C to 32.3°C, with a mean of 29.47°C (SD 1.21). Relative humidity varied between 57% and 95%, with an average of 74.3% (SD 6.92), while daily rainfall showed wide variation from 0 to 203.2 mm (mean 7.76 mm; SD 19.25).

Table 1. Descriptive statistics of daily PSC 119 calls and weather variables in Semarang City, 2024.

Variable	Mean	SD	Minimum	Maximum
Total Calls (cases/day)	68.86	29.21	17	137
Average Temperature (°C)	29.47	1.21	25.9	32.3
Humidity (%)	74.3	6.92	57	95
Rainfall (mm)	7.76	19.25	0	203.2

Effect of Temperature on PSC 119 Calls

The DLNM analysis demonstrated a non-linear association between temperature and the number of PSC 119 calls. Compared with the reference temperature of 29°C, the risk of calls increased significantly at both lower and higher temperatures. At 25.9°C, the risk increased by 2.61-fold (95% CI: 1.27–5.37), while at 32.3°C the risk increased to 1.66-fold (95% CI: 1.23–2.26). The exposure–response curve showed a clear U-shaped pattern, indicating elevated risks at both temperature extremes. Lag effects over 0–3 days were relatively stable, with no evidence of prolonged delayed effects.

Table 2. Relative risk (RR) estimates of PSC 119 calls associated with daily temperature exposure (lag 0–3 days).

Temperature (°C)	RR	95% CI
25.9	2.61	1.27–5.37
29	1	—
32.3	1.66	1.23–2.26

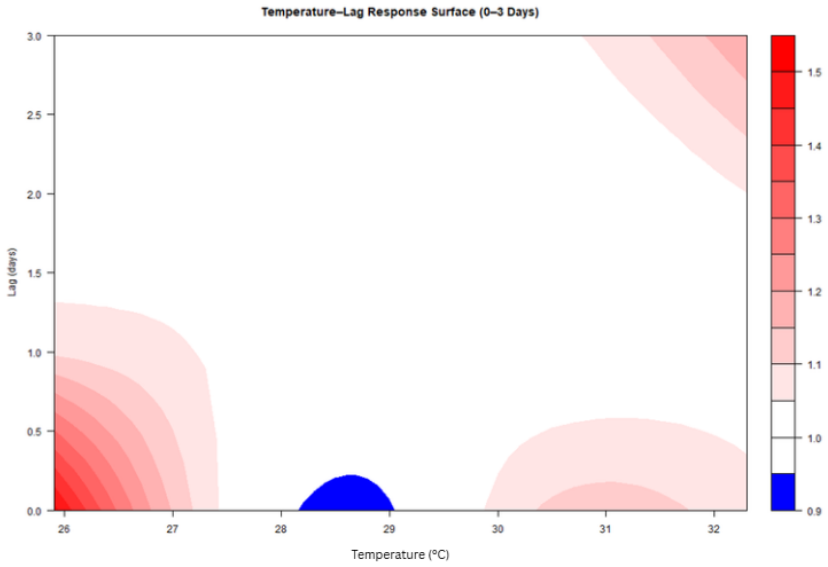

Figure 1. Temperature–lag response surface (DLNM)

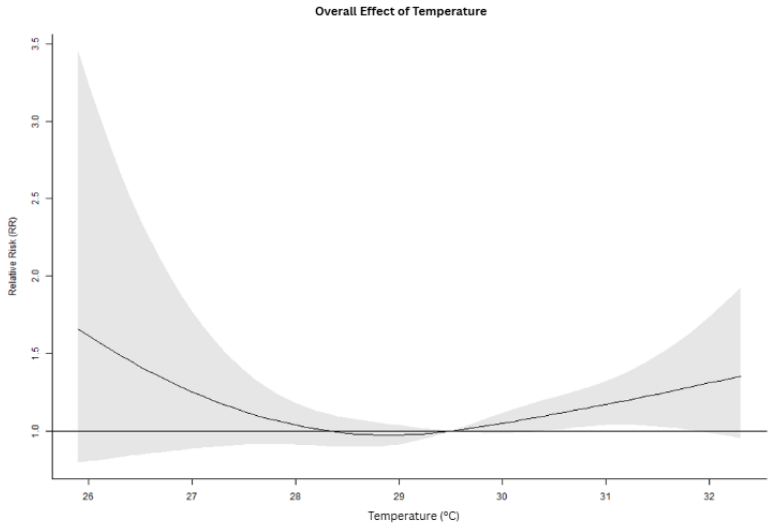

Figure 2. Overall effect of temperature on PSC 119 calls

Effect of Humidity on PSC 119 Calls

Humidity exhibited a non-linear relationship distinct from that of temperature. At a relative humidity of 75%, the risk of PSC 119 calls increased by 12% (RR = 1.12; 95% CI: 1.06–1.19). In contrast, at higher humidity levels (85.7%), the risk significantly decreased (RR = 0.42; 95% CI: 0.19–0.94). This pattern was clearly illustrated in the humidity exposure–response curve.

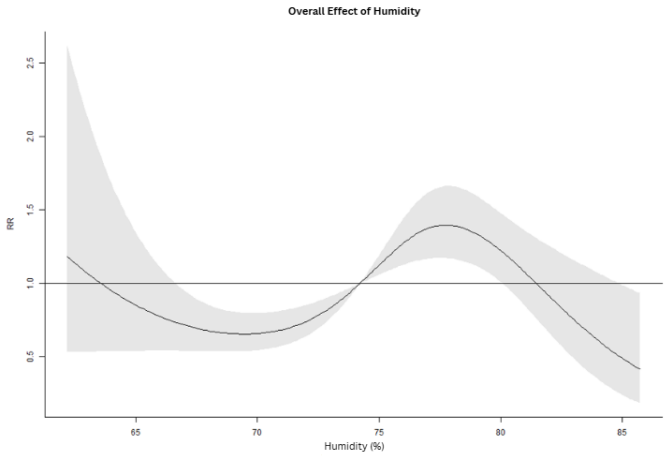

Figure 3. Overall effect of humidity on PSC 119 calls (lag 0–3 days)

Effect of Rainfall on PSC 119 Calls

Rainfall was also significantly associated with PSC 119 calls. On days without rainfall (0 mm), the risk of calls nearly doubled (RR = 1.98; 95% CI: 1.21–3.26). Light rainfall of 10 mm was associated with a 43% increase in risk (RR = 1.43; 95% CI: 1.09–1.86), while moderate rainfall of 20 mm showed a smaller but still significant increase in risk (RR = 1.12; 95% CI: 1.01–1.25).

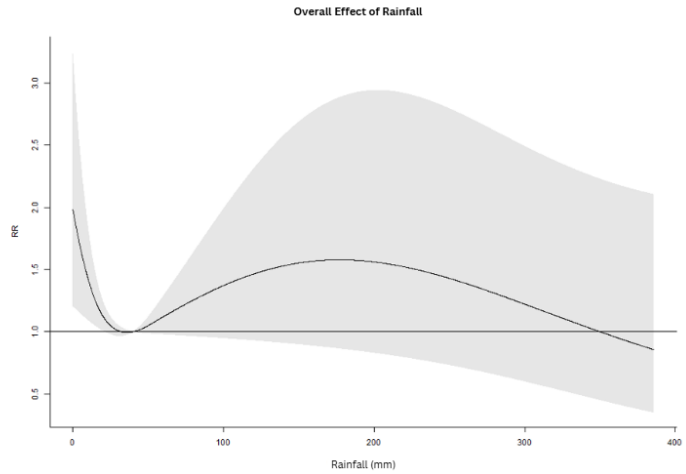

Figure 4. Overall effect of rainfall on PSC 119 calls (lag 0–3 days)

Table 3. RR estimates for PSC 119 calls by humidity and rainfall (lag 0–3 days)

Variable	Exposure levels	RR	95% CI
Humidity (%)	75	1.12	1.06–1.19
	85.7	0.42	0.19–0.94
Rainfall (mm)	0	1.98	1.21–3.26
	10	1.43	1.09–1.86
	20	1.12	1.01–1.25

This study demonstrates that weather variability significantly influenced the number of PSC 119 calls in Semarang City throughout 2024. Among the examined weather variables, temperature emerged as the most dominant factor affecting PSC 119 service demand. These findings are consistent with global evidence indicating that temperature, humidity, and rainfall are important determinants of increased medical emergency incidents [19]. Recent systematic reviews have reported that both heat waves and cold spells consistently increase the incidence of cardiovascular, respiratory, and injury-related events requiring emergency medical services [20]. In line with these findings, the present study shows that both low and high temperatures significantly increased the risk of PSC 119 calls.

Temperature exhibited the strongest effect on PSC 119 call risk at both low (25.9°C) and high (32.3°C) exposure levels. The observed U-shaped association is consistent with studies conducted in China, which reported that the health effects of extreme temperatures may occur within hours and persist for several days following exposure, particularly for conditions sensitive to thermal stress [10]. Other studies applying Distributed Lag Non-linear Models (DLNM) have similarly demonstrated that both extreme heat and extreme cold are associated with increased emergency medical service utilization [21].

Extreme temperatures may trigger a range of physiological responses. Heat exposure can lead to vasodilation, reduced blood pressure, increased heart rate, dehydration, electrolyte imbalance, and heat-related illnesses, including heat exhaustion and heat stroke [10]. These mechanisms provide biological plausibility for the observed increase in emergency service demand during periods of thermal extremes.

In addition to temperature, relative humidity also influenced the risk of PSC 119 calls, exhibiting a more complex non-linear pattern. The risk increased at moderate humidity levels (75%) but declined significantly at very high humidity (85.7%). Similar patterns have been reported in studies examining emergency department visits, where risk profiles were influenced by the combined effects of temperature and humidity [22]. Elevated risk at moderate humidity may reflect increased thermal discomfort, which can exacerbate cardiovascular and respiratory strain. Previous studies have also suggested that humidity affects emergency visits through respiratory mechanisms and heat-related stress, with non-linear exposure–response relationships consistent with the present findings [23]. Conversely, the reduced risk observed at very high humidity levels may be associated with decreased outdoor activity during highly humid or pre-rain conditions, potentially lowering the likelihood of accidents or events requiring PSC 119 response. Prior research indicates that the relationship between humidity and health outcomes may vary according to community behavior and local environmental contexts [22].

Rainfall demonstrated a weaker effect compared with temperature but remained significantly associated with PSC 119 call volume, particularly under no-rain conditions (0 mm), followed by light to moderate rainfall (10–20 mm). These findings are consistent with studies from Korea reporting that wet road conditions and abrupt weather changes contribute to increased traffic accidents and emergency incidents [24]. Overall, the relatively smaller contribution of rainfall further supports the conclusion that temperature is the most influential weather factor affecting PSC 119 workload.

The application of the Distributed Lag Non-linear Model (DLNM) was appropriate for this analysis, as it allows for the assessment of non-linear exposure–response relationships and delayed effects, consistent with recommendations in recent epidemiological studies [25]. The results indicate that most weather-related effects on PSC 119 calls are acute and occur within a short lag period of 0–3 days. These findings have important implications for strengthening PSC 119 preparedness systems and support the integration of weather-based early warning mechanisms into emergency service operations.

This study has several strengths, including the use of daily data over a full calendar year and the application of DLNM to capture complex non-linear and lagged relationships between weather variables and emergency service demand. The findings underscore the importance of incorporating weather-based information, particularly temperature forecasts, into PSC

119 preparedness and operational planning, such as workforce scheduling, ambulance deployment, and resource allocation. However, several limitations should be acknowledged. The analysis did not stratify PSC 119 calls by type, and other environmental factors, such as air pollution and traffic density, were not included. These limitations may constrain cause-specific interpretation of weather-sensitive emergency demand and could result in more conservative risk estimates. Despite these limitations, the consistency of the findings across weather variables and lag structures supports the robustness of the observed associations.

CONCLUSIONS AND RECOMMENDATIONS

This study demonstrates that weather variability significantly influences the volume of PSC 119 calls in Semarang City. Temperature emerged as the most influential factor, with substantially elevated risks observed at both low and high temperature extremes, indicating a clear non-linear association. Relative humidity exhibited a more complex pattern, whereby moderate humidity levels were associated with increased PSC 119 call risk, while very high humidity levels appeared to exert a protective effect. Rainfall showed a comparatively smaller influence; however, no-rain to light-rain conditions were associated with higher call volumes. Most weather-related effects occurred within short lag periods (0–3 days), suggesting an acute response of emergency service demand to changes in weather conditions.

These findings highlight the importance of integrating weather-based information, particularly temperature forecasts, into the preparedness and operational planning of PSC 119 services to support proactive ambulance deployment, workforce scheduling, and resource allocation. Future research should incorporate call-type stratification, additional environmental factors such as air pollution, and multi-city analyses to further strengthen the evidence on the impact of weather variability on emergency medical service demand in Indonesia.

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