Agromet 37 (2): 99-107, 2023

Agromet
journal.ipb.ac.id/index.php/agromet
ISSN : 0126 - 3633

Climate influence on Diarrhea Disease in Tropical Regions based on Systematic Literature Review

Dela Arinda, Rini Hidayati, Muh. Taufik
Department of Geophysics and Meteorology, Faculty of Mathematics and Natural Sciences, IPB University, Dramaga Campus, Bogor, Indonesia 16680

ARTICLE INFO

Received
28 July 2023

Revised
06 September 2023

Accepted for Publication
18 September 2023

Published
10 November 2023

doi: 10.29244/j.agromet.37.2.99-107

Correspondence:
Rini Hidayati
Department of Geophysics and Meteorology, IPB University, Dramaga Campus, Bogor, Indonesia 16680
Email: rinihidayati@apps.ipb.ac.id

ABSTRACT

Diarrhea disease presents a significant public health concern due to its impact on mortality, and research showed that climate plays an important role on diarrhea prevalence. However, effect of climate on diarrhea incidence was inconsistent among climate factors. Here, we investigated this inconsistency thorough systematic literature review. Our review encompassed the formulation of research questions, development of literature search strategies, and the establishment of inclusion/exclusion criteria for systematic data extraction. We carried out an extensive search from peer-review literature databases including Scopus, Pubmed, and Proquest for articles published between January 2000 to March 2023. We found that 74 studies focusing on diarrhea diseases and climate influencing factors met our inclusive criteria. Climate factors that affected diarrhea were rainfall, temperature, humidity, and climate seasonality. Our findings revealed that a positive association between diarrhea and rainfall was consistently observed. Other climate factors (temperature and humidity) indicated a positive correlation as well, although viral diarrhea exhibited a negative correlation with temperature. Further, bacterial and parasitic diarrhea diseases were more prevalent in the rainy season, whereas viral diarrhea occurred more frequently during the dry season with lower temperatures.

KEYWORDS
association, diarrhea, inconsistent, rainfall, temperature

INTRODUCTION

Diarrhea disease causes of high mortality and morbidity globally (Deshpande et al., 2020; Syafei and Hidayati, 2018). The disease is particularly prevalent among children under five-year old, ranking the fourth causes of death worldwide (Strong et al., 2021). Specifically, among children under five years old, the diseases were associated for approximately 525,000 deaths annually, stemming from a total of 1.7 billion cases of childhood diarrhea each year (Yeasmin et al., 2022). The incidence of diarrhea disease is projected to rise in response to projected warm climate in the future (Trtanj et al., 2016). Climate change affects the quantity and quality of water resources, potentially increasing the presence, spread, and transmission of diarrhea pathogens (Carlton et al., 2016, 2014; Van Elsas et al., 2011). WHO estimated an increased death of 48,000 per year caused by diarrhea between 2030 and 2050 (WHO 2018).

The issue of climate-sensitive diseases is expected to surge in developing nations characterized by tropical climates (Campbell-Lendrum et al., 2015), leading to a projected rise in diarrhea diseases. Research efforts have examined the relationship between rainfall, temperature, and humidity with diarrhea (Hashizume et al., 2008; Lee et al., 2017; Thompson et al., 2015). Research showed diverse outcomes about the relationship, with some indicating a positive link, while others suggest the opposite association (Hashizume et al., 2007; Lee et al., 2017; Prasetyo et al., 2015). To address the variations in the findings on the association between climate variables and diarrhea disease, a

comprehensive and systematic examination of the association is urgently required. Recent systematic reviews conducted by Kraay et al., (2020) and Liang et al., (2021) revealed a positive correlation between temperature and diarrhea diseases caused by bacteria and parasites. Nevertheless, Extreme rainfall events lead to an increase in cases of diarrhea, while the association between non-extreme rainfall and diarrhea diseases exhibited a non-linear pattern (Kraay et al., 2020).

This study builds upon the recent systematic reviews conducted by Kraay et al., (2020) and Liang et al., (2021), expanding the scope to investigate the connection between relative humidity and diarrhea diseases, along with exploring seasonal patterns in such diseases. Our systematic review specifically explores the impact of climate on diarrhea diseases in tropical regions, which are susceptible to health issues. By synthesizing existing literatures, our review aims: (i) to provide a comprehensive understanding of the relationship between climate effects and diarrhea diseases, (ii) to analyse the factors contributing to the inconsistency in this relationship, and the seasonal variations in diarrhea diseases.

RESEARCH METHODS

Research Questions and Search Strategy

The formulation of research questions marked the initial step in the systematic literature review. Establishing the questions served as the starting point for identifying the limitations of the research problems. The research questions for this study are as follows:

1. How does climate affect diarrhea disease?
2. What causes the influence of climate on diarrhea disease to be inconsistent?
3. What is the seasonal pattern of diarrhea disease?

The literature search was carried out using the PubMed, Scopus, and ProQuest databases. The literature search used keywords compiled based on PECO (Population, Exposure, Comparison, and Outcome) (Cook and West, 2012). Initial keywords for search "name of tropical climates", for exposure to "rain", "rainfall", "precipitation", "temperature", and "humidity". For outcomes we used "diarrhea" and "diarrhoea".

Inclusion Criteria and Exclusion Criteria

Any literature included in this systematic observation must meet specific inclusion and exclusion criteria. The inclusion criteria for this study consisted of

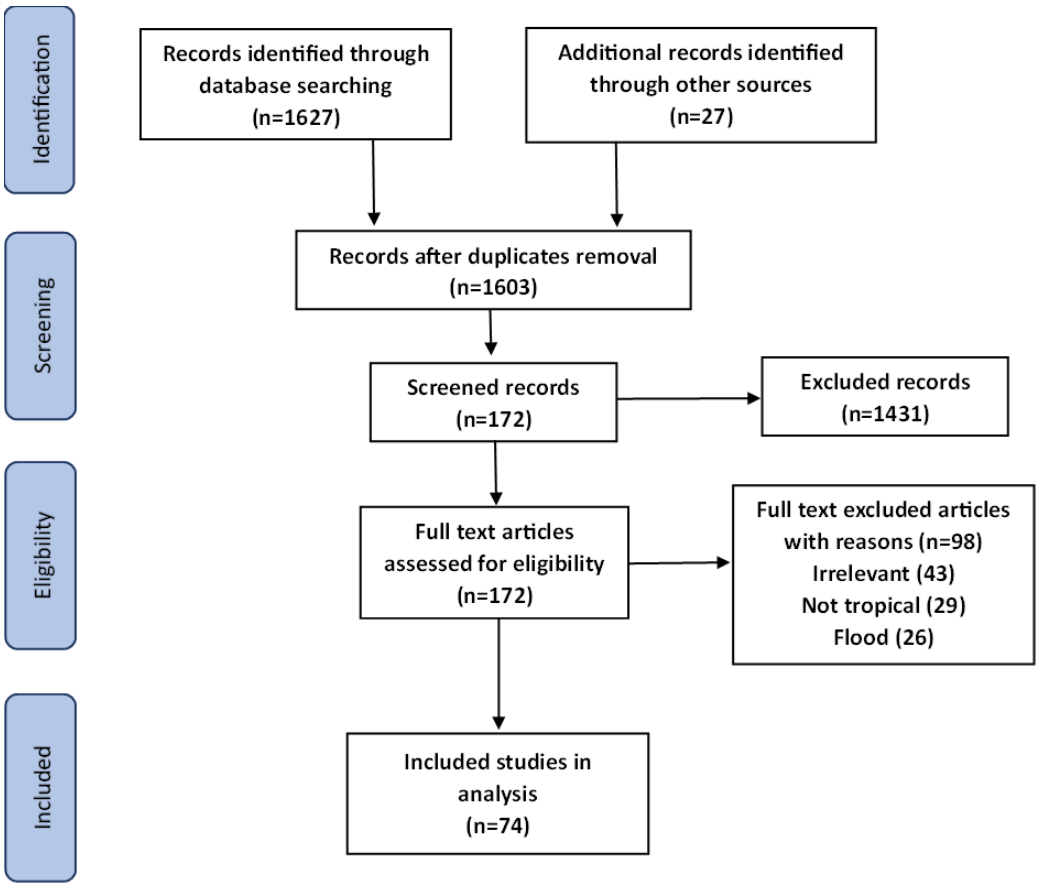

Figure 1. Flowchart of PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) following the procedure described by Moher et al., (2009).

diarrhea in humans, exposure to literature containing one of the climatic factors (rainfall, temperature, humidity, and seasonality) associated with diarrhea, literature written in English, the study area categorized as a tropical climate, and literature published between January 2000 and March 2023. The exclusion criteria encompassed gray literature and overlapping studies. The PRISMA diagram was used to visualize literatures that met these criteria (Moher et al., 2009).

Extraction Information

Once literature meeting the inclusion and exclusion criteria was selected, information extraction was conducted for each piece of literature. This extraction focused on the relationship between climate influences and diarrhea diseases, the factors contributing to the inconsistencies in this relationship, and the seasonal patterns of diarrhea diseases.

RESULTS AND DISCUSSION

Study selection and characteristics

The results of the literature search, including the search, filtering, and selection stages to identify literature that met the criteria are shown in Figure 1. During the search process, 1,654 studies were identified, of which 74 met the final criteria. The studies included in the analysis examined at least one of the climate-related factors. The selection of study areas was based on regions with tropical climates, as classified by the Köppen system, including tropical climate types such as Af, Am, and Aw. Out of the 74 studies, 31 locations exhibited these climate types, as presented in Figure 2.

The systematic review revealed that the Aw climate type was in 59 studies, the Am climate type was in eight studies, the Af climate type was in six studies, and a combination of Af and Am was only in one study. The study locations encompassed low, middle, and high-income countries. Based on the country income categories, most studies (44 studies) were conducted in lower-middle-income countries, followed by upper-middle-income countries (17 studies), low-income countries (12 studies), and high-income countries (1 study). The study locations spanned across the continents of Africa, Americas, Asia, and Oceania. Specifically, there were 27 papers from the African continent, 12 from the American continent, 33 from the Asian continent, and two from the Oceania continent. Most research was predominantly carried out in Bangladesh (nine studies), India (eight studies), and Ghana (six studies).

The results showed that the influence of climate on diarrhea disease has been studied more extensively in urban areas (37 studies) than in rural areas (16 studies). Urban areas receive more attention for research as characterized by: (i) accessibility of people to health services and (ii) accessibility of researcher to health data and information. We found that high population density in urban areas, along with the limited availability of water sources compared to rural areas, have created favorable conditions to the spread of diarrhea diseases.

Rainfall

Our results revealed an inconclusive correlation between rainfall and diarrhea diseases. Out of the 28 studies, a positive association was observed between rainfall and diarrhea diseases. Conversely, 12 studies reported negative associations, while four studies showed no distinct association between rainfall and the incidence of diarrhea. The studies employed diverse definitions of rainfall exposure, encompassing extreme or heavy rainfall, low extreme rainfall, total weekly and monthly rainfall, average monthly and annual rainfall, monthly median rainfall, and both maximum and minimum weekly rainfall, as well as rainfall anomalies.

Inconsistent associations have been observed between rainfall and diarrhea diseases. The inconsistencies may arise from the complex transmission routes and the influence of non-climatic factors (Guzman Herrador et al., 2015). Furthermore, antecedent rainfall was believed to affect the association, as suggested by prior studies (Carlton et al., 2014; Kraay et al., 2020; Levy et al., 2009). The systematic review revealed four relevant studies, which investigated wet and dry periods (Carlton et al., 2014, p. 201; Deshpande et al., 2020; Levy et al., 2019; Mertens et al., 2019). These studies aimed to establish a connection between heavy or extreme rainfall and the incidence of diarrhea diseases while considering antecedent rainfall conditions. Our findings suggested that heavy or extreme rainfall following a dry period is associated with an increased incidence of diarrhea. In contrast, heavy or extreme rainfall after a wet period showed a lower incidence of diarrhea.

The influence of antecedent rainfall on the occurrence of diarrhea may relate to the "concentration-dilution" hypothesis. This theory encompasses two key principles. First, the concentration hypothesis suggests that during periods of limited rainfall or “dry conditions”, pathogens can accumulate in the environment, intensifying the risk of diarrhea. Higher rainfall is associated with an increased risk of diarrhea diseases as it introduces more pathogens into the environment. In contrast, the dilution effect, suggests that regular rainfall washes pathogens away, hindering their accumulation in the environment and subsequently reducing the risk of diarrhea spread (Carlton et al., 2014; Kraay et al., 2020). Figure 3 illustrates the concept of the concentration-

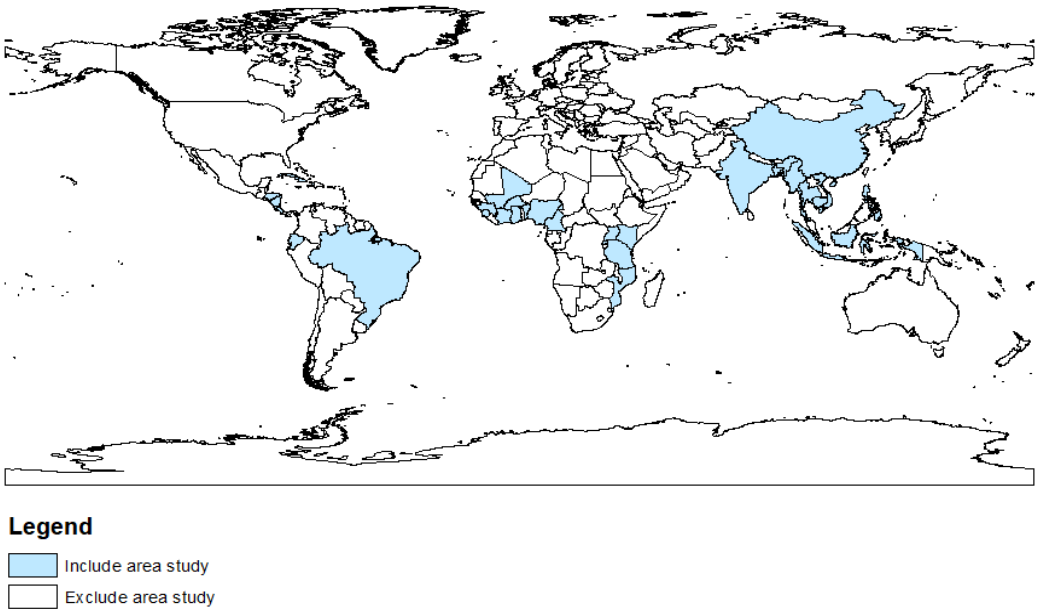

Figure 2. The countries included in the literature study are distributed across the tropical region.

dilution hypothesis. Some shortcomings aroused when studying the effect on rainfall and the specific pathogens that cause diarrhea. Generally, research indicated a positive association between bacterial and parasitic causes of diarrhea and rainfall (Charles et al., 2014; Kaminsky et al., 2015; Lee et al., 2017; Oguttu et al., 2017; Tellevik et al., 2015). Conversely, diarrhea caused by viral agents appeared to exhibit a negative relationship with rainfall (Hasan et al., 2018; Sumi et al., 2013; Ureña-Castro et al., 2019).

Temperature

The relationship between temperature and diarrhea showed diverse findings. Among the examined studies, 18 reported a positive association, five indicated a negative association, and four showed no significant association. The papers used multiple temperature definitions, including average weekly and monthly temperatures, monthly maximum and minimum temperatures, extreme temperature conditions, average annual temperature, and diurnal temperature range. These inconsistencies in the association between temperature and diarrhea disease may be attributed to the diverse range of pathogens, which were responsible for causing diarrhea, including bacteria, viruses, and parasites. Each pathogen type responds differently to climate factors, and modifications in these climatic conditions can affect pathogen survival and infectivity (Ureña-Castro et al., 2019).

The findings highlighted the difficulties in comprehensively accounting for the diverse pathogens involved in diarrhea diseases, which may have contributed to the observed variability in the association. In general, studies examining the relationship between bacterial and parasitic pathogens and diarrhea diseases demonstrated a positive association (Berendes et al., 2019; Lee et al., 2017; Trærup et al., 2011; Wu et al., 2018; Yang et al., 2022). Conversely, the presence of viral pathogens showed a negative correlation with diarrhea diseases (Hasan et al., 2018; Prasetyo et al., 2015; Sarkar et al., 2013; Sumi et al., 2013). It is noteworthy that bacteria and parasites tended to thrive in higher-temperature conditions, while viruses exhibit a preference for lower-temperature environments (Mellor et al., 2016; Ureña-Castro et al., 2019).

Relative Humidity

Studies that examined the relationship between humidity and diarrhea showed a positive association were found in seven studies, and four studies reported a negative association. Compared to rainfall and temperature, humidity was rarely studied. A systematic review showed an inconsistent association between humidity and diarrhea disease. Humidity affects the biological processes of pathogens (Carlton et al., 2014)

The role of relative humidity in increasing diarrhea diseases through the life of diarrhea-causing microorganisms and their vectors (Dharmayanti et al., 2022). Two studies analyzed the relationship between humidity and diarrhea caused by bacteria. The study showed a positive association between bacteria diarrhea and humidity. High humidity is an excellent place to grow and develop bacteria (Lee et al., 2017; Pérez-Corrales and Leandro-Sandí, 2019). Studies that examined viral diarrhea in relation to humidity showed inconsistent results. This inconsistent association may

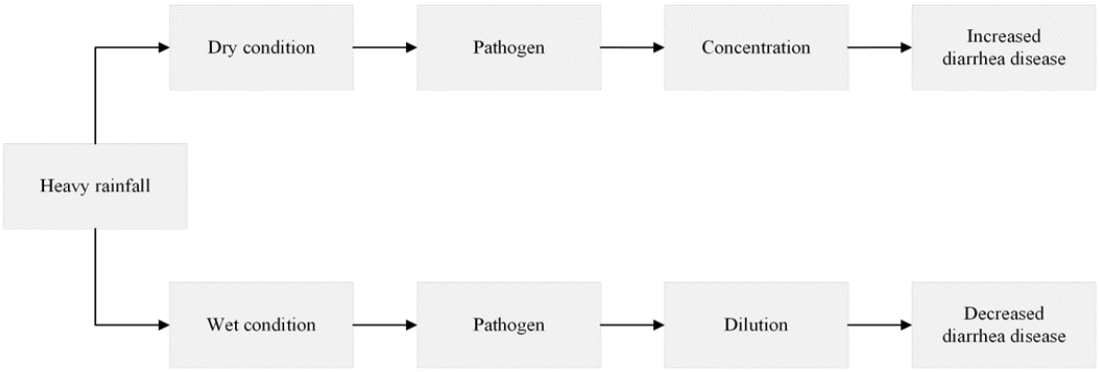

Figure 3. Conceptual framework of the concentration-dilution theory for the rainfall effect on diarrhea incidence (modified from Kraay et al., 2020).

relate to viral pathogens (such as rotavirus diarrhea) that can survive under low and high humidity (Wibawa et al., 2023).

Climate Seasonality

Differences in seasonal patterns were observed in the pathogens responsible for diarrhea diseases. A systematic review of relevant studies revealed variations in the incidence of diarrhea diseases caused by different pathogens in response to seasonal changes. During dry and cold seasons, there was a notably higher occurrence of rotavirus-related diarrhea (Chao et al., 2019; Hashizume et al., 2008; Moe et al., 2005; Omore et al., 2016). Conversely, the incidence of diarrhea attributed to rotavirus was lower during the rainy season, as reported by Enweronu-Laryea et al., (2014) and Das et al., (2014).

On the other hand, cases of Human parechovirus and Norovirus-related diarrhea showed an increase during the rainy season (Becker-Dreps et al., 2017; Hossain et al., 2019; Malasao et al., 2019). Notably, diarrhea caused by bacteria and parasites were more prevalent during the rainy season, as observed in the studies by Robert et al., (2021), Das et al., (2014), Eibach et al., (2015), and Lee et al., (2017). Furthermore, it is important to mention that diarrhea diseases caused by bacteria can endure and even thrive in high-temperature conditions (Charles et al., 2014).

Causes of Inconsistent Associations

The findings from a systematic review revealed an inconclusive correlation between diarrhea diseases and climatic factors (such as rainfall, temperature, and humidity) in tropical regions. This variability is attributed to the diversity of diarrhea pathogens, which exhibited regional variations (Aik et al., 2020; Thompson et al., 2015). The association between climatic influences and diarrhea disease becomes more precise when the analysis considers specific diarrhea-causing pathogens. However, the limited inclusion of pathogen types in these studies complicated drawing definitive conclusions regarding the relationship between climatic factors and diarrhea diseases.

Out of the 43 studies examined, 13 did not specify the pathogen type, potentially encompassing bacterial, viral, or parasitic origins (all causes), while 13 studies focused on bacterial pathogens, and another five studies focused on viral and parasitic pathogens. The occurrence of diarrhea disease is influenced by a complex interplay of climatic factors rather than being solely attributed to a single factor. Notably, these factors include rainfall, temperature, and humidity, which collectively contribute to diarrhea disease incidence (Sumi et al., 2013). Several literatures supported the notion that the synergy among these climatic variables can impact the prevalence of diarrhea diseases (Hasan et al., 2018; Onanuga et al., 2014; Sumi et al., 2013; Ureña-Castro et al., 2019; Wu et al., 2018). Study conducted by Ureña-Castro et al., (2019) showed the interaction between rainfall and temperature was found to mitigate the occurrence of diarrhea disease.

Conversely, a study in Costa Rica revealed an increased diarrhea during periods of low rainfall and temperature. In Kolkata, India, a timeseries analysis demonstrated a peak in diarrhea incidence when temperature, humidity, and rainfall were at low level. This tripartite interaction heightened the risk of rotavirus-induced diarrhea disease (Sumi et al., 2013). Another study reported a reduction in diarrhea cases resulting from the interaction between high temperatures and heavy rainfall (Hasan et al., 2018). The incidence of diarrhea was influenced by the interplay of

low rainfall and high temperatures (Onanuga et al., 2014; Wu et al., 2018). This may relate to reduced water availability due to low rainfall, and elevated temperatures provide an environment conducive to the growth of diarrhea pathogens, such as bacteria and parasites.

Furthermore, low humidity and reduced rainfall levels intensify the transmission of viral diarrhea due to the airborne dispersion of fecal material (Sumi et al., 2013). Examining the interactions among the climatic

factors painted a more comprehensive explanation of their impact on the prevalence of diarrhea diseases. Notably, low rainfall coupled with low temperatures increases the occurrence of rotavirus-induced diarrhea, while low rainfall and high temperatures were associated with a higher prevalence of bacterial diarrhea. Additionally, low rainfall combined with low humidity was linked to an increased incidence of rotavirus diarrhea. It's worth noting that existing literature has primarily examined each climate influence in isolation, without considering their combined effects.

However, there was a notable gap in the literature as there was limited analysis regarding the potential impact of high rainfall combined with high temperatures on diarrhea diseases, as well as the influence of high rainfall paired with high humidity. Rainfall can serve as a vector for the transmission of diarrhea diseases, while humidity is a key factor in the biological growth of pathogens (Lee et al., 2017). Furthermore, it's important to acknowledge that sanitation infrastructure, including drainage canals, may act as a modifier in the relationship between climatic factors and diarrhea diseases. But the existing literatures did not provide comprehensive information on the role of sanitation infrastructure, which limits our ability to further analyze the interplay between climate factors and diarrhea diseases, particularly in the context of canal drainage.

CONCLUSIONS

The association between diarrhea disease and climatic factors (rainfall, temperature, and humidity) in the tropics showed an inconsistent relation. Limited studies, which include pathogens on the treatment/ analysis, may contribute to the decisions regarding the association of diarrhea and climatic factor. Each region may have different types of pathogens, so including the pathogens will provide more precise results regarding the association. In general, we found a positive association between climatic factor and diarrhea diseases, except for temperature with viral pathogens having a negative association. Humidity and viral pathogens had a non-linear association because viruses (rotavirus) can live in high or low humidity. Generally, bacterial and parasitic diarrhea incidence was higher during the rainy season, whereas viral diarrhea incidence was more prevalent during the dry season.

ACKNOWLEDGEMENT

The authors would like to thank IPB for providing a MSc scholarship to the first author under the fast-track scheme. We thank two anonymous reviewers for their valuable comments and suggestions to improve the manuscript.

REFERENCES

Aik, J., Ong, J., Ng, L.-C., 2020. The effects of climate variability and seasonal influence on diarrhoeal disease in the tropical city-state of Singapore – A time-series analysis. International Journal of Hygiene and Environmental Health 227, 113517. https://doi.org/10.1016/j.ijheh.2020.113517.

Becker-Dreps, S., Cuthbertson, C.C., Bucardo, F., Vinje, J., Paniagua, M., Giebultowicz, S., Espinoza, F., Emch, M., 2017. Environmental factors associated with childhood norovirus diarrhoea in León, Nicaragua. Epidemiol. Infect. 145, 1597–1605. https://doi.org/10.1017/S0950268817000322.

Berendes, D.M., Leon, J.S., Kirby, A.E., Clennon, J.A., Raj, S.J., Yakubu, H., Robb, K.A., Kartikeyan, A., Hemavathy, P., Gunasekaran, A., Roy, S., Ghale, B.C., Kumar, J.S., Mohan, V.R., Kang, G., Moe, C.L., 2019. Associations between open drain flooding and pediatric enteric infections in the MAL-ED cohort in a low-income, urban neighborhood in Vellore, India. BMC Public Health 19, 926. https://doi.org/10.1186/s12889-019-7268-1.

Campbell-Lendrum, D., Manga, L., Bagayoko, M., Sommerfeld, J., 2015. Climate change and vector-borne diseases: what are the implications for public health research and policy? Phil. Trans. R. Soc. B 370, 20130552. https://doi.org/10.1098/rstb.2013.0552.

Carlton, E.J., Eisenberg, J.N.S., Goldstick, J., Cevallos, W., Trostle, J., Levy, K., 2014. Heavy Rainfall Events and Diarrhea Incidence: The Role of Social and Environmental Factors. American Journal of Epidemiology 179, 344–352. https://doi.org/10.1093/aje/kwt279.

Carlton, E.J., Woster, A.P., DeWitt, P., Goldstein, R.S., Levy, K., 2016. A systematic review and meta-analysis of ambient temperature and diarrhoeal diseases. Int. J. Epidemiol. 45, 117–130. https://doi.org/10.1093/ije/dyv296.

Chao, D.L., Roose, A., Roh, M., Kotloff, K.L., Proctor, J.L., 2019. The seasonality of diarrheal pathogens: A retrospective study of seven sites over three years. PLoS Negl Trop Dis 13, e0007211. https://doi.org/10.1371/journal.pntd.0007211.

Charles, M., Delva, G.G., Boutin, J., Severe, K., Peck, M., Mabou, M.M., Wright, P.F., Pape, J.W., 2014. Importance of Cholera and Other Etiologies of Acute Diarrhea in Post-Earthquake Port-au-

Prince, Haiti. The American Society of Tropical Medicine and Hygiene 90, 511–517. https://doi.org/10.4269/ajtmh.13-0514.

Cook, D.A., West, C.P., 2012. Conducting systematic reviews in medical education: a stepwise approach. Medical Education 46, 943–952. https://doi.org/10.1111/j.1365-2923.2012.04328.x.

Das, S.K., Begum, D., Ahmed, S., Ferdous, F., Farzana, F.D., Chisti, M.J., Latham, J.R., Talukder, K.A., Rahman, M.M., Begum, Y.A., Faruque, A.S.G., Malek, M.A., Qadri, F., Ahmed, T., Alam, N., 2014. Geographical diversity in seasonality of major diarrhoeal pathogens in Bangladesh observed between 2010 and 2012. Epidemiol. Infect. 142, 2530–2541. https://doi.org/10.1017/S095026881400017X.

Deshpande, A., Chang, H.H., Levy, K., 2020. Heavy Rainfall Events and Diarrheal Diseases: The Role of Urban–Rural Geography. The American Journal of Tropical Medicine and Hygiene 103, 1043–1049. https://doi.org/10.4269/ajtmh.19-0768.

Dharmayanti, I., Tjandrarini, D.H., Hidayangsih, P.S., 2022. Climatic Factors and Childhood Diarrhea in South Kalimantan in 2017-2020. SOUTHEAST ASIAN J TROP MED PUBLIC HEALTH 53.

Eibach, D., Krumkamp, R., Al-Emran, H.M., Sarpong, N., Hagen, R.M., Adu-Sarkodie, Y., Tannich, E., May, J., 2015. Molecular Characterization of Cryptosporidium spp. among Children in Rural Ghana. PLoS Negl Trop Dis 9, e0003551. https://doi.org/10.1371/journal.pntd.0003551.

Enweronu-Laryea, C.C., Sagoe, K.W.C., Mwenda, J.M., Armah, G.E., 2014. Severe Acute Rotavirus Gastroenteritis in Children Less Than 5 Years in Southern Ghana: 2006–2011. Pediatric Infectious Disease Journal 33, S9–S13. https://doi.org/10.1097/INF.0000000000000045.

Guzman Herrador, B.R., De Blasio, B.F., MacDonald, E., Nichols, G., Sudre, B., Vold, L., Semenza, J.C., Nygård, K., 2015. Analytical studies assessing the association between extreme precipitation or temperature and drinking water-related waterborne infections: a review. Environ Health 14, 29. https://doi.org/10.1186/s12940-015-0014-y.

Hasan, M.A., Mouw, C., Jutla, A., Akanda, A.S., 2018. Quantification of Rotavirus Diarrheal Risk Due to Hydroclimatic Extremes Over South Asia: Prospects of Satellite-Based Observations in Detecting Outbreaks. GeoHealth 2, 70–86. https://doi.org/10.1002/2017GH000101.

Hashizume, M., Armstrong, B., Hajat, S., Wagatsuma, Y., Faruque, A.S., Hayashi, T., Sack, D.A., 2007. Association between climate variability and hospital visits for non-cholera diarrhoea in Bangladesh: effects and vulnerable groups. International Journal of Epidemiology 36, 1030–1037. https://doi.org/10.1093/ije/dym148.

Hashizume, M., Armstrong, B., Wagatsuma, Y., Faruque, A.S.G., Hayashi, T., Sack, D.A., 2008. Rotavirus infections and climate variability in Dhaka, Bangladesh: a time-series analysis. Epidemiol. Infect. 136, 1281–1289. https://doi.org/10.1017/S0950268807009776.

Hossain, M.J., Saha, D., Antonio, M., Nasrin, D., Blackwelder, W.C., Ikumapayi, U.N., Mackenzie, G.A., Adeyemi, M., Jasseh, M., Adegbola, R.A., Roose, A.W., Kotloff, K.L., Levine, M.M., 2019. Cryptosporidium infection in rural Gambian children: Epidemiology and risk factors. PLoS Negl Trop Dis 13, e0007607. https://doi.org/10.1371/journal.pntd.0007607.

Kaminsky, R.G., Lagos, J., Raudales Santos, G., Urrutia, S., 2015. Marked seasonality of Cyclospora cayetanensis infections: ten-year observation of hospital cases, Honduras. BMC Infect Dis 16, 66. https://doi.org/10.1186/s12879-016-1393-6.

Kraay, A.N.M., Man, O., Levy, M.C., Levy, K., Ionides, E., Eisenberg, J.N.S., 2020. Understanding the Impact of Rainfall on Diarrhea: Testing the Concentration-Dilution Hypothesis Using a Systematic Review and Meta-Analysis. Environ Health Perspect 128, 126001. https://doi.org/10.1289/EHP6181.

Lee, H.S., Ha Hoang, T.T., Pham-Duc, P., Lee, M., Grace, D., Phung, D.C., Thuc, V.M., Nguyen-Viet, H., 2017. Seasonal and geographical distrib 105 of bacillary dysentery (shigellosis) and associated climate risk factors in Kon Tum Province in Vietnam from 1999 to 2013. Infect Dis Poverty 6, 113. https://doi.org/10.1186/s40249-017-0325-z.

Levy, K., Hubbard, A.E., Eisenberg, J.N., 2009. Seasonality of rotavirus disease in the tropics: a systematic review and meta-analysis. International Journal of Epidemiology 38, 1487–1496. https://doi.org/10.1093/ije/dyn260.

Levy, M.C., Collender, P.A., Carlton, E.J., Chang, H.H., Strickland, M.J., Eisenberg, J.N.S., Remais, J.V., 2019. Spatiotemporal Error in Rainfall Data:

Consequences for Epidemiologic Analysis of Waterborne Diseases. American Journal of Epidemiology 188, 950–959. https://doi.org/10.1093/aje/kwz010.

Liang, M., Ding, X., Wu, Y., Sun, Y., 2021. Temperature and risk of infectious diarrhea: a systematic review and meta-analysis. Environ Sci Pollut Res 28, 68144–68154. https://doi.org/10.1007/s11356-021-15395-z.

Malasao, R., Khamrin, P., Kumthip, K., Ushijima, H., Maneekarn, N., 2019. Molecular epidemiology and genetic diversity of human parechoviruses in children hospitalized with acute diarrhea in Thailand during 2011-2016. Arch Virol 164, 1743–1752. https://doi.org/10.1007/s00705-019-04249-2.

Mellor, J., Kumpel, E., Ercumen, A., Zimmerman, J., 2016. Systems Approach to Climate, Water, and Diarrhea in Hubli-Dharwad, India. Environ. Sci. Technol. 50, 13042–13051. https://doi.org/10.1021/acs.est.6b02092.

Mertens, A., Balakrishnan, K., Ramaswamy, P., Rajkumar, P., Ramaprabha, P., Durairaj, N., Hubbard, A.E., Khush, R., Colford, J.M., Arnold, B.F., 2019. Associations between High Temperature, Heavy Rainfall, and Diarrhea among Young Children in Rural Tamil Nadu, India: A Prospective Cohort Study. Environ Health Perspect 127, 047004. https://doi.org/10.1289/EHP3711.

Moe, K., Hummelman, E.G., Oo, W.M., Lwin, T., Htwe, T.T., 2005. Hospital-Based Surveillance for Rotavirus Diarrhea in Children in Yangon, Myanmar. J INFECT DIS 192, S111–S113. https://doi.org/10.1086/431509.

Moher, D., Liberati, A., Tetzlaff, J., Altman, D.G., for the PRISMA Group, 2009. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. BMJ 339, b2535–b2535. https://doi.org/10.1136/bmj.b2535.

Oguttu, D.W., Okullo, A., Bwire, G., Nsubuga, P., Ario, A.R., 2017. Cholera outbreak caused by drinking lake water contaminated with human faeces in Kaiso Village, Hoima District, Western Uganda, October 2015. Infect Dis Poverty 6, 146. https://doi.org/10.1186/s40249-017-0359-2.

Omore, R., Tate, J.E., O'Reilly, C.E., Ayers, T., Williamson, J., Moke, F., Schilling, K.A., Awuor, A.O., Jaron, P., Ochieng, J.B., Oundo, J., Parashar, U.D., Parsons, M.B., Bopp, C.C., Nasrin, D., Farag, T.H., Kotloff, K.L., Nataro, J.P., Panchalingam, S., Levine, M.M., Laserson, K.F., Nuorti, J.P., Mintz, E.D., Breiman, R.F., 2016. Epidemiology, Seasonality and Factors Associated with Rotavirus Infection among Children withModerate-to-Severe Diarrhea in Rural Western Kenya, 2008–2012: The Global Enteric Multicenter Study (GEMS). PLoS ONE 11, e0160060. https://doi.org/10.1371/journal.pone.0160060

Onanuga, A., Igbeneghu, O., Lamikanra, A., 2014. A study of the prevalence of diarrhoeagenic Escherichia coli in children from Gwagwalada, Federal Capital Territory, Nigeria. Pan Afr Med J 17. https://doi.org/10.11604/pamj.2014.17.146.3369.

Pérez-Corrales, C., Leandro-Sandí, K., 2019. Diarrheagenic Escherichia coli in Costa Rican children: a 9-year retrospective study. BMC Res Notes 12, 297. https://doi.org/10.1186/s13104-019-4313-1.

Prasetyo, D., Ermaya, Y., Martiza, I., Yati, S., 2015. Correlation between climate variations and rotavirus diarrhea in under-five children in Bandung. Asian Pacific Journal of Tropical Disease 5, 908–911. https://doi.org/10.1016/S2222-1808(15)60955-0.

Robert, E., Grippa, M., Nikiema, D.E., Kergoat, L., Koudougou, H., Auda, Y., Rochelle-Newall, E., 2021. Environmental determinants of E. coli, link with the diarrheal diseases, and indication of vulnerability criteria in tropical West Africa (Kapore, Burkina Faso). PLoS Negl Trop Dis 15, e0009634. https://doi.org/10.1371/journal.pntd.0009634

Sarkar, R., Kang, G., Naumova, E.N., 2013. Rotavirus Seasonality and Age Effects in a Birth Cohort Study of Southern India. PLoS ONE 8, e71616. https://doi.org/10.1371/journal.pone.0071616.

Strong, K.L., Pedersen, J., White Johansson, E., Cao, B., Diaz, T., Guthold, R., You, D., Requejo, J., Liu, L., 2021. Patterns and trends in causes of child and adolescent mortality 2000–2016: setting the scene for child health redesign. BMJ Glob Health 6, e004760. https://doi.org/10.1136/bmjgh-2020-004760.

Sumi, A., Rajendran, K., Ramamurthy, T., Krishnan, T., Nair, G.B., Harigane, K., Kobayashi, N., 2013. Effect of temperature, relative humidity and rainfall on rotavirus infections in Kolkata, India. Epidemiol. Infect. 141, 1652–1661. https://doi.org/10.1017/S0950268812002208.

Syafei, M., Hidayati, R., 2018. Pengaruh Ketinggian Tempat dan Curah Hujan Pada Penyakit Diare (Studi Kasus: Kabupaten Bogor). J.Agromet 28, 33. https://doi.org/10.29244/j.agromet.28.1.33-39.

106

Tellevik, M.G., Moyo, S.J., Blomberg, B., Hjøllo, T., Maselle, S.Y., Langeland, N., Hanevik, K., 2015. Prevalence of Cryptosporidium parvum/hominis, Entamoeba histolytica and Giardia lamblia among Young Children with and without Diarrhea in Dar es Salaam, Tanzania. PLoS Negl Trop Dis 9, e0004125. https://doi.org/10.1371/journal.pntd.0004125.

Thompson, C.N., Zelner, J.L., Nhu, T.D.H., Phan, M.V., Hoang Le, P., Nguyen Thanh, H., Vu Thuy, D., Minh Nguyen, N., Ha Manh, T., Van Hoang Minh, T., Lu Lan, V., Nguyen Van Vinh, C., Tran Tinh, H., Von Clemm, E., Storch, H., Thwaites, G., Grenfell, B.T., Baker, S., 2015. The impact of environmental and climatic variation on the spatiotemporal trends of hospitalized pediatric diarrhea in Ho Chi Minh City, Vietnam. Health & Place 35, 147–154. https://doi.org/10.1016/j.healthplace.2015.08.001.

Trærup, S.L.M., Ortiz, R.A., Markandya, A., 2011. The Costs of Climate Change: A Study of Cholera in Tanzania. IJERPH 8, 4386–4405. https://doi.org/10.3390/ijerph8124386.

Trtanj, J., Jantarasami, L., Brunkard, J., Collier, T., Jacobs, J., Lipp, E., McLellan, S., Moore, S., Paerl, H., Ravenscroft, J., Sengco, M., Thurston, J., 2016. Ch. 6: Climate Impacts on Water-Related Illness. The Impacts of Climate Change on Human Health in the United States: A Scientific Assessment. U.S. Global Change Research Program. https://doi.org/10.7930/J03F4MH4.

Ureña-Castro, K., Ávila, S., Gutierrez, M., Naumova, E.N., Ulloa-Gutierrez, R., Mora-Guevara, A., 2019. Seasonality of Rotavirus Hospitalizations at Costa Rica's National Children's Hospital in 2010–2015. IJERPH 16, 2321. https://doi.org/10.3390/ijerph16132321.

Van Elsas, J.D., Semenov, A.V., Costa, R., Trevors, J.T., 2011. Survival of Escherichia coli in the environment: fundamental and public health aspects. ISME J 5, 173–183. https://doi.org/10.1038/ismej.2010.80.

Wibawa, B.S.S., Maharani, A.T., Andhikaputra, G., Putri, M.S.A., Iswara, A.P., Sapkota, A., Sharma, A., Syafei, A.D., Wang, Y.-C., 2023. Effects of Ambient Temperature, Relative Humidity, and Precipitation on Diarrhea Incidence in Surabaya. IJERPH 20, 2313. https://doi.org/10.3390/ijerph20032313.

Wu, J., Yunus, M., Ali, M., Escamilla, V., Emch, M., 2018. Influences of heatwave, rainfall, and tree cover on cholera in Bangladesh. Environment International 120, 304–311. https://doi.org/10.1016/j.envint.2018.08.012.

Yang, M., Chen, C., Zhang, X., Du, Y., Jiang, D., Yan, D., Liu, X., Ding, C., Lan, L., Lei, H., Yang, S., 2022. Meteorological Factors Affecting Infectious Diarrhea in Different Climate Zones of China. IJERPH 19, 11511. https://doi.org/10.3390/ijerph191811511.

Yeasmin, S., Hasan, S.M.T., Chisti, M.J., Khan, M.A., Faruque, A.S.G., Ahmed, T., 2022. Factors associated with dehydrating rotavirus diarrhea in children under five in Bangladesh: An urban-rural comparison. PLoS ONE 17, e0273862. https://doi.org/10.1371/journal.pone.0273862.