

Impact of Climate Change on Waterborne Diseases: Directions towards Sustainability

Yong-Ju Jung ¹, Naing Aung Khant ², Heejung Kim ^{2,*} and Sim Namkoong ^{3,*}

¹ Ministry of Health & Welfare Gongju National Hospital, Gongju 32601, Republic of Korea; jjy1930@korea.kr

² Department of Geology, Kangwon National University, Chuncheon 24341, Republic of Korea; khant@kangwon.ac.kr

³ Department of Biochemistry, Kangwon National University, Chuncheon 24341, Republic of Korea

* Correspondence: hydroqueen@kangwon.ac.kr (H.K.); simn@kangwon.ac.kr (S.N.); Tel.: +82-33-250-8560 (H.K.); +82-33-250-8512 (S.N.)

Abstract: Climate change has significantly influenced the spread of waterborne diseases (WBDs), which affect environmental quality and human life. The impact of climate change is greatest in developing countries, especially in the Association of Southeast Asian Nations (ASEAN) countries. *Vibrio cholerae*, a waterborne pathogen, is most susceptible to and most prevalent during severe climatic changes. The Philippines is regularly exposed to tropical cyclones, such as Bopha in 2012 and Haiyan in 2013, because of its geographical location, while Cyclone Nargis in 2008 caused over 95% of the damage and casualties seen in the preceding two decades in Myanmar. Therefore, implementing policies to adjust to these climate changes and to safeguard their citizens from the effects of WBDs is imperative for ASEAN countries. This study aimed to (1) investigate the effects of climate change on health and to understand the policy requirements to prevent or minimize its negative impact and (2) explore the link between the Sustainable Development Goals (SDGs) and the effects of climate change on WBDs to determine perspectives for global sustainability. The framework of the SDGs should be adapted to ASEAN countries to improve legislation, laws, and regulations on climate-related health issues. Efficient collaboration among scientists, researchers, health professionals, and policymakers will assist in addressing the problems associated with the impact of climate change on WBDs in ASEAN countries.

Keywords: climate change; waterborne disease; Sustainable Development Goals; sustainable future



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1. Introduction

Climate change has significantly and severely affected the environment and human life. Large numbers of casualties have been reported owing to extremely high temperatures and cold waves worldwide, including in Europe and Asia [1–4]. Moreover, the detrimental effects of climate change on sectors such as agriculture and tourism, and the service sector result in significant economic losses, in addition to the loss of life and property [5]. Climate change entails changes in the ecosystem, with a significant impact on the habitat and daily life activities of not only large animals but also small insects (e.g., mosquitoes and mites) and rodents (e.g., mice) [6]. Consequently, this association between climate change and small living organisms may greatly amplify health risks in many countries, as most infectious diseases are transmitted to humans through vector-borne pathogens, such as mosquitoes, mites, and mice [6]. These causative pathogens may alter the timing, intensity, and distribution of infectious diseases, according to the fluctuations in temperature, precipitation, and humidity [6].

Furthermore, the impacts of climate disasters, such as droughts and floods, on human health include not only direct injuries or fatalities but also indirect impacts on individual nutrition levels owing to food production losses [7]. Although these issues are highly evident in developing countries, economically developed countries may also encounter

food security issues if climate change persists. Moreover, with increasing exposure to extreme climate events, the number of people experiencing mental health problems, such as melancholy, tension, pain, sense of deprivation, sadness, mental impairment, and suicide, is also gradually increasing [8].

Water-borne infectious diseases refer to diseases that develop mainly in the digestive system of the human body and are mediated by water or water-related foods (such as fish and shellfish), fruits, and vegetables. Climate change is changing precipitation patterns, causing rising sea levels, and altering seawater salinity, whilst also impacting several factors such as surface water temperature and the reproduction, survival, and sustenance of viruses and bacteria in waterbodies, which consequently affects human health [8,9]. Cholera and typhoid are representative bacterial foodborne or waterborne infectious diseases, which are clearly associated with temperature increases. The chance of developing *Salmonella* infections increases by 5–10% with every 1 °C increase in global temperature [9].

Enhancing the sustainability of the ecosystem by minimizing the negative impacts of ongoing climate change is a crucial part of the climate crisis response. As global warming continues to progress despite various efforts at both the international and national levels, adapting appropriately to the changing climate status is important. According to the previous literature, the effects of climate change on human health include heat- and cold-related diseases caused by extreme temperatures, heat waves, and cold waves; diseases caused by ecosystem changes; air quality-related diseases; and chronic diseases [10]. Naturally, risks, such as missing people, injuries, and fatalities from natural disasters (e.g., droughts, typhoons, and floods), are also consequences of climate change on humans. Furthermore, the risk of diarrhea, one of the most common waterborne diseases (WBDs), can potentially increase owing to heavy rainfall and high temperatures [10–13].

The available literature indicates that studies are shifting the focus from establishing correlations between climatic conditions and the outcomes of WBDs to merely projecting those correlations into the future while estimating and planning adjustment measures [13,14]. The concurrent influence of particular factors on the outcome, such as habitat loss, excessive travel and relocation of individuals, insecticide and drug resistance, industrialization, population explosion, and the unavailability of healthcare aid, makes it challenging to pinpoint the influence of climate change on the increasing occurrence of WBDs [14]. Additionally, one of the most important aspects of achieving sustainable development is having a clear understanding of how climate change will affect WBDs. Accordingly, this study aimed to (1) investigate the effects of climate change on human health from an adaptive perspective and understand the policies required to prevent or minimize the negative impacts and (2) explore the link between the Sustainable Development Goals (SDGs) and the effects of climate change on WBDs to determine current and future perspectives on global sustainability. The collaboration and interdisciplinary connection with political management and science can have a positive impact on the climate change problems affecting water-borne diseases. Alternative suggestions and communication were organized into three parts: the perspective view of the Southeast Asia countries' situation, discussion about the sustainability directions, and the challenges and blueprint.

In the perspective view, we presented a mini overview of climate change's impact on water-borne diseases mainly by pathogens and common status and the Global Climate Risk Index of Southeast Asian countries. As a second session, the discussion of the direction of sustainability is followed as the second part in order to give insights into the relationship between climate change's impact on water-borne diseases and the Sustainable Development Goals. Lastly, the challenges and blueprint from the main interest of Southeast Asian countries have been drawn.

2. Materials and Methods

The search was carried out by conducting a search through "Google Scholar," "Web of Science," and "PubMed". The primary search was carried out through the Web of Science database with additional searches through the Google Scholar and PubMed databases.

The Web of Science database was used to search for articles, reviews, and reports with the keywords “water-borne diseases, climate change, climate impact factor, drinking water condition, sustainable future”. Because there were few papers before 2000, we narrowed down the time of publication, analyzing the impacts of climatic elements on water-borne diseases between the time periods from January 2000 to December 2022. Moreover, published reports from the WHO and UNICEF were also reviewed in order to comprehensively acquire all relevant studies in Southeast Asian countries. The search was carried out as a follow-up search in Google Scholar and PubMed by focusing on the keywords of “water-borne diseases,” and “climate change in each Southeast Asia country”. The internet databases’ article titles, key terms, and abstracts were searched.

3. Results and Discussion

3.1. Perspectives on the Impact of Climate Change on WBDs

WBDs have long been recognized as a significant public health issue worldwide, particularly in developing countries. In the context of climate change, vector-borne diseases, foodborne diseases, and WBDs are the major infectious diseases globally [15]. Humans can be exposed to WBDs by washing, bathing, and/or drinking water contaminated with pathogens. Pathogens modify their environmental habitats and survival behaviors according to changes in climate, which can lead to the transmission of pathogens [16,17]. Furthermore, even in developed nations, concerns about WBDs persist [18]. Generally, climate change and global warming events have increased the occurrence of WBDs [15–18]. As some developing nations lack an adequate and reliable health infrastructure that can monitor and retain records of past and present conditions of the WBDs, the influence of climate change on WBDs is incomprehensible in these nations [19]. Several WBDs exist, such as cholera, salmonellosis, typhoid, hepatitis A and E, diarrhea, leptospirosis, giardiasis, shigellosis, amoebiasis, dracunculiasis, cryptosporidiosis, *Campylobacter* enteritis, and poliomyelitis [20]. The issue of WBDs is becoming increasingly serious because of insufficient clean drinking water [21]. Children are more vulnerable to WBDs than adults because children have an impaired immune defense system and self-control [22]. The fecal–oral pathway, in which human feces are ingested through contaminated food or water and which mostly arises from inadequate sewage management and unsanitary conditions, is a frequent passage for the transmission of WBDs. Moreover, when the distance between the toilets outside households and wells is not sufficiently large (more than 50 m), there is a higher chance of fecal–oral pathogens entering wells, which could be the main water source for villagers [23] (Figure 1).

The influence of climate change on the environment is one of the main threats to human health at present, and many studies have indicated that the incidence of WBDs will increase [24–27]. Extreme weather-related WBDs will disproportionately affect particular populations and probably exacerbate pre-existing health inequities. For example, *Vibrio cholerae* is the most common pathogen linked to extreme climate change processes [28]. Furthermore, climate change may increase the risk of WBDs because of changes in the quality of water sources and the frequency of natural disasters that might consequently contaminate water supplies. Eventually, infectious diseases, such as cholera, dysentery, and typhoid, may become more common. According to the World Health Organization, 1.1 billion individuals consume water that is moderately polluted by feces, and 1.8 billion people die per year from diarrhea, a WBD [29,30]. The association between climatic factors and WBDs can vary significantly between countries and geographic areas [23,25,31]. Typhoid and cholera are the two main illnesses that pose a serious threat to and have a significant impact on human health. Developing nations, particularly the Association of Southeast Asian Nations (ASEAN) countries, will inevitably suffer disproportionately from WBD epidemics and climate change disasters, such as heavy rains, flooding, increasing temperatures, and droughts. This, coupled with large populations, high poverty rates, low development levels, and limited adaptive capacity, makes ASEAN countries vulnerable to health issues associated with climate change [31].

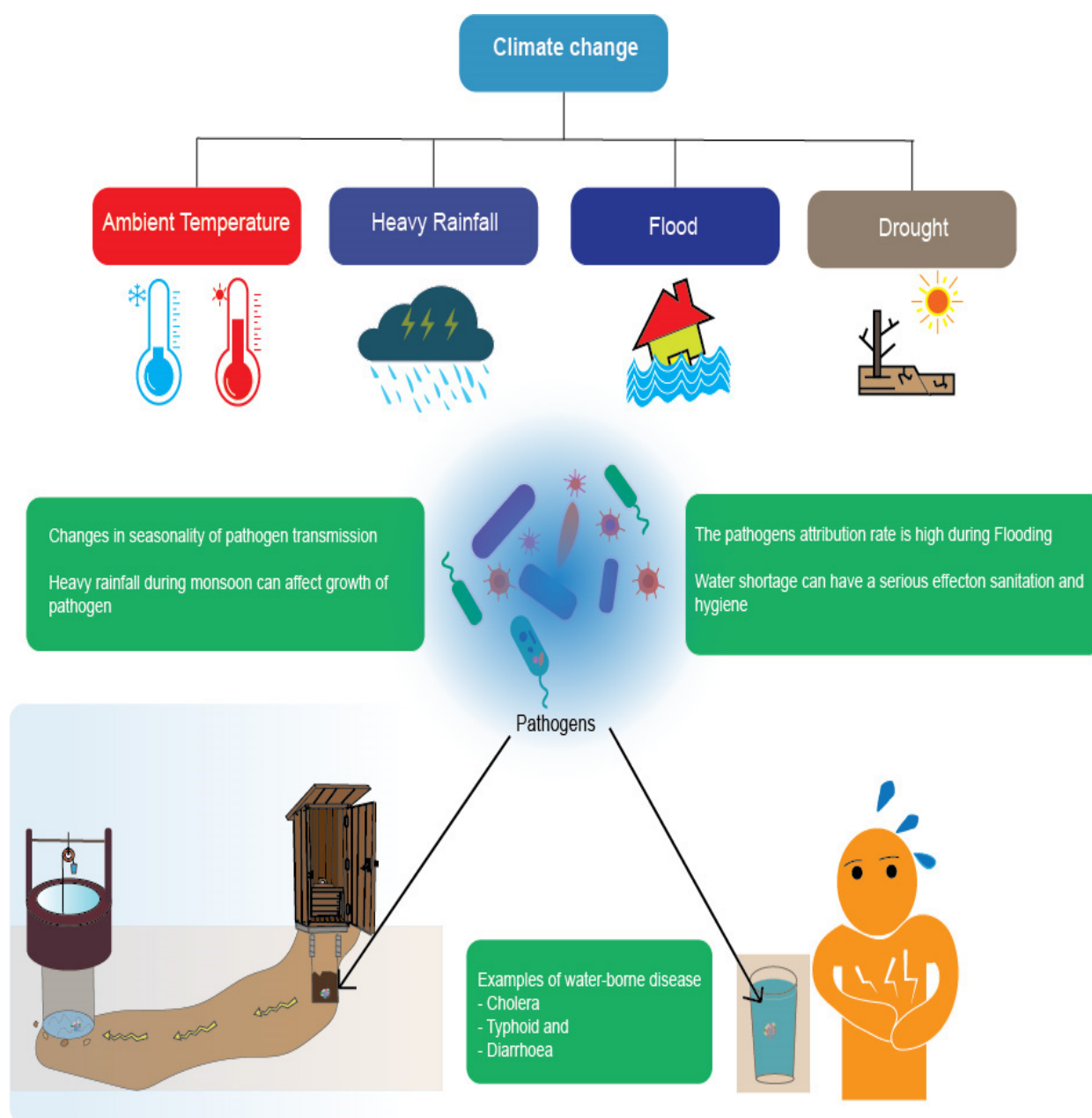


Figure 1. Graphical illustration of the impacts of climate change on the occurrence of water-borne diseases caused mainly by pathogens.

WBDs in ASEAN countries are underestimated because such cases have not been reported and explored in specific regions. The understanding of scientific approaches and public policy (government, policymakers, and researchers) should be balanced to minimize the impact of climate change on WBDs in ASEAN countries. Among the 11 ASEAN countries, 4 (Myanmar, the Philippines, Thailand, and Vietnam) have been included in the top 10 ranks of the Global Climate Risk Index (GCRI) (Table 1). The GCRI is determined by combining quantitative and qualitative data, such as information on extreme weather occurrences, socioeconomic indices, and professional opinions. The GCRI was initially released in 2005, and it has gained widespread recognition as a tool for evaluating the risk of climate change and increasing awareness of the need for adaptation and mitigation actions. The GCRI has grown in importance as a tool for assessing climate change risk and informing policy decisions at national and international levels since governments, NGOs, and academic researchers have used the GCRI to identify the nations and regions that are

most vulnerable to climate change. The GCRI was selected because it is a crucial resource for comprehending and mitigating the efforts of climate change, as well as for advancing sustainable development and climate resilience. Based on variables such as social and economic development, infrastructure, and governance, the GCRI assigns countries a ranking based on their exposure and sensitivity to climate-related risks such as floods, droughts, heat waves, and storms. In particular, floods, droughts, sea-level rises, and tropical events (cyclones and typhoons) are the prevailing major climate occurrences in ASEAN countries, whilst the most common WBDs are diarrhea, cholera, and typhoid (). The severity of natural disasters and diseases could be because of the lack of coping mechanisms to manage instant water overflows, such as deluge sanitation and water drainage systems, to manage instant water flow [32,33]. The GCRI of the Philippines and Myanmar was higher than that of other countries, indicating that these two countries are the most likely to suffer the consequences of climate change on WBDs. Usually, countries that lack strong infrastructure and local authorities (government), such as Myanmar, and countries that have small separate islands, such as the Philippines, are more vulnerable to climate change than other countries. Mitigation and remediation issues for emergencies, susceptibility to WBDs, and resilience to disasters are primary issues in such countries [34,35]. Consuming a large amount of low-quality water in the summer can increase the potential risk of ingesting waterborne pathogens, which can lead to serious diarrhea and cholera. [11]. In ASEAN countries, children defecating in public rural open areas near streams or lakes can increase the risk of typhoid, paratyphoid, and cholera infections during the monsoon season, heavy rainfall events, and floods. These climate events increase the transmission of *Vibrio cholerae* and other bacteria that are transmitted from feces to drinking water or food systems [36–38]. Poor sanitation and low drinking water quality are responsible for approximately 80% of infections in developing nations [39]. However, participating in global climate change mitigation efforts, such as carbon reduction targets under the Paris Agreement, is important for ASEAN countries.

Table 1. Typical extreme climate events and common water-borne diseases (WBDs) with the Global Climate Risk Index (GCRI, 1999–2018) in the Southeast Asian countries.

Country	Extreme Climate Events	Common WBDs	GCRI	Source of Drinking Water	References
Brunei Darussalam	Floods, sea-level rise, and heat waves	Diarrhea	175	Surface water (rivers) and tap water	[40–43]
Burma (Myanmar)	Floods, cyclones, and droughts	Acute diarrhea, cholera, dysentery, and typhoid	2	Surface water (rivers and lakes), and groundwater (tube and dug wells)	[40,44,45]
Cambodia	Floods, droughts, and typhoons	Diarrhea and typhoid	12	Surface water (rivers), and groundwater (hand-dug wells)	[40,46,47]
Timor-Leste	Floods and droughts	Diarrhea, cholera, and typhoid	nd	Surface water, spring water, and groundwater	[48,49]
Indonesia	Tropical cyclones, floods, droughts, and tsunamis	Diarrhea, cholera, typhoid, and leptospirosis	77	Surface water (rivers) and groundwater	[40,50,51]
Laos	Floods and droughts	Diarrhea and cholera	76	Surface water (rivers; the Mekong) and groundwater	[40,52]
Malaysia	Floods, rainfall-induced landslides, and droughts	Cholera and typhoid	114	Surface water (rivers), tap water, spring water, and groundwater	[40,53,54]

Table 1. Cont.

Country	Extreme Climate Events	Common WBDs	GCRI	Source of Drinking Water	References
The Philippines	Typhoons, ambient temperatures, heat waves, and floods	Cholera, acute bloody diarrhea, and typhoid	4	Surface water (rivers, lakes, and river basins) and groundwater reservoir	[40,44,55,56]
Singapore	Sea-level rise, heat waves, and floods	Cholera and typhoid (only in rare cases)	180	Imported water, local catchment area, reclaimed water, and desalinated (purified) water	[40,57,58]
Thailand	Sea-level rise, floods, and droughts	Cholera, typhoid, and paratyphoid	8	Groundwater and surface water (river basins)	[40,44,59,60]
Vietnam	Sea-level rise, floods, and droughts	Cholera, dysentery, typhoid, and diarrhea	6	Surface water (rivers; the Red and Mekong rivers) and groundwater	[40,44,61,62]

Note(s): nd, not described.

3.2. Directions towards Sustainability: SDGs and Climate Change-Related WBDs

Interdisciplinary and transdisciplinary studies are required to advance the direction of sustainability related to the impacts of climate change on WBDs. Human activities have been responsible for initiating climate change even before the Industrial Revolution, and climate change has been accelerating since the mid-19th century [63,64]. Consequently, the impacts of climate change on WBDs are major challenges in developing countries, particularly in Southeast Asia. The SDGs have been implemented to identify the common goals and missions for preventing and controlling WBDs arising owing to climate change [65].

To ensure world peace and welfare, alleviate poverty, and protect natural resources for future generations, the United Nations announced 17 SDGs in 2015. Integrated intervention with the SDGs should be focused on to design a prevention-strategy-based blueprint, which will help to reduce the impact of damage caused by WBDs in each ASEAN country.

Several SDGs, particularly, SDGs 3, 6, 11, 13, and 17, are directly related to WBDs and climate change worldwide. ASEAN countries should attempt to achieve these specific goals to achieve a more sustainable future (Table 2).

Table 2. Overview of Sustainable Development Goals (SDGs) 3, 6, 11, 13, and 17 and targets related to preventing water-borne diseases (WBDs) impacted by climate change.


SDGs	The Interrelationship between the Impacts of Climate Change on WBDs and SDGs	Specific Targets of the SDGs
 <p>3 GOOD HEALTH AND WELL-BEING</p>	<p>Attempt to eradicate WBDs by the end of 2030 and enhance global cooperation to recognize, control, and mitigate local and foreign health risks</p>	<p>3.3 and 3.d</p>

Table 2. Cont.

SDGs	The Interrelationship between the Impacts of Climate Change on WBDs and SDGs	Specific Targets of the SDGs
	Aim to ensure widespread access to affordable and sanitary drinking water, increase funding for water- and sanitation-related initiatives, such as desalination technology and wastewater treatment methods, and boost engagement of local people by the end of 2030	6.1, 6.a, and 6.b
	Try to reduce the proportion of fatalities and financial losses caused by water-related diseases, with an emphasis on developing countries, and promote financial and technical help to construct sustainable and sound structures using local materials by the end of 2030	11.5 and 11.c
	Aim to increase global preparedness for climate-related risks and natural catastrophes and the effectiveness of climate change strategy planning, mitigation, and adaptation (including early warning signs)	13.1, 13.2, and 13.3
	Aim to strengthen the global partnership for the SDGs and share information, technology, and financial resources with developing countries and respect each country's policies and strategies for implementing efforts to eradicate poverty and achieve the SDGs	17.15 and 17.16

Among the SDGs, SDG number 3 (Good Health and Well-Being) and 13 (Climate Action) are the most relevant to the impacts of climate change on WBDs. Moreover, both SDG 3 and 13 aim to reduce illness and increase human well-being worldwide, and both include reducing the occurrence of WBDs and implementing immediate measures to fight climate change and its consequences, especially on WBDs. Furthermore, SDGs 6 (Clean Water and Sanitation), 11 (Sustainable Cities and Communities), and 17 (Partnerships for the Goals) are also important in terms of the impact of climate change. SDG 6, which aims to guarantee that everyone has access to affordable and clean drinking water, is important considering that climate change may significantly affect the accessibility and sustainability of water sanitation. Furthermore, creating comprehensive, sustainable, durable, and safe communities in cities is an objective of SDG 11, which also strives to augment the public approach to secure drinking water and reduce damages arising from WBDs. SDG 17 aims

to improve the implementation processes and stimulate international collaboration for sustainable development, which is a key point for ASEAN countries because they require a strong partnership with a focus on achieving the SDGs in the future.

3.3. Challenges and Blueprint

Worldwide, policymakers and decision-makers encounter the difficulty of applying the SDGs concurrently with the expectation of achieving overall environmental progress [64]. Several developmental directions have been presented at stages where full-scale investigations and assessments have not yet been conducted [6,29,38]. First, revising laws and regulations that are not appropriate for the legal system is necessary to ensure swift operation and to maintain internal stability. In Southeast Asian countries, there are different laws and organizations which are influenced by WBDs; however, it is necessary to determine their actual impact on the waterborne disease rates in each of these countries through statistical analysis. From a long-term perspective, considering the enactment of separate laws is also vital for maintaining climate quality. Second, the investigation and reporting systems for infectious diseases have been established successfully, but the surveillance and reporting systems for other climate factors (such as the impact of temperature changes, precipitation, and drought on WBDs) are insufficiently developed; therefore, surveillance (monitoring) and reporting systems in ASEAN countries must be established for assessment. Third, in many instances, the causal relationship and correlation between climate change and the mechanism of occurrence of each WBD have not been clearly revealed. Accordingly, long-term investment in research and development is needed to identify the medical connections between climate change and various illnesses. Fourth, the health authority (for example: the Disease Control and Prevention Agency; the department name can differ depending on each ASEAN country), which currently lacks functions and roles in relation to climate health, should be reinforced by adding more experts related to the climate health domain and expanding their organizations. In ASEAN countries, there are laws and organizations that address WBDs and encourage access to clean water, including The Clean Water Act in the Philippines, the Water Resources Management Law in Vietnam, the National Environmental Agency and Environmental Protection and Management Act in Singapore, the Water Pollution Control Act in Thailand, and the Environmental Quality Act in Malaysia. Nonetheless, there is still room for improvement in the assessment of the effect of climate change on WBDs, and more statistical research would be necessary to ascertain the precise impact on and any correlation with WBDs in those countries. The above four policy blueprints could play a vital role mostly in Southeast Asian nations and it will be helpful to build adaptation or mitigation strategies for the impact of climate change on WBDs.

4. Conclusions

In conclusion, climate change events influence WBDs, which pose a serious public health concern, particularly in ASEAN countries. Cholera and typhoid are the most common WBDs. Identifying the effects of climate change on WBDs (not only cholera and typhoid) is the first stage of assessing climate change impacts on human health. Thus, WBDs should be controlled and prevented strategically. The SDGs offer a suitable framework for addressing the effects of climate change on WBDs. Therefore, observing the relationship between the SDG targets and the impact of climate change on WBDs may provide new perspectives and new policy options. By making progress and achieving specific SDGs, we can lower the prevalence of WBDs and build a more adaptable and sustainable future.

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