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The triple burden of disease due to heavy rainfall in the low-middle-income countries: a scoping review

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Abstract

Background: Climate change has significantly impacted on human health. Excessive rainfall due to climate change was found to be a risk factor of the burden of disease and injuries. Therefore, this review aims to determine the burden of disease, including CDs, NCDs, and Injuries due to heavy rainfall in middle-income countries due to climate change.

Methods: This scoping review includes the published literature from January 2011 to December 2022 (12 years). A comprehensive search for articles was performed through PubMed, Science Direct, and Web of Science, employing a combination of keywords and Boolean functions. The articles were imported into the referencing software EndNote, and duplicate data files were subsequently eliminated. Two authors independently conducted article screening and data extraction. A total of 26 articles were included in the scoping review. The data extraction method was narrative synthesis and description.

Results: Communicable diseases such as Influenza and Malaria were more prevalent during the rainy season. Increased rainfall also contributes to an increased number of road traffic accidents. Flooding due to heavy rainfall is another health risk, especially in LMICs. The acute impacts of flooding include drowning, heart attacks, and hypothermia. Collateral damage from flooding includes injuries, infections, water-borne diseases, respiratory diseases, and mental health concerns.

Conclusion: Strategies and public health measures should be planned to reduce this burden. Also, policies and procedures should be developed to prevent such climate change concerns.

Keywords: Burden, Disease, Climate change, Public health, Environment

1 Introduction

Climate change has recently caused alarming global issues, including human health and disease. Following climate models, the anthropogenically warmer climate caused by greenhouse gas emissions contributes to heavy rain events, resulting in future changes in rainfall being more extreme and challenging than predicted [1]. Increased frequency of heavy rainfall due to global climate change facilitates the risk of diseases, making it a

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public health priority to identify the role of precipitation in the occurrence of diseases [2]. Heavy precipitation increases human exposure to waterborne pathogens by mobilizing the pathogens and transporting them into wells, rivers, and coastal water. Consequently, it also heightens the risk of floods, sewage overflow, and contamination of drinking water pipes, potentially exposing humans to waterborne infectious diseases [3]. Furthermore, excessive or heavy rainfall significantly influences regions with aging infrastructure and combined sewage systems, affecting water quality [4]. High rainfall results in pockets of standing water, an ideal breeding ground for hosts and vectors such as insects, mosquitoes, and rodents [2]. As mentioned in the literature an elevated risk of disease outbreaks was associated with heavy rainfall in developed [3, 5–7] and developing countries [4, 8–13]. However, most studies have focused on diseases precipitated due to heavy rainfall in developed countries [3, 5–7]. Curriero et al. reported heavy rainfall events with precipitation levels over the 90th percentile, anticipating approximately 50% of waterborne disease outbreaks in the United States from 1948 to 1994 [5]. Furthermore, excessive rainfall was a significant factor in waterborne disease epidemics in Canada over 26 years from 1975 to 2001 [6]. A prior study in Taiwan linked heavy rainfall, followed by an enterovirus outbreak contaminating drinking water, consequently, leading to epidemics causing severe illnesses, which are fatal to human health [7]. Literature further mentions heavy rainfall was a common extreme weather condition linkedwith disease outbreaks. The most prevalent pathogen, *Vibrio* spp., linked with severe water-related weather events, causes illness outbreaks in Asia, Africa, and South America [3]. Ahmed et al. mentioned a previous study associating the climatic risk index (CRI) with an inverse relation to the susceptibility of nations to natural disasters. They found that developing countries with low-middle income, such as Afghanistan, Serbia, and Bosnia, are the most affected by natural disasters [13]. In India and Thailand, leptospirosis outbreaks have been linked to excessive rainfall [8, 9]. Literature further reports outbreaks of Cholera in Bangladesh were reported to be linked with heavy precipitation [10]. An expected risk of drinking water contamination in developing Southeast Asia and Africa is based on increased fecal contamination reported due to heavy rainfall and high temperatures in Tanzania. This emphasizes the need to protect the most susceptible countries from the harsh consequences of climate change [11]. The young Indian population encountered a correlation between diarrhea and excessive precipitation, possibly because severe rainfall exposes children to washed pathogens that build during dry periods [12]. Jagai et al. indicated an elevated risk of gastrointestinal disease among individuals exposed to contaminated drinking water supply by combined sewer overflow, followed by extreme precipitation [4]. Additionally, an association between climate change, such as high rainfall and rising temperatures, with water-borne diseases such as dengue fever, enterovirus infection, and Japanese encephalitis is reported in Taiwan [2]. Ahmed et al. also associated climate change with water-borne diseases like dengue and malaria [13]. The prevalence of malaria is dependent on the intensity of rainfall. In addition, approximately 33% of the world's population resides in the areas associated with dengue transmission [14]. Climate change impacts almost all countries globally. However, developing countries are more sensitive and vulnerable to catastrophic events [13]. Waterborne outbreaks cause approximately 80% of diseases in developing nations such as Pakistan [15]. Over recent years economically challenged developing countries have been severely impacted by natural disasters. In addition, there is limited protection for developing countries such as Sub-Saharan Africa, home to half of the world's impoverished population, lacking access to education and funds to overcome natural calamities [13]. To overcome the recent economic crises, it is suggested to adopt strategies and policies to counter climate change [13].

The burden of communicable diseases is still very high in low- and middle-income countries (LMICs), which are currently undergoing transition, including countries in South Asia and Africa. These communicable diseases have somewhat decreased in LMICs because of continuous economic progress, but the burden of injuries and NCDs has also increased, creating a "triple burden of disease" in LMICs [16].

This data focuses on the vulnerability and exposure to diseases followed by heavy rainfall in developing countries, about the possible impact of climate change, linked to rise of potential diseases in LMICs. This review aims to determine the burden of disease, including communicable diseases, non-communicable diseases, and injuries due to heavy rainfall in LMICs, due to climate change.

2 Methods

We have carried out a scoping review of all available studies with cross-sectional study designs or surveys on the burden of disease due to climate change in LMICs. The studies considered were based on prevalence numbers, percentages, and statistics around the topic. Statistics such as odds ratios, risk ratios, hazard ratios, and risk rates were not considered in the study. "Preferred Reporting Items for Systematic reviews and Meta-Analyses extension for Scoping Reviews (PRISMA-ScR) guidelines were used to develop this scoping review."

2.1 Information sources and timeline

A comprehensive search for articles was performed using PubMed, Science Direct, and Web of Science. The review includes the published literature from January 2011 to December 2022 (12 years). Using data from 2011–2022 ensures a robust analysis by capturing long-term trends, major policy and system changes, and significant external events. This period also includes recurrent heavy rains and floods in South Asia, which influenced population health and service utilization, strengthening the study's context, relevance, and reliability.

2.2 Eligibility criteria

2.2.1 Inclusion criteria

We have included all original peer-reviewed journal articles published in the English language and articles that at least have an abstract available from LMICS. The included studies were observational, qualitative studies, and mixed-method studies. Prevalence was reported from observational, quantitative, and mixed-methods articles. Narrative descriptions were extracted from qualitative and mixed-methods studies.

2.2.2 Exclusion criteria

We have excluded non-peer-reviewed articles, letters to the editors, and conference proceedings. Non-human subject articles, articles in a language other than English, and studies not involving LMICs. Grey literature (e.g., reports, thesis, preprints) was excluded.

Studies reporting only effect measures (e.g., odds ratios, risk ratios, hazard ratios) or analytical outcomes were excluded. This review focused on cross-sectional studies providing prevalence or descriptive statistics to ensure comparability and consistent synthesis of population-level patterns.

2.3 Search strategy

The search was carried out employing a combination of keywords and Boolean functions. The search terms were "climate change, rainfall, heavy rainfall, disease, the burden of disease, LMICs." These words were used individually and in combination to get the best results.

((((((((("Climate Change"[Mesh])) OR "Rain"[Mesh]) AND "Disease"[Mesh]) OR "Global Burden of Disease"[Mesh]) OR "Illness Behavior"[Mesh]) OR ("Communicable Diseases, Emerging"[Mesh] OR "Communicable Diseases, Imported"[Mesh] OR "Communicable Diseases"[Mesh])) OR "Noncommunicable Diseases"[Mesh]) OR ("injuries" [Subheading] OR "Wounds and Injuries"[Mesh])) AND "Floods"[Mesh].

2.4 Study selection

The identified articles were imported into the referencing software Endnote, and duplicate data files were subsequently eliminated. Two authors independently conducted article screening and data extraction. English-language peer-reviewed articles were considered only. Duplicates were removed at the title screening stage. A total of 15 articles were eligible at the full article review stage. Figure 1 illustrates the process of article selection. A flow chart of search and study selection with included and excluded studies is presented in Fig. 1.

2.5 Data extraction method

The methodology for data extraction is narrative synthesis and description, which is an approach to a scoping review by the synthesis of findings from multiple studies. We have used the mixed-method study review (MMSR) methodology of the Joanna Briggs Institute (JBI), which is suitable for mixed-methods narrative reviews, as we have both qualitative and quantitative studies in our review. We have followed the convergent integrated approach, specifying what information from the quantitative and qualitative studies has been considered while constituting the findings. Quantitative studies have been included along with descriptive studies that provide information about the magnitude and statistical significance, comprising an average or a percentage that profiles the study samples. For descriptive studies, the data were extracted, and for the qualitative studies included in the review, themes and subthemes relevant to the review question were systematically extracted and supported with illustrative data from the original papers. Coding was conducted by two reviewers independently, with discrepancies discussed and resolved through consensus. Although formal inter-coder reliability statistics were not calculated, we used iterative cross-checking to enhance consistency. Each finding has then been assigned credibility based on the congruency of the finding with supporting

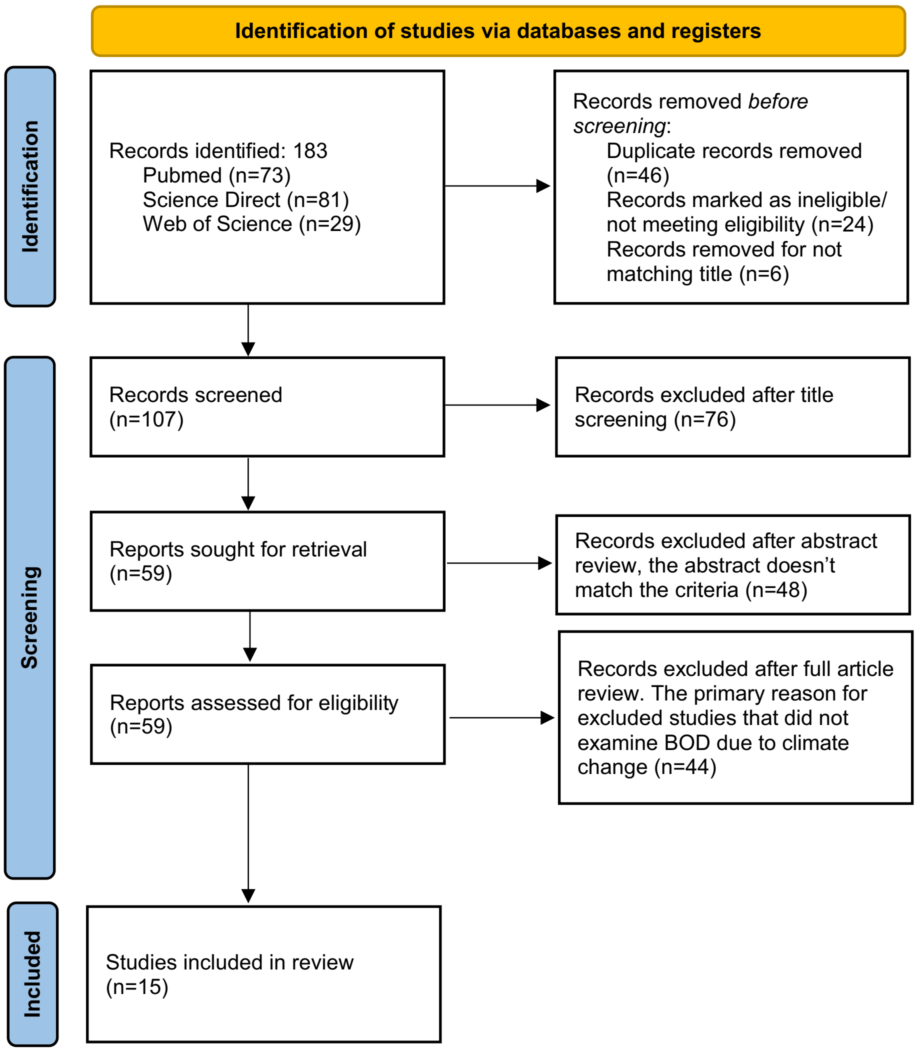

Fig. 1 PRISMA flow chart

data. The quality of the overall study was assessed by following the critical appraisal of quality assessment JBI.

Quantitative and qualitative data from studies in the review by two independent reviewers (BI & ZD) have been included in specific details about the populations, study methods, context, and outcomes of relevance to the review question. Quantitative data comprises data-based outcomes of descriptive or inferential statistics, while qualitative data comprises themes or subthemes with corresponding illustrations. Credible data relates to those conclusions that are interpretations, plausibly considering the data and the theoretical framework.

Two individual authors (BI & ZD) independently extracted the data in an Excel sheet any disagreement was resolved by the third author (SS), who included specific details about the climate change and burden of disease.

Heterogeneity was addressed by methodically mapping out the features of the study and organizing the results into thematic groups according to variations in the population, the intervention, and the results. It was not possible to perform statistical pooling or meta-analysis due to the significant variety in study designs, measurements, and contexts.

2.6 Inter-rater agreement

To ensure methodological rigor, the two reviewers independently conducted article screening and data extraction. Inter-rater agreement was assessed to evaluate consistency and identify areas of disagreement. We calculated the Cohen's kappa coefficient, which quantifies agreement beyond chance. Reporting this metric clarifies the reliability of the review process and demonstrates that discrepancies were systematically resolved through discussion and consensus.

2.7 Data transformation

An Excel sheet was developed including details of studies i.e., author, year, location, objectives, population/sample size (where applicable) and results summary. Following extraction, the data were transformed into textual descriptions and narrative interpretation of the quantitative results to respond directly to the review question, including the percentages, and the assembled data were categorized as injuries, CDs and NCDs due to heavy rainfall. The data was narrated in a way to provide a contextual understanding about the available literature.

2.8 *Quality assessment of the selected studies (n = 15)*

Qualitative studies (n = 3): The majority showed a clear alignment between the goals of the study, the techniques used to gather the data, and the interpretation of the findings. Typical methodological flaws were unclear ethical approval procedures and inadequate reporting on researcher reflexivity.

Quantitative studies (n = 10): Most employed credible, trustworthy outcome measures and appropriately addressed confounding variables. However, other studies reported poor response rates and insufficient reporting of sampling procedures.

Mixed-Method studies (n = 2): The majority met both qualitative and quantitative quality standards, but the mixed-methods synthesis process was less transparent since data strand integration was not always well explained.

3 Results

Extracted data is available in Table 1.

3.1 Injuries due to rainfall

Extreme rainfall has contributed not only to an increase in road traffic injuries globally but also to the prevalence of certain diseases in LMICs [17]. Unfortunately, LMICs cannot combat not only the disease burden but also the injury burden due to a lack of resources and protection in their respective regions around the globe. A report studying climate-sensitive health conditions, including malnutrition, malaria, diarrheal illness, and flood-related fatalities, concluded that these effects are seen primarily in LMICs, specifically in African countries [18].

Table 1 Findings from the included studies

Author & year	Country/location	Population/sample size	Study design	Exposure/factor	Outcomes	Results summary
Agrawal et al. 2013	Uganda	800 households	Cross-sectional	Flooding	Injuries	3.14% of the flood-affected population had injuries. Injury rate per 1000 was 31 (Males 32/1000, Females 31/1000)
Asefa et al. 2015	Ethiopia	712 taxi drivers	Cross-sectional	Rainy weather	Road traffic injuries	26.4% of drivers reported injuries from road traffic crashes due to adverse and rainy weather
Zhai et al. 2019	Hong Kong	2,794 pedestrians	Observational	Heavy rainfall	Severe injury/death	25.1% (702) pedestrians killed or severely injured due to crashes during heavy rainfall
Chen et al. 2012	Taiwan	National surveillance data (1994–2008)	Ecological time-series	Extreme precipitation	Infectious diseases	Extreme precipitation altered distribution of infectious diseases
Jean et al. 2006	Taiwan	Community outbreak	Outbreak investigation	Rainfall & contaminated water	Enterovirus epidemic	Enterovirus epidemic linked to rainfall and contaminated well water
Phosri 2022	Thailand	Multi-province	Time-series	Rainfall	Leptospirosis	Rainfall significantly associated with leptospirosis incidence with distributed lag effects
Pappachan et al. 2004	Kerala, India	State-level data	Ecological study	Rainfall	Leptospirosis epidemics	Rainfall patterns strongly correlated with leptospirosis epidemics
Islam et al. 2009	Matlab, Bangladesh	Local population	Observational	Climate variability	Cholera	Climate variability significantly affected cholera transmission dynamics
Guo et al. 2021	Tanzania	Case study	Case study	Short-term climate variability	Water quality impact	Short-term climate variability negatively impacted drinking water quality

Table 1 (continued)

Author & year	Country/location	Population/sample size	Study design	Exposure/factor	Outcomes	Results summary
Mertens et al. 2019	Tamil Nadu, India	Cohort of young rural children	Cohort study	Heavy rainfall & high temperature	Diarrhea	Heavy rainfall and high temperature increased diarrhea among children
Baqir et al. 2012	Pakistan	Flood-affected population	Observational	Monsoon flooding	GI, respiratory, skin infections	Infectious diseases (GI, respiratory, skin) rose sharply after monsoon flooding
Abedin et al. 2019	Bangladesh (coastal)	Coastal population	Qualitative/mixed	Climate change & water scarcity	Mental health outcomes (NCDs)	Climate change and water scarcity increased health vulnerabilities and need for adaptation. Flooding and extreme weather events are associated with increased stress, anxiety, depression, and PTSD symptoms. Evidence is largely indirect, often inferred from displacement, livelihood loss, and reduced access to services rather than measured clinically
Chowdhury et al. 2018	Bangladesh	National infectious disease data	Ecological time-series	Rainfall, temperature, humidity	Climate-sensitive diseases	Rainfall, temperature, and humidity are associated with climate-sensitive diseases
Azziz-Baumgartner et al. 2012	Bangladesh	National surveillance (2008–2010)	Surveillance analysis	Rainfall	Respiratory infections	Seasonal influenza and severe respiratory infections linked with rainfall
Luo et al. 2018	Vietnam (Hanoi)	Urban flooding assessment	Ecological study	Extreme rainfall	Flood inundation risk	Historical and extreme rainfall caused significant flood inundation risk

Heavy rainfall results from the global rise in temperature due to greenhouse gas emissions. Heavy rainfall increases flooding and landslides, particularly in LMICs, which have extremely detrimental effects on the economy, environment, and human health. Landslides can cause serious human and extreme economic losses [19]. As climate change continues to worsen, extreme rainfall will then increase in frequency as well as in severity, thus leading to greater and more catastrophic landslides worldwide [19]. The Intergovernmental Panel on Climate Change (IPCC) has predicted that a growing number of landslides will soon be caused by extreme rainfall due to climate change [19]. This will result in humans, most notably in LMICs, becoming more and more vulnerable to the devastating effects of this natural disaster. LMICs are ill-equipped to handle this environmental burden and suffer great losses from these landslides. In February 2010, several days of heavy rainfall in the Baduda and Butaleja Districts of Eastern Uganda caused extreme flooding and landslides. This flooding and landslides caused extreme destruction to infrastructure, crops, water, and sanitation, displacement of people, and increased levels of mortality and morbidity throughout the region including 3.14% of population had injuries. The injury rate per was 31/1000 population [20]. Landslides cause a significant loss of lives every year. Studies have shown that 17% of fatalities from adverse weather events or natural disasters are due to landslides [19]. Preventative measures, such as warning systems and evacuation protocols, must be established to prepare the population for landslides more adequately, especially in vulnerable regions worldwide. If preventative measures are enacted, there will be a better likelihood of survival and a more effective medical protocol, improving patient outcomes [20].

Increased rainfall also contributes to an increased amount of road traffic accidents. Vehicular crashes and pedestrians are at greater risk for collisions when adverse weather conditions such as rainfall, occur. The current literature has stated a significant correlation between road traffic accidents and rainfall [21]. In 2013, the World Health Organization Status Report on Road Safety estimated that around 1.24 million deaths occur yearly due to road traffic crashes. Yet, most of this load is carried by LMICs [22]. Of all these fatalities due to road traffic accidents, 13.8% of the crashes resulted from rainfall [22]. A study concluded that regions with a higher number of monthly rainy days and maximum rainfall result in higher crash rates [23]. Not only can adverse weather conditions be a risk factor for road traffic accidents, but they can also increase the severity of the crashes when they occur [24]. Climate change has caused discrepancies in precipitation and air temperature; therefore, storms, heat waves, and heavy rainfall are growing in frequency [25]. Inclement weather negatively affects vehicle performance, pavement conditions, driver behavior, and visibility [26]. During rain, there is a reduction in road surface friction force, which can increase the likelihood of crashes with increased intensity. Wet roads can result in the tires being unable to grip the road at an adequate level, thus, increasing the risk of dangerous encounters on the road [21]. Ivan et al. (2010) concluded that when analyzing the association between wet pavement friction and crash incidence statistically, there was an association between the two, thus demonstrating that rain does cause an increase in vehicle crash risk. Rain can also hinder the effectiveness of headlights, taillights, and braking lights while also obstructing the driver's vision [27]. Some studies have shown that the risk factor for being in a road traffic accident can be increased by 100% or more due to the reduction in visibility during rain events [26].

According to the Texas Department of Transportation (TxDOT), 16,818 crashes in a rural setting occurred under rainy conditions in 2015, four-fold greater than any other adverse weather condition [28]. Rain conditions substantially increase overall crash risk, which is 70% higher in a rain event than in an average clear day condition [28]. Keay and Simmons' study demonstrated that rainfall is a consistent driving hazard [29]. A study conducted in Thailand reported a higher number of road traffic injuries in both the Northern and Southern provinces due to rainfall [21]. This study also concluded that road accidents account for the highest number of ambulance dispatches all over Thailand. The frequency of ambulance dispatches has increased every year and has increased by 32.8% from the years 2012 to 2018 [21]. The World Health Organization has tried to encourage countries to create a proposal with the Sustainable Development Goal in mind to reduce the number of injuries and deaths globally due to road traffic crashes by 50% and therefore creating a safe and sustainable transport system by the year 2030 [30].

Pedestrians are also at high risk for road traffic accidents, especially during rain. The current literature emphasizes environmental and social factors such as pedestrian behavior, road environment, crash circumstances, vehicular speed, traffic control, and driver behavior as risk factors concerning a pedestrian's safety [25]. Adverse weather conditions have been linked as one of the leading causes of pedestrian injuries [25].

In Hanoi in 2008, a long and heavy rainfall period from late October through early November caused the most disastrous flood since 1973. During this flooding period, 27 injuries were reported within the first month. Three suffered from a bone fracture, and twelve suffered a contusion and laceration. Falls were also common and accounted for nine injuries during the first month of flooding. One person was injured due to drowning, and one was injured due to their involvement in a road traffic accident [31].

3.2 Communicable diseases due to rainfall

Communicable diseases are also a big risk factor for mortality and morbidity during the rainy or monsoon seasons. Influenza has one of the highest mortality and morbidity rates and therefore is one of the most serious diseases in humans [32]. Around the globe, the urban population is continuing to rise and now constitutes around half of the world's population. Around one-third of the urban population lives in informal settlements or slums [32]. These informal settlements consist of communities of people who are likely of the lower classes and do not have adequate access to water, sanitation, and basic infrastructure, as well as live in badly constructed and crowded housing. This overcrowding, insufficient sanitation, and lack of resources cause these residents to be extremely susceptible to infectious diseases such as influenza and other acute respiratory diseases [32]. A study done in Bangladesh demonstrated that Influenza A had a significant association with rainfall. This could be attributable to more time spent inside during the rainy season and higher transmission rates. The major peaks of influenza being seen during the rainy season could also be due to high humidity and temperature, where this virus thrives at optimal levels and transmission rates [32]. Tuberculosis (TB) can also increase in prevalence during rainy seasons. This could also be due to higher levels of indoor crowding during the rainy season, especially in slums, or informal settlements, which are seen a lot in LMICs. A study demonstrated that TB cases significantly increased during the rainy season. It was concluded that TB CNRs have a seasonal variation, peaking at the beginning and end of the rainy season. TB prevalence increases significantly when there is heavy rainfall [33].

Other infectious diseases that are more prevalent during the rainy seasons specifically include diarrhea, malaria, and pneumonia on a global scale. Malaria frequency in the Chittagong hill tracts of Bangladesh had the highest frequency of cases during the rainy season. Taiwan and Bangladesh also saw a significant increase in diarrheal disease during the rainy season. Enteric fever also prevailed during the monsoon season in Dhaka, Bangladesh, with the highest number of enteric fever (45%). Pakistan and India also had an increased burden of malaria during the rainy season [34].

Due to this lack of resources, dengue fever, diarrhea, and other epidemic diseases are prevalent. Not only are these diseases increasing the burden on these already vulnerable populations, but there is also no way to combat these diseases due to a lack of healthcare [35, 36].

Infectious diseases also result from increased rainfall and floods, most notably in LMICs. High levels of rainfall cause increasing amounts of microbiological agents in the surface water. Flooding can lead to increased levels of runoff of microbial pathogens can cause water contamination and a rise in infectious diseases. Gastrointestinal diseases in children are a common consequence of unsanitary water. Direct contact with unclean water can lead to skin infections such as conjunctivitis, dermatitis, and ear, nose, and throat infections [35, 36].

Acute asthma, skin rashes, gastroenteritis outbreaks, reparatory infections, infected wounds, injury complications, poisoning, an increase in the communicable disease burden, and starvation are also results of increased rainfall and therefore increased flooding around the globe [37].

3.3 Non-communicable diseases due to rainfall

Flooding can permanently impact the economy and environment in regions where a lack of resources makes it nearly impossible to recover which doesn't only cause financial distress but mental distress as well. Though the correlation in the literature was not explored well between NCDs and heavy rainfall impact chronic illnesses, disability, long-term mental health concerns, and poverty-related diseases were discussed as long-term concerns the public health [38]. The general and working class suffer most but vulnerable population such as elderly population and disabled people who are subject to living in poor conditions, such as informal settlements, do not have access to adequate food or sanitary resources were most affected with the mental health issues specially depression.

4 Discussion

Climate change has been predicted to cause a global rise in temperature shortly, along with increasing precipitation levels across the globe [39]. Human health is vulnerable to the effects of climate change, both directly and indirectly, through the burden of disease. There is increasing urbanization around the world, thus leading to a greater risk of disasters and global climate change which has an impact on a substantial number of the population. These areas are more vulnerable to storms, landslides, and floods [19]. As climate change continues to cause greater environmental impacts, the frequency and intensity of disasters and adverse weather conditions will also increase. Subsequent impacts on the environment and society due to climate change and global warming include wildfires, tropical cyclones, floods, droughts, dust storms, disease outbreaks, and the heightening of chronic diseases [40]. Storms (30%) and floods (47%) were the most common adverse weather conditions from the period of 1969–2018, increasing over the years due to climate change (extreme weather and climate change). The most deaths caused by weather include mortality by storms (39%), floods (16%), and droughts (34%) [17]. Although disaster risk reduction strategies are being implemented, it is also essential to understand the impact of the increased adverse weather conditions on the environment and human health.

Unfortunately, LMICs must endure a greater burden of climate change despite how these countries and regions do not contribute as much as high-income countries to greenhouse gas emissions [40]. A lot of the population in LMICs lives in informal settlements or slums. These slums are ill-equipped to deal with the consequences of climate change, thus putting them at a greater risk for natural hazards such as heavy rainfall and landslides [41]. The 2019 Intergovernmental Panel on Climate Change Special Report on Climate Change and Land observed that due to global warming from 1850–1900, extreme weather events have increased in frequency, duration, and intensity in most areas of the world. Some of the effects have been increased heavy precipitation across the globe and increased rainfall frequency throughout many regions [42].

Flooding due to heavy rainfall is another health risk, especially in LMICs. Climate change causes alterations to the normal patterns of precipitation and a rise in the sea level, thus creating more frequent and intense floods in different regions around the world [37]. Flooding makes up about 40% of all-natural disasters globally and is the reason behind around half the deaths that occur during a natural disaster. Over the past 20 years, over 400,000 million people have been exposed to flooding annually. From 1987 to 1997, 44% of the floods occurred in Asia, killing around 228,000 lives [37, 38]. The acute impacts of flooding include drowning, heart attacks, bodily injuries, and hypothermia. Collateral damage from flooding includes injuries, infections, water-borne diseases, respiratory diseases, and mental health concerns. Unfortunately, post-traumatic stress disorder prevails even after the water has receded and the recovery process is long and treacherous.

Injuries, infectious diseases, and road traffic accidents due to adverse weather conditions can be prevented or less severe due to preparations and protocols being implemented to deal with these potentially lethal risk factors. Specific risks and vulnerabilities will vary by region in terms of the severity of the rainfall or the resources that can be acquired. Still, an efficient approach should be implemented to create safety protocols and diagnose vulnerabilities in specific regions. Utilizing a risk/benefit approach to produce educated decisions will work to better prepare regions for adverse weather conditions such as heavy rainfall. Heavy rainfall, flood preparation, and mitigation strategies must be created and adapted for each region worldwide [31]. In doing so, the public health burden accompanying heavy rainfall and floods will be mitigated. Along with decreasing the burden of injuries and diseases, hospitals and medical facilities will be better prepared for the cases that arise from rainfall, resulting in better patient outcomes overall [40].

4.1 Strengths and limitations

This is one of the reviews focusing on the burden of disease due to climate change resulting in heavy rainfall in LMICs. LMICs have been affected most by this and there was no such evidence for the burden of disease resulting from climate change. Moreover, this study discussed the triple burden of disease including communicable and non-communicable diseases and injuries. The reviews and studies in the past have not touched all aspects of the burden of disease. Further, this includes an extensive review of articles for the last two decades. The limitation of this study's it doesn't provide estimates or confidence intervals to measure the strength of the association of BOD with rainfall resulting from climate change. The limitations include a proper data extraction along including all the factors contributing to burden of disease and particular climate change parameters. The study did not depict from the existing literature that what was the nature of the floods and heavy rainfall and the incidents happening were due to natural issues or man-made factors contributed to it.

5 Conclusion

This review informs that the heavy rainfall due to climate change has impacted human health and the environment, increasing disease burden especially infectious diseases and injuries. This disease burden further raises the incidence of morbidity and mortality in LMICs. The burden of disease due to heavy rainfall in LMICs influences human health and financial conditions. Strategies and public health measures should be planned to reduce this burden and out-of-pocket payment expenses. Also, policies and procedures should be developed to prevent such climate change concerns.

Abbreviations

CRI	Climatic Risk Index
IPCC	Intergovernmental Panel on Climate Change
LMICs	Low- and middle-income countries
TB	Tuberculosis
TxDOT	Texas Department of Transportation
WHO	World Health Organization

Acknowledgements
None.

Author contributions
SS—conceptualization, supervision, methodology, investigation, writing original draft and final draft. BS & ZA—methodology, writing, reviewing & editing final draft. All authors have read and approved the final version of the manuscript.

Funding
Not applicable.

Data availability
No datasets were generated or analysed during the current study.

Declarations

Ethics approval and consent to participate
This review is based entirely on publicly available literature and did not involve human participants; therefore, ethical approval was not required.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

Received: 8 April 2025 Accepted: 1 March 2026
Published online: 07 March 2026

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