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Research article

Associations between meteorological variation and hospitalisations for rotavirus infections in Kuala Lumpur, Malaysia

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A B S T R A C T

Objectives: Rotavirus (RoV) infections have emerged as a significant public health concern around the world. Understanding the relationship between climatic conditions and hospitalisations due to RoV infections can help engage effective prevention strategies. This study aims to investigate the potential associations between meteorological variability and RoV-related hospitalisations in Kuala Lumpur, Malaysia.
Methods: Hospitalization data from a tertiary teaching hospital in Kuala Lumpur over a twelve-year period were retrospectively collected. Concurrently, meteorological data were obtained from the Malaysian Meteorological Department (MetMalaysia) including variables of temperature, humidity, precipitation, and atmospheric pressure to further demonstrate relationship with RoV-associated hospitalisations.
Results: The results indicated positive correlations between increased rainfall, rainy days, humidity, and RoV-related hospitalisations, suggesting the influence of environmental factors on the transmission of RoV.
Conclusions: This study highlights positive associations between meteorological variations and hospitalizations for RoV infections in Kuala Lumpur, Malaysia. Further investigations, including national-level data, are needed to deepen our understanding of these associations, particularly within the context of Malaysia and to develop targeted interventions for disease prevention and control.

1. Introduction

Globally, rotavirus (RoV) stands as the predominant cause of severe acute gastroenteritis (AGE) in children under the age of five, posing a significant burden on public health, leading to a substantial number of fatalities and healthcare visits each year. It alarmingly contributes to around 200,000 deaths worldwide in children less than five years [1–3] despite the introduction of RoV vaccine since 2006. While it has been shown that there is a significant decrease in mortality since the commencement of global national immunization initiatives, many countries have yet to integrate RoV vaccination into their programs. In Malaysia, the use of two rotavirus vaccines namely Rotarix® and Rotateq® are restricted to private use. RoV infection is responsible for approximately 27 mortalities and

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hospitalization of around 31,000 patients per year in Malaysia [4]. It imposes a major financial burden of approximately 84 million USD on both the government and the public annually [5]. Prior epidemiological studies have explored the relationships between meteorological factors and RoV infection, showing several implications that are dependent on the study location. In various climatic regions across the globe, peaks in RoV infections are frequently observed in winter [6] autumn or spring [7–11]. It was also observed that RoV gastroenteritis (RVGE) exhibited a relatively consistent occurrence throughout the year in tropical countries, specifically Southeast and Southern Asia [12]. A few studies suggested temperature and rainfall play important roles in regulating both viral survival outside the host as well as virus spreading and persistence in the environment [8,9]. Elevated temperatures and increased precipitation were correlated with a decrease in RoV infection rate. In a study conducted by Levy et al. [9], it was noted that prolonged RoV survival is not associated with higher temperatures. The findings indicated that for every 1 °C increase in mean temperature, there was a 10% reduction in RoV incidence. Additionally, a 1 cm increase in monthly rainfall corresponded to a 1% decrease in incidence, and a 1% rise in relative humidity was associated with a 3% reduction in rotavirus incidence. Most human activities are susceptible to climate influences, therefore the interplay between these factors is very important in understanding the dynamics of diseases like rotavirus and their potential connections to climatic, geographic, economic, or human behavioural variables [13].

Kuala Lumpur, the capital city of Malaysia, experiences a tropical climate characterized by elevated humidity levels and stable temperatures ranging from 25 °C to 32 °C throughout the year [14]. The climate in Malaysia is influenced by two distinct monsoon seasons: the Northeast monsoon, occurring from November to March with heavy rainfall, and the Southwest monsoon, which brings drier conditions from late May to September [15]. Throughout the year, rainfall levels in the region remain consistently high, with an average annual precipitation of 3,085.5 mm (mm) [16]. Monthly precipitation shows relatively stable patterns, with average values ranging from around 200 mm during June and July to approximately 350 mm in November and December [16]. To date, limited research has been conducted to explore the correlation between RoV infection and weather conditions in Malaysia. The primary objective of this study is to investigate the association between admissions for RoV infection in a tertiary teaching hospital in Kuala Lumpur and key meteorological factors such as number of rainy days, rainfall, and humidity.

2. Material and methods

This single-centre, retrospective study was conducted at Hospital Canselor Tuanku Muhriz (HCTM), The National University of Malaysia, situated in Kuala Lumpur, Malaysia. Patient records from the paediatric wards, specifically those diagnosed with AGE in January 2010 to December 2021 were obtained from the medical record department. In HCTM, it is routine to send stool samples for all AGE cases for RoV antigen and bacterial culture. Hence, we also looked at data from the Microbiology Laboratory, HCTM which included information on all stool samples received from the paediatric ward that tested positive for RoV. This additional data source was used to assure thorough coverage and accuracy in our analysis of RoV cases in this study.

Data on climate variables, including number of rainy days, rainfall (mm), relative humidity (%), Mean Sea Level (MSL) pressure (hPa), surface wind speed (m/s), mean cloud cover (Oktas), and day temperatures (°C) of Kuala Lumpur for 2010 to 2021 were obtained from the Malaysian Meteorological Department (MetMalaysia). We then analysed the collected climate data to identify trends and patterns. Graphical representations were generated to visualise the variations in each climate variable over the 12-year period. From there, we determined the seasonal peaks of RoV in our centre. We define seasonal peaks as one or two consecutive months with the greatest number of positive RoV tests in a particular year, as described by Urena-Castro et al. [11].

The data were then analysed further using Statistical Package for Social Sciences (SPSS) Version 27. A Spearman correlation analysis was done to explore the relationships between average monthly admissions for AGE and monthly RoV infection cases, and

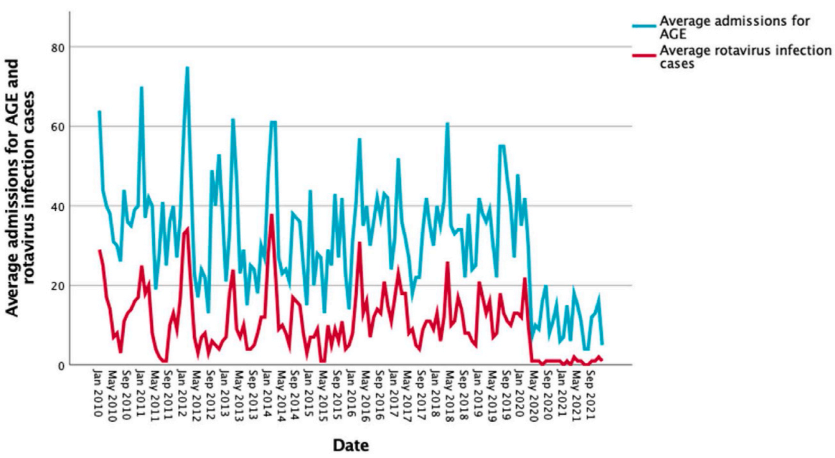

Fig. 1. Temporal trend of average admissions for AGE and rotavirus infection cases. Between January 2010 and December 2021, 4551 patients were admitted to the paediatric ward of HCTM for Acute Gastroenteritis (AGE). The yearly average of AGE diagnoses was 79.3 ± 110.113 patients, equivalent to a monthly average of 31.60 ± 14.356 cases.1493 individuals (32.8%), were laboratory confirmed to have a rotavirus (RoV) infection.

climatic variables including rainfall, rainy days, and relative humidity. The climate variables data were offset by two months considering the potential time delayed effect of RoV infection. The relationship was considered to be significant at $p < 0.05$.

This study was conducted in accordance with the Declaration of Helsinki, and approved by the Universiti Kebangsaan Malaysia Research Ethics Committee (JEP-2023-356).

3. Results

3.1. Incidence of AGE and confirmed RoV infections

Between January 2010 and December 2021, a total of 4551 patients, with the average of 79.3 ± 110.113 patients diagnosed with AGE yearly, and were admitted to the paediatric ward of HCTM. This equates to an average of 31.60 ± 14.356 AGE cases per month. A total of 1493 (32.8%) of the AGE patients were laboratory confirmed to have a RoV infection (Fig. 1). Assuming all patients were tested for RoV antigen, the mean is 10.37 ± 7.885 cases per month.

Fig. 2A presents a monthly overview of AGE admissions from 2010 to 2021, revealing a consistent monthly average of 28–40 admissions throughout the years. Fig. 2B depicts the monthly overview of confirmed RoV infection from 2010 to 2021. However, it is observed that the years 2020 and 2021 deviate from this trend due to the unprecedented impact of the COVID-19 pandemic, resulting in significantly lower admission rates for AGE. The analysis of trends reveals a consistent pattern in the occurrence of RoV infection throughout the year, but the trend peaks from January to April, and October every year.

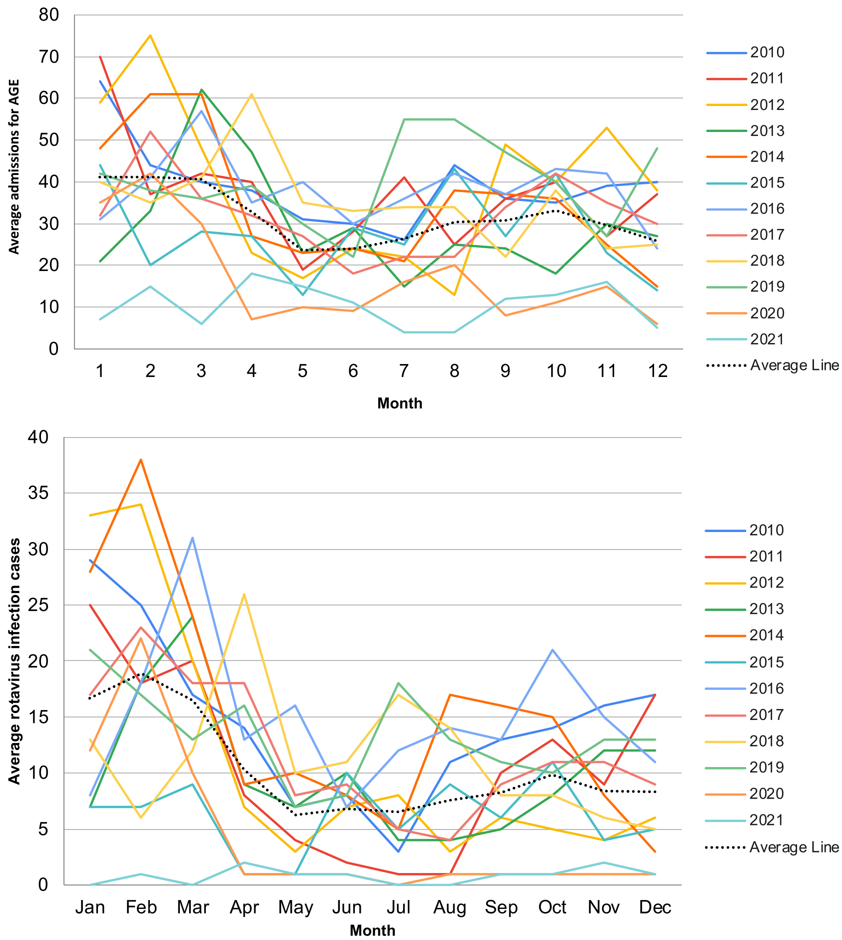

Fig. 2. A: Average admissions for acute gastroenteritis (AGE) cases every month from 2010–2021. This graph provides a monthly summary of admissions related to AGE from 2010 to 2021 and illustrates a consistent monthly average of 28–40 AGE admissions throughout the 12 years. **B: Monthly distribution of confirmed rotavirus (RoV) infections from 2010 to 2021.** Trend analysis reveals a consistent pattern of RoV infection throughout the years, with peak occurrences in January to April and October annually. The years 2020 and 2021 deviate from the typical trend due to the unprecedented impact of the COVID-19 pandemic, resulting in significantly lower admission rates for AGE.

3.2. Climates in Kuala Lumpur, Malaysia

An analysis of the average monthly climatic variables reveals consistent patterns throughout the study period (Fig. 3a–d). The data shows a consistent trend of high rainy days and rainfall levels in Kuala Lumpur during the early (January to May) and late months of the year (October to December). Relative humidity remains steady around 72%–78% during this period. In terms of temperature, the data indicates a consistent day temperature of around 27–28 °C throughout the year, with only slight variations among the months.

3.3. Relationship between average monthly admissions for AGE, monthly RoV infection cases, and climatic factors

The relationship between average monthly admissions for AGE, monthly RoV infection cases, and climatic factors was further examined (Table 1). Significance factors identified through our correlation analysis revealed rainfall, rainy days, and humidity as variables of interest since the remaining factors exhibited minimal variation throughout the study period. To obtain a more reliable dataset, the weather data was offset by 2 months (k = 2). A Spearman correlation analysis was then conducted to establish a more dynamic correlation (Fig. 4a). There is a strong relationship between average monthly admissions for AGE and monthly count of rainy days ($p = 0.004$), monthly rainfall amount ($p = 0.006$), and monthly relative humidity ($p = 0.002$) (Fig. 4b–d). It was determined that there is a positive correlation between monthly RoV infection cases and the monthly count of rainy days ($p = 0.022$), monthly rainfall amount ($p = 0.014$), and monthly relative humidity ($p = 0.019$) (Fig. 4e–g). From this observation, it is evident that admissions and RoV infection are often preceded by rainy days, rainfall, and relative humidity.

4. Discussion

This study aimed to determine the correlation between meteorological variables and RoV infection in Kuala Lumpur with the

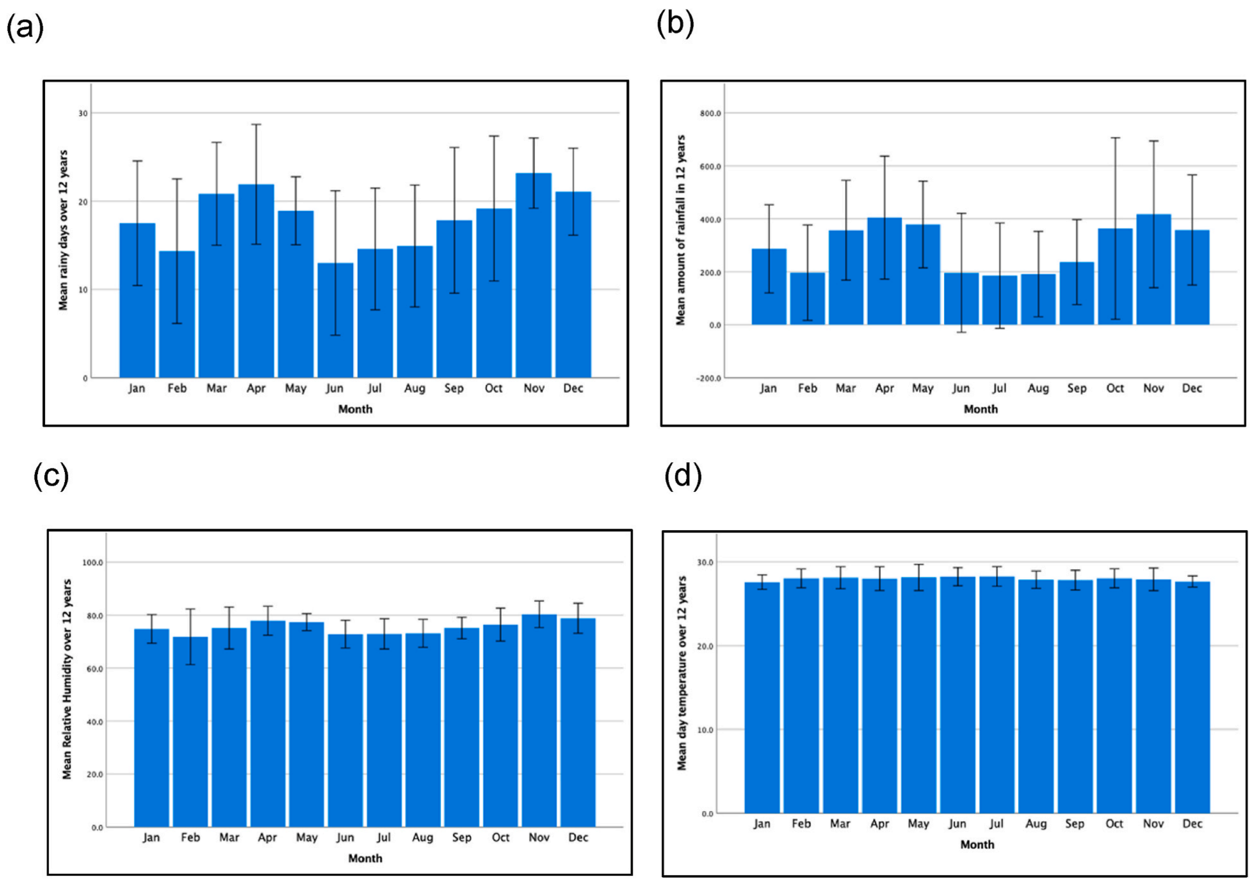

Fig. 3. Monthly averages of (a) rainy days, illustrates the monthly averages of rainy days. A consistent pattern indicating elevated rainy days during the early months (January to May) and late months (October to December) throughout the 12-year study. **(b) Rainfall** bar graph depicts the monthly averages of rainfall in Kuala Lumpur. Similar to rainy days, the data reveals a persistent trend of higher rainfall levels during the early and late months of the year. **(c) Relative humidity** graph displays the monthly averages of relative humidity. Throughout the study period, relative humidity remains stable between 72% and 78% and **(d) Day temperature** averages of day temperatures in Kuala Lumpur maintaining an approximate range of 27 °C–28 °C throughout the entire years with minimal variations among the months.

Table 1
The relationship between average monthly admissions for acute gastroenteritis (AGE), monthly rotavirus(RoV) infection cases, and climatic factors.

Variables	r-value	p-value
Average monthly admissions for AGE and monthly RoV infections	0.694	<0.001**
Average monthly admissions for AGE and monthly count of rainy days	0.259	0.004**
Average monthly admissions for AGE and monthly rainfall amount	0.250	0.006**
Average monthly admissions for AGE and relative humidity	0.276	0.002**
Monthly RoV infection cases and monthly count of rainy days	0.208	0.022*
Monthly RoV infection cases and monthly rainfall amount	0.223	0.014*
Monthly RoV infection cases and relative humidity	0.214	0.019*

* p-value <0.05.
** p-value <0.01.

primary objective to associate seasonal patterns of RoV occurrence. This is useful particularly for predicting and preparing for peak periods of RoV activity and improving resource allocation in healthcare settings especially in Malaysia. A few studies conducted in tropical countries have been exploring the association between AGE in general or RoV occurrence and meteorological factors such as rainfall, humidity, and rainy days but show conflicting results. A study by Kraay et al. corroborated our findings that in general, the occurrence of diarrhoea is more frequent during seasons with higher rainfall [17]. In Surabaya, Indonesia, Wibawa et al. [18] observed a diarrhoea incidence of 11.4 cases per 100,000 population, especially during the rainy season. In contrast, Mejiozem et al. [19] concluded that lower rainfall levels and higher temperatures were associated with the highest prevalence of RoV-induced diarrhoea. This is supported by a study conducted in Vietnam, which observed a statistically significant difference in RoV detection between the dry and rainy seasons and indicated that RoV was more frequently detected during the dry season compared to the rainy season [20,21].

It is hypothesized that the occurrence of extreme rainfall connected to higher cases of diarrhoea as it leads to the flushing of pathogens into the environment after a dry period [22]. Excessive rainfall has the potential to impact water quality by carrying enteric pathogens and subsequently contributing to an elevated risk of diarrhoea transmission. However, it can also be speculated that during a wet period, the presence of excessive rainfall acts as a protective factor against diarrhoea by diluting the concentration of pathogens [17]. Nevertheless, this theory of the impact of rainfall on diarrhoea in tropical regions may not be fully applicable due to the variability of precipitation patterns.

While RoV transmission typically occurs through direct person-to-person contact or contact with contaminated surfaces, the significance of waterborne transmission is gaining attention [23]. It is worth noting that flash floods are a recurring phenomenon in Kuala Lumpur [24]. Flash floods pose several risks that can contribute to the higher transmission of RoV. A study in Vietnam observed the disease burden associated with rotavirus A in floodwater due to traffic activities demonstrated a substantial infection probability per person per exposure, ranging from 0.96 to 0.98 [25]. Firstly, the inundation of urban areas during floods leads to contamination of water sources with faecal matter, potentially containing RoV particles. Flood introduces a considerable volume of contaminated water, increasing the likelihood of pathogens entering water supplies. Rotaviruses exhibit remarkable resilience in the environment and able to survive several weeks on surfaces and within both drinking and recreational water sources [9]. Colston et al. noted the protective effects of drinking water from deeper tube wells, as they are less susceptible to flood-related contamination [23]. This contaminated water can then serve as a medium for the spread of the virus, especially in densely populated areas where proper sanitation and clean water access may be compromised during flood events [26]. Simulation models with mechanistic details by Kraay et al. proved that the spread of RoV among communities linked by waterways can be an indirect mode of transmission in tropical settings, and this is greatly influenced by the velocity of the water flow [27]. Moreover, the displacement of individuals and disruption of infrastructure caused by floods can exacerbate the risk of RoV transmission. Overcrowded evacuation centres and temporary settlements often lack proper hygiene facilities, increasing the likelihood of person-to-person transmission of the virus. The close proximity of individuals in such settings, coupled with compromised sanitation conditions, creates an environment conducive to the rapid spread of RoV. A study by Jones et al. [28] observed the occurrence of flooding in one of the Solomon Islands triggered a widespread epidemic of diarrhoea, extending to areas not directly impacted by the floods. In the city with the most flooding, 38% of the tested cases detected RoV. This speculation about a higher persistence of RoV during high rainfall within floods needs to be further investigated and understood.

In addition to the aforementioned factors, it can be postulated that during periods of extreme rainfall, humans are prone to shelter seeking behaviour, resulting in reduced outdoor activities and increased proximity within households. This change in behaviour may contribute to a higher likelihood of RoV transmission occurring between household members. As suggested by Räsänen [29], the connection between seasonal epidemiology and human behavior, considering factors such as holiday seasons versus school and daycare periods, which involve increased indoor crowding and the use of public transportation. The complex interplay between rainfall patterns, local geography, sanitation infrastructure, and human behavior makes it challenging to draw definitive conclusions regarding the direct relationship between rainfall and diarrheal disease incidence [30].

Our study also reveals a significant association between humidity and RoV infection, aligning with the findings of Ghoshal et al. [6] that observed humidity levels ranging from 60% to 79% were particularly conducive to the prevalence of RoV disease. Higher humidity levels can potentially enhance RoV survival in the environment and prolong its infectivity [27,31–33].

Although we could not calculate the correlation between RoV incidence and temperature due to minimal variation in average temperatures across different years, the available data indicates that a 1 °C increase in temperature corresponds to a 4–10% decrease in

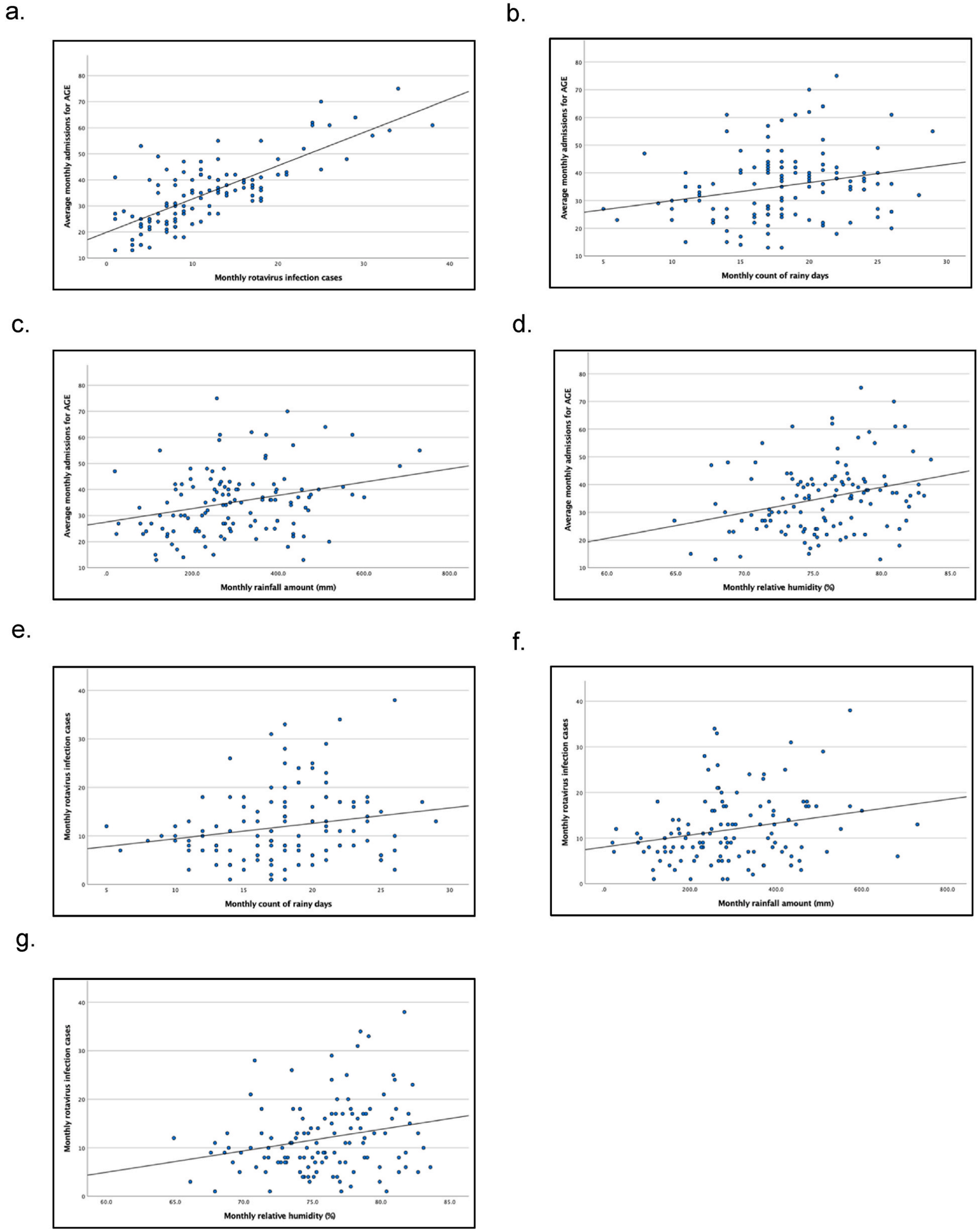

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Fig. 4. The relationship between average monthly admissions for AGE, monthly RoV infection cases, and climatic factors. This figure illustrates the results of a Spearman correlation analysis examining the relationship between **(a)** average monthly admissions for Acute Gastroenteritis (AGE), monthly Rotavirus (RoV) infection cases, and selected climatic factors. A strong correlation between average monthly AGE admissions and the monthly count of **(b)** rainy days ($p = 0.004$), **(c)** monthly rainfall amount ($p = 0.006$), and **(d)** monthly relative humidity ($p = 0.002$). The correlation analysis also reveals a positive relationship between monthly RoV infection cases and the **(e)** monthly count of rainy days ($p = 0.022$), **(f)** monthly rainfall amount ($p = 0.014$), and **(g)** monthly relative humidity ($p = 0.019$).

the incidence of RoV associated diarrheal disease in tropical regions [6]. RoV diarrhoea could potentially be heightened due to the favourable conditions for viral replication and survival that low temperatures provide [18]. On the contrary note, the same study also observed elevated temperatures in the western, southern, and eastern regions of Surabaya were associated with an increased risk of diarrhoea [18]. An interesting observation by a study [34] that even when stored for 2.5 months, RoV particles in faeces exhibit stability and remain potentially infectious in vitro, even under ambient temperatures exceeding 30 °C. Therefore, it is essential to recognize that while temperature variations may indeed influence the incidence of RoV associated diarrheal disease, it is equally crucial not to overlook the stability and infectious potential of active RoV particles present in faeces. This underscores the importance of implementing effective hygiene practices to combat RoV infections. Hygiene practices, including proper handwashing techniques, sanitation measures, and the use of clean water sources, play a vital role in interrupting the faecal-oral route of transmission [35]. By practising good hygiene, individuals can minimise the risk of exposure to RoV particles and reduce the chances of infection.

Theoretically, rising in temperatures is associated with increased rainfall and humidity. Therefore, it is possible that the simultaneous increase in temperature, rainfall, and humidity collectively contribute to the increased occurrence of RoV diarrhoea cases. Further investigation is necessary to establish a more comprehensive understanding of how these interconnected variables contribute to the increased occurrence of RoV associated diarrheal cases in different regions and climatic conditions. Conflicting results in existing studies prevent definitive conclusions on the association between climate factors and RoV transmission, and it remains unclear why the relationship between rotavirus infection and climate factors varies across countries. The use of different analysis methods in various studies could potentially have impacted the outcomes. Additionally, limited research in tropical countries hinders drawing firm conclusions based on a few studies alone. Maximising the utilisation of ambient and environmental data closely linked to disease dynamics has significant potential to advance public health through simulation and prediction methods. This approach can greatly improve our understanding and ability to anticipate disease patterns, leading to more effective strategies for disease management and prevention.

We have identified several limitations in this study. The focus on the Kuala Lumpur area limits the generalisability of findings and may not fully represent the broader population. Different results might have been obtained if the study had been conducted in various parts of Malaysia. Additionally, limitations in RoV serotype data and the potential influence of other contributing factors may have limited our observations.

5. Conclusion

In this research, we explored the relationship between RoV infection and meteorological factors, showing a noteworthy positive correlation with increased rainfall, a higher number of rainy days, and elevated humidity levels. This correlation highlights the potential influence of climatic conditions on RoV transmission dynamics in the tropical setting of Kuala Lumpur, Malaysia. However, to gain a more comprehensive understanding and validate the findings, it is crucial to compare the data obtained from multiple centres or at the national level on RoV infections with regional meteorological data. Such an approach will enable the identification of broader trends and potential variations in the impact of meteorological factors on RoV transmission across different geographical regions.

Undoubtedly, conducting more extensive studies in tropical regions becomes important to sharpen our comprehension of the complex interplay between climate and RoV infections. Tropical climates offer unique environmental conditions that may significantly affect viral survival, transmission routes, and host susceptibility. By understanding into these interactions better, public health authorities can strategise targeted interventions and mitigation strategies to effectively combat RoV outbreaks in tropical areas. Furthermore, the integration of simulation and prediction methodologies using ambient and environmental data can prove instrumental in enhancing our ability to anticipate and prepare for disease patterns driven by meteorological factors. By leveraging such predictive models, public health agencies can be better equipped to respond proactively to potential spikes in RoV infections during periods of increased rainfall or humidity, allocating resources and implementing preventive measures accordingly. In conclusion, this study highlights the importance of considering climatic influences on infectious diseases like RoV. The positive correlation observed between RoV infection and specific meteorological variables emphasises the necessity of comprehensive and region-specific research. By undertaking more extensive investigations in tropical regions and applying advanced predictive methods, we can work towards reducing the burden of RoV infections and improving overall public health outcomes in these areas.

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Data availability statement

The data supporting the findings of this study are available within the article and are not publicly available due to patient privacy issues. It is available from the corresponding author, upon reasonable request with the permission of The National University of Malaysia and MetMalaysia.

CRediT authorship contribution statement

Mohammad Shukri Khoo: Writing – review & editing, Writing – original draft, Visualization, Formal analysis, Data curation. **Ahmad Hathim Ahmad Azman:** Writing – original draft, Visualization, Software, Formal analysis, Data curation. **Noor Akmal Shareela Ismail:** Writing – review & editing, Supervision, Project administration, Methodology, Conceptualization. **Asrul Abdul Wahab:** Supervision, Resources, Project administration, Methodology, Data curation. **Adli Ali:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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