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Health consequences of climate change in Bangladesh: An overview of the evidence, knowledge gaps and challenges

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Abstract

Climate change affects almost all aspects of human life, including health. This is particularly true in densely populated and low lying deltas such as Bangladesh. However, the climate-health nexus is a relatively poorly explored domain of research, which is a cause for concern given the country's intrinsic vulnerability to climatic impacts. The impact of climate change on human health and well-being can be manifested through different pathways and can be categorized as being direct or indirect, mediated through complex biophysical and social dynamics. The direct effects of climate change that have been observed in Bangladesh include morbidity and mortality due to heat stress, cyclones, floods, droughts and other weather extremes at different spatio-temporal scales. The indirect effects adopt more complex routes which includes, threatening food and water security due to salinity intrusion, and spread of infectious diseases due to changes in vector and pathogen ecology. Social dynamics in Bangladesh, such as those related to gender roles, poverty and power relations, also influence how the effects of climate change are experienced by different segments of the society. The Government of Bangladesh has a number of measures already in place, efforts that have been complemented by local interventions. Evidence to take robust health policy decisions related to climate change is limited and scattered, while there is a lack of multi-disciplinary research efforts. Considering these limitations, generating and summarizing scientific evidence is vital for informing a resilient health system against future public health concerns in climate vulnerable countries such as Bangladesh and in other low-income regions.

This article is categorized under:

Assessing Impacts of Climate Change > Evaluating Future Impacts of Climate Change

KEYWORDS

adaptation, Bangladesh, climate change, health

1 | INTRODUCTION

Climate change has been declared by the Lancet Commission and the World Health Organization (WHO) as being "the biggest global health threat of the 21st century" (Costello et al., 2009; Rahman et al., 2019; Watts et al., 2017). The analysis of the climate-health nexus has received much attention since the first report of the Intergovernmental Panel on Climate Change (IPCC) was published in 1990 (Gosling, Lowe, McGregor, Pelling, & Malamud, 2009). Subsequently, a substantial amount of evidence has been generated showing the adverse impact of climate change on human health in the past decade (Haines, Kovats, Campbell-Lendrum, & Corvalán, 2006; McMichael, 2013; McMichael, Woodruff, & Hales, 2006). However, this evidence, to a large extent, comes from high income countries. There are significant gaps in knowledge about the climatic change induced impact on health, livelihood and well-being in lower middle income countries such as Bangladesh, which is one of the most climate vulnerable countries in the world.

While there is some piecemeal evidence available in Bangladesh to understand the link between climate change and increased mortality and morbidity from certain health conditions, there is a lack of a summary of existing evidence and common understanding about the effects of climate change on broader health and wellbeing. This is of particular concern since Bangladesh is intrinsically vulnerable to the effects of climate change due to its unique geographical location as a low lying river delta (Syvitski et al., 2009) with a relatively long coastline, subtropical climate, natural resource-dependent economy and high population density characterized by inequality and poverty (Brouwer, Akter, Brander, & Haque, 2007; Huq et al., 2004; Khan, Xun, Ahsan, & Vineis, 2011; Watts et al., 2017). The impact of climate change on disease patterns worldwide will be profound, especially in lower middle income countries such as Bangladesh where existing vulnerability to poor health remains a substantial problem to date. To understand the specific modality of this phenomenon, it is important to recognize that climate change may cause health impacts through multiple pathways, directly or indirectly (Berry, Bowen, & Kjellstrom, 2010; Frumkin, Hess, Luber, Malilay, & McGeehin, 2008; McMichael & Haines, 1997), specially mediated through social and environmental factors. The direct effects of climate change include increased biological consequences of heat stress, extreme weather events such as floods, drought, and increased frequency and intensity of cyclones (for specific seasons) among others (Balaguru, Taraphdar, Leung, & Foltz, 2014; Singh, Khan, & Rahman, 2000; Webster, Holland, Curry, & Chang, 2005). On the other hand, population health may be indirectly threatened through changes in air pollution, spread of disease vectors, changes in ecological processes and services, food and water insecurity, under-nutrition, displacement and mental ill-health (McMichael, 2013).

Despite the importance of the subject, the climate-health nexus has been a somewhat neglected branch of climate research in Bangladesh. Gray literature outputs are available but those cannot make their way to peer-reviewed journal articles due to the lack of capacity of local researchers. The bulk of climate research in Bangladesh consists of research on agricultural, hydrological and other environmental concerns, showing a noticeable shortage of health researchers in the field. In addition, there is yet to be a comprehensive review of whatever scattered information is available on the topic. The present review aims to fill the gap by compiling existing evidence within our reach. We effectively outline what is known and what is unknown on the matter. The paper also attempts to discuss the potential challenges in research and adaptation practice regarding the complex interlinkages between climate change and health. We hope that this review will contribute to the ongoing conversation on the climate change discourse and serve as a reference for interdisciplinary stakeholders.

1.1 | Methodology

While the present review is not a systematic one, we nonetheless aimed to capture a large majority of the published literature on the topic of health impacts of climate change in Bangladesh. To this end, we primarily relied on the database of "Gobeshona," a network of climate change researchers in Bangladesh. Gobeshona has a comprehensive knowledge repository on climate change studies and action in Bangladesh, currently constituting more than 2000 published articles on the topic. The key inclusion criterion was focused on gathering articles that primarily focused on health impacts of climate change in Bangladesh. We supplemented this initial article pool with articles extracted from the Web of Science and Google Scholar. Due to limited organizational access to full—text articles from these databases, however, we often had to rely on abstracts rather than complete articles. Finally, to provide context on the country-specific climate change impacts, we also included some papers on climate change research carried out in other countries. These papers invariably charted broad trends of the health impacts, as opposed to consequences specific to particular diseases.

For the sections on gaps and challenges, we compiled expert opinion based on the feedback received from a panel of health sector experts and climate change researchers on a half-day workshop titled "Climate Change and Health consultation

meeting" on 21st January, 2016 at UNFPA, Bangladesh, country office and a follow-up workshop on 27th February, 2016 at the head office of the International Centre for Diarrheal Disease Research, Bangladesh (icddr,b).

1.2 | Brief description of the geography and socio-economic background of Bangladesh

Geologically, Bangladesh is a relatively recently developed low-lying river delta—the largest in the world, located in South Asia between the Himalayan mountain range and the Bay of Bengal. The country is characterized by a subtropical monsoon climate, a wide range of ecosystems, and an agrarian economy owing to its fertile soil. Bangladesh has a relatively high literacy rate, and has made improvements in reducing mortality from natural hazards despite very high population density (1,200 per km^2), very low average income (about USD1450 per year), persistent poverty, and high exposure to natural hazards (Chowdhury et al., 2013). Bangladesh has also achieved remarkable improvement in socio-economic and health sectors since its independence in 1971, maintaining a yearly GDP growth of 6% (Helal & Hossain, 2013). With a total fertility rate of 2.3 births per women and an overall life expectancy (at birth) of 71 years, the country is very much on track for achieving the infant child mortality and under 5 mortality targets of the Sustainable Development Goals (GED, 2015; NIPORT, Mitra and Associates, ICF International, 2016). However, progress towards achieving universal health coverage is still slow. In addition, as a country going through epidemiological and demographic transition, the double burden of communicable and non-communicable disease, including the emergence and re-emergence of other diseases, is becoming a predominant problem in the country (WHO, 2015).

1.3 | The impacts of climate change in Bangladesh and future projections

Bangladesh is one of the most climate vulnerable countries in the world (Huq, 2001), ranking sixth on the Global Climate Risk Index 1996–2015 prepared by the German Watch (Kreft, Eckstein, Junghans, Kerestan, & Hagen, 2014). The government of Bangladesh has identified a set of 12 vulnerabilities that are critical for the country within the changing climate: (1) Sea Level Rise (2) Cyclone (Intensity and Frequency) (3) Deeper Penetration of Saline Water (4) Erratic Rainfall (5) Flood (Intensity and Frequency) (6) Drought (7) River Bank Erosion (8) Health (9) Food Security (10) Water Security (11) Landslide in (Chittagong) Hill Tracts and 12) Migration (BBS, 2017).

The country's climate has experienced a significant warming during 1970–2010. The mean rate of annual temperature increase by 0.02°C per year is much stronger than the global average (Rahman & Lateh, 2016). There has also been a decrease in the number of cool nights and increase in the number of warm nights over this period for both hot and cold seasons (Gosling et al., 2011). Total precipitation has also seen a small increase since 1960 (Gosling et al., 2011).

A number of studies have attempted to project climatic factors such as temperature, rainfall, and extreme weather events using climate models. While these climate model-based projections are intrinsically uncertain, there are some clear points of confluence among the simulated trends. A recent study reported projections to the end of the 21st century assuming high emissions under Representative Concentration Pathway (RCP) 8.5. These are from 10 global models that had been dynamically downscaled using three fine resolution regional climate models (11 projections in all) (Fahad et al., 2018). They project an average annual temperature increase of 4.2°C (with a range from 3.2 to 5.8°C) over Bangladesh for the 2080s compared to 1860–1880, with greater warming in the southwestern and south central regions of the country. For precipitation, results from most models project large increases in precipitation during the premonsoon period (i.e., March, April, and May), relative to 1971–2000. In contrast, most models indicate declines in precipitation during the postmonsoon period (e.g., in October). For different regions of Bangladesh, model projections of annual precipitation change vary both in their magnitude and sign (Fahad et al., 2018).

Scientific evidence and climate model projections further indicate a potential increase of tropical cyclone intensity (Emanuel, 2013), increased likelihood of extreme sea level events (particularly in the second half of the century) (Kay et al., 2015), as well as increased frequency of high water coastal events. The area vulnerable to cyclones could increase from 14% to 69%, with a 1–3 m inundation depth for a 27 cm sea level rise (SLR) and a 10% increase in wind speed by the year 2050 as projected in one study for coastal Bangladesh (Dasgupta et al., 2014). There is also a projected increase in flooding duration and inundation area and depth, due to global warming induced glacier melting in the Himalayas (Immerzeel, Pellicciotti, & Bierkens, 2013; Mirza, Warrick, & Ericksen, 2003).

1.4 | The health impacts of climate change in Bangladesh

Climate model projections are worrying because Bangladesh is particularly vulnerable to the impacts of climate change (Alam, Alam, Mushtaq, & Clarke, 2017). Because of the synergistic actions of extreme weather events, rising temperatures and continuing population growth, public health outcomes like mortality, injury, spread of diseases, damage to healthcare infrastructure and public health services will be negatively affected (Shultz, Russell, & Espinel, 2005). Any discussion on the consequences of climate change on health needs to be prefaced with the following caveat: factors like population growth, socio-economic conditions, health system capacity, urbanization, land use changes and depletion of fresh water resources can significantly modulate climate change effects. This brings to the fore the problem of attribution—while studies in Bangladesh have investigated, and established, associations between climate change and certain health outcomes; it is much more difficult to tease out effects that can be attributed specifically to anthropogenic climate change. A large amount of research in Bangladesh has been carried out on cholera, respiratory infection, watery diarrhea and skin problem (during and postflood period) (Kunii, Nakamura, Abdur, & Wakai, 2002; Schwartz et al., 2006; Yusof, Siddique, Baqui, Eusof, & Zaman, 1988), mortality and climatic trends (Alam, Lindeboom, Begum, & Kim Streatfield, 2012; Hashizume et al., 2009; Lindeboom, Alam, Begum, & Kim Streatfield, 2012), pre-eclampsia and hypertension associated with salinity in drinking water (Khan et al., 2014b; Talukder, Rutherford, Phung, Islam, & Chu, 2016), temperature extremes and causes of death (Burkart et al., 2014), vector borne diseases like malaria and their association with meteorological factors (Haque et al., 2009), among many others. Most of these studies investigate associations between climate change and particular diseases. In addition to the attribution problem referred to earlier, there continues to be a lack of information regarding the multi-faceted impact on broader aspects of health, such as on health systems and well-being." These impacts are discussed in more detail in the following sections, in terms of their direct and indirect consequences."

1.5 | Direct effects

Health impacts may occur directly due to changes in temperature and precipitation (Smith et al., 2014). The direct effects of climate change also include increased heat stress, floods, drought and increased frequency of intense storms. The overall intensity of tropical cyclones as well as the frequency of more intense cyclones is projected to increase over the 21st century. Research conducted worldwide indicates that public health consequences associated with cyclones can include: infectious diseases, psycho-social effects, displacement, damage to healthcare infrastructure, disruption of public health services, transformation of ecosystems, social dislocation, loss of jobs and livelihoods and economic crisis (Shultz et al., 2005). One of the major direct public health risks imposed by climate change is increased heat-related mortality and morbidity (Gosling et al., 2017; Hajat, Vardoulakis, Heaviside, & Eggen, 2014). This is a major concern for Asian megacities such as Dhaka, the capital of Bangladesh (Kovats & Akhtar, 2008). The frequency and intensity of heat waves is expected to increase in Bangladesh in the future (Kirtman et al., 2013). Studies in Bangladesh have already indicated the possibility of temperature increase leading to different negative health outcomes among the exposed population (Burkart et al., 2014). Moreover, precipitation may also affect mortality differently depending on the season through different mechanisms (Burkart & Kinney, 2016). Extreme weather events such as drought in Bangladesh have been found to have resulted in higher occurrence of dysentery and diarrhea due to use of unsafe water because most water sources dried out (Dey et al., 2012).. However, such relationships may vary over space (e.g., administrative districts and climatic zones) within Bangladesh as well as according to age, socio-economic status and causes of mortality. A similar pattern is noticed in the case of temperature extremes, where strong heat effects were linked to different causes of death for different subpopulations and age groups (Burkart et al., 2014). Those living in urban areas are more vulnerable than those living in rural areas (Burkart et al., 2011). Study in rural Bangladesh suggests no association between high temperature and increased mortality but a positive association between low temperature and mortality (Hashizume et al., 2009). Major cities in Bangladesh such as Dhaka, Chittagong and Khulna will be affected adversely due to weather related extremes (Alam & Rabbani, 2007). There is also a lot of interest in how rising temperatures affects economic productivity and impacts residents' and workers' health, especially in the ready-made garments sector which is the backbone of the country's economy.

1.6 | Indirect effects

1.6.1 | Salinity intrusion and health

Rising sea levels in the Bay of Bengal due to climate change and other nonclimatic factors such as local land use change and ground subsidence contribute to salinity intrusion in coastal waters of this deltaic country (Rahman et al., 2019; Syvitski et al.,

2009). A number of studies suggested that drinking water salinity is associated with pre-eclampsia and gestational hypertension in pregnant women and increased cardio-vascular diseases and stroke risks (Khan et al., 2011; Khan et al., 2014b). Studies also found evidence of positive association between higher salinity in drinking water and hypertension (Khan, Scheelbeek, et al., 2014b; Talukder et al., 2016), a phenomenon that could be exacerbated by ongoing salinity intrusion in soil and water due to climate change and sea level rise (Payo et al., 2017). Salinity intrusion could also lead to reduced farm productivity and increased food insecurity in coastal Bangladesh (Clarke, Williams, Jahiruddin, Parks, & Salehin, 2015) which eventually leads to both internal and international migration (Chen & Mueller, 2018). Studies suggest reduced farm productivity due to soil salinity in Bangladesh (Ali, 2006; Rabbani, Rahman, & Mainuddin, 2013), a trend that is expected to hold with rising sea level. A modeling exercise by the World Bank indicates that increased soil salinity from a 0.3 m sea level rise alone will cause a net reduction of 0.5 million metric tons of rice production in Bangladesh. This is likely to have large health and nutritional consequences in the country, as it is one of the major rice consumers in the world.

1.6.2 | Infectious diseases

Climate change is expected to alter the range and burden of many infectious diseases. The evidence of susceptibility is particularly compelling in the case of water and vector-borne diseases. Changes in meteorological factors like temperature and precipitation have been found to affect the dynamics of different vector borne diseases, such as malaria, dengue, and visceral leishmaniasis which is commonly known as Kala-azar (Banu, Hu, Guo, Hurst, & Tong, 2014; Hossain, Noiri, & Moji, 2011; Reid, Haque, Roy, Islam, & Clements, 2012) and also found to be linked to cholera (Shahid, 2010) and the spread of diarrhea diseases (Hashizume et al., 2007). Environmental factors can shape these dynamics by exerting their effects on vector abundance, the ability of the pathogen to survive outside the host, environmental contamination of water sources and the dampening of host immunity (Altizer, Ostfeld, Johnson, Kutz, & Harvell, 2013; Metcalf et al., 2017).

1.6.3 | Waterborne diseases

With a claim to 11% of the under-five mortality in Bangladesh, diarrhea disease outbreaks are still a major cause for concern in the country (Black et al., 2010). It has been estimated that there will be around 800,000 additional cases of *Escherichia coli* associated diarrhea in Bangladesh in the near term (2016–2035), when temperatures are projected to increase by 0.8°C (Philipsborn, Ahmed, Brosi, & Levy, 2016). Temperature has also been shown to be positively associated with the occurrence of typhoid (Dewan, Corner, Hashizume, & Ongee, 2013). In addition to changes in temperature, both droughts and heavy precipitation have been implicated as being associated with increased risk of diarrheal diseases in Bangladesh. Decline in groundwater levels during droughts can force families reliant on tube wells to seek drinking water from other sources which may be contaminated leading to increased risk of exposure to diarrheal pathogens (Dey et al., 2012). Heavy rainfall and flooding events in Bangladesh, which can lead to contamination of drinking water (Wu, Yunus, Islam, & Emch, 2016), have been linked to increased occurrence of cholera, typhoid as well as diarrheal diseases caused by salmonellae, shigellae and *E. coli* (Cash et al., 2014; Schwartz et al., 2006; Wu, Yunus, et al., 2016). In particular, research on cholera burden has highlighted how the changing climate may alter the landscape of diarrheal diseases in Bangladesh. Cholera has been shown to be the predominant cause of flood-associated diarrheal epidemics in Bangladesh (Schwartz et al., 2006). The seasonality and interannual variability of cholera incidence in Bangladesh is associated with temperature, rainfall, and sea surface temperatures (Hashizume, Faruque, Wagatsuma, Hayashi, & Armstrong, 2010; Koelle & Pascual, 2004; Pascual, Chaves, Cash, Rodó, & Yunus, 2008). There is also evidence that the relationship between the El Nino Southern Oscillation (ENSO) and cholera outbreaks has strengthened in Bangladesh in recent years (Pascual, Bouma, & Dobson, 2002; Rita, 2009; Rodo, Pascual, Fuchs, & Faruque, 2002). The causative agent of cholera, the bacterium *Vibrio cholerae*, is naturally present in riverine, coastal, and estuarine ecosystems, and climatic shifts may affect its occurrence and distribution (de Magny et al., 2008). Cholera in Bangladesh was shown to be correlated with increased sea surface temperature and sea surface height (Lobitz et al., 2000). This is thought to be mediated by an increase in phytoplankton bloom. Indeed, researchers have reported correlations between cholera cases in Bangladesh and chlorophyll concentrations in the Bay of Bengal, the latter being a surrogate measure of phytoplankton (Emch et al., 2008; de Magny et al., 2008). The outcome of all of this is the possible increase of cholera outbreak frequency with the projected increase of sea surface temperature of the Bay of Bengal in the coming decades. Changes in salinity and temperature can also affect abundance of cholera pathogens. Even under conservative climate change scenarios, *Vibrio cholerae* presence is predicted to increase in areas with suitable environmental conditions (Escobar et al., 2015).

Natural disasters such as cyclones can also affect vibrio abundance in estuaries (Lara et al., 2009), further increasing the risk of disease outbreaks.

1.6.4 | Vector-borne diseases

As for vector-borne diseases (VBD), climate and weather can affect VBD burden by shaping the geographic distribution, population abundance, lifespan, and transmission potential of vectors (Lafferty & Mordecai, 2016). Studies done in Bangladesh and elsewhere show that malaria and dengue transmission are associated with variabilities in temperature, rainfall, humidity, as well as the ENSO (Banu et al., 2014; Banu et al., 2015; Bouma & Kaay, 1996; Pascual, Cazelles, Bouma, Chaves, & Koelle, 2008; Reid et al., 2012), possibly becoming more widespread and even more severe (Githeko, Lindsay, Confalonieri, & Patz, 2000; Hossain et al., 2011; Hunter, 2003). The geographical distribution of *Plasmodium falciparum*, the parasite causing malaria, has been projected to expand due to climate change (Caminade et al., 2014; Confalonieri et al., 2007) However, the complex and nonlinear response of vectors to climatic conditions (such as temperature), as well as the presence of other mediating factors such as population changes, makes forecasting the future burden of diseases challenging (Lafferty & Mordecai, 2016; Metcalf et al., 2017). Other vector-borne diseases in Bangladesh are also likely to be affected by climatic shifts. For instance, increases in mean temperatures may provide a better breeding environment for sand flies that transmit Visceral Leishmaniasis (Kala-azar) (Hossain et al., 2011).

1.6.5 | Zoonotic diseases

The emergence and endemicity of zoonotic diseases are also shaped by climatic factors. Flooding events, in combination with overcrowding and poor sanitation, can lead to greater risk of Leptospirosis outbreaks, a zoonotic disease spread via skin contact with contaminated water and soil contaminated by the bacterium, usually spread through the urine of many domestic and wild animals such cattle, pigs, dogs, foxes and rats (Lau, Smythe, Craig, & Weinstein, 2010). Leptospirosis is increasingly recognized as a problem in urban settings in low and middle income countries, especially within urban slums. One study conducted in a low-income urban setting in Bangladesh found that about 8% of febrile persons identified via surveillance had leptospirosis (Kendall et al., 2010). Increased frequency of flooding events could increase disease burden in the future, although more research is needed in this area (Lau et al., 2010; Lipp, Huq, & Colwell, 2002).

Since the first outbreak was identified in 2001, Bangladesh has experienced frequent outbreaks of Nipah Virus Encephalitis. Bats are the primary reservoirs of Nipah virus—in Bangladesh human cases have been linked to the consumption of date palm sap that is contaminated with the virus from bats (Luby et al., 2009). Changes in the climate may shift the current distribution of flying foxes, introducing the virus to previously unexposed areas. Extreme weather events, such as heat waves, could also increase the risk of transmission to humans by placing bat populations under physiological stress that could trigger prolonged viral shedding (Daszak et al., 2013; Hunter, 2003). More research is needed to explore the possible climatic effects on Nipah cases in Bangladesh.

1.6.6 | Food and water security

Climate change has serious ramifications on the four dimensions of household food security: food availability, accessibility, utilization and stability. Floods, droughts and changes in rainfall patterns are expected to negatively impact food, nutrition and livelihoods in Bangladesh. Moreover, the quality of food might also be affected. A serious consequence of climate induced decrease in crop yields is a net increase in poverty in the country (Hertel, Burke, & Lobell, 2010). Household food insecurity adversely affects women and children (Nasreen, 2008; Strategy & Plan, 2009). Climate change affects the agriculture and aquaculture sectors as a whole, and the effects can be manifested in various ways, for example, damage of coastal rice production areas (Wassmann et al., 2009), decline in crop productivity which will eventually lead to food price hikes, increased dependence on groundwater for irrigation, seasonal shifts in cultivation and harvesting, increased use of pesticides, reduced fish species and production.

1.7 | Social dynamics and mediating factors

Climate change affects the social and environmental determinants of health—clean air, safe drinking water, sufficient food and secure shelter. However, climate change is not the only factor that will determine the ultimate health outcomes

(Confalonieri et al., 2007). Factors, such as population growth, socio-economic conditions, health system capacity, urbanization, land use changes and depletion of fresh water resources, can have a larger effect on heath, either independently or by modifying existing climatic effects on health.

Although the impacts of climate change will be felt disproportionately by the poor and most vulnerable (Ayers, Huq, Faisal, & Hussain, 2014), such impacts are not gender-neutral. Women will bear the biggest toll. Data on disaster related mortality (from 141 countries) suggests that, on average more women and girls die in natural disasters and their aftermath impact than men or boys, a pattern that has been noticed during past cyclones (1970, 1991, and 2007) in Bangladesh (Ikeda, 1995; Sommer & Mosley, 1972). Restriction on women's mobility (social restrictions, gender specific clothes, gendered role of caring for the young), fewer opportunities to access information on the risk and about the way to minimize the risk, and the lack of agency with regard to decisions to evacuate, have been implicated as causes of such gender differences in mortality (Nasreen, 2008). Moreover, compared to girls, boys are more likely to receive preferential treatment in rescue efforts after disaster (Neumayer & Plümper, 2007).

Climate change will also amplify existing inequalities, reinforcing the disparity between women and men in their vulnerability to, and capacity to cope with the impacts of climate change. Climate change increases inequality through multiple pathways such as increasing exposure of poor and marginalized populations to climatic extremes and susceptibility to damages caused by disasters, and by reducing the capacity to recover from such damages (Islam & Winkel, 2017). Women disproportionately suffer from the impacts of climate change because of cultural norms and the inequitable distribution of roles, resources and power, especially in lower middle income countries such as Bangladesh. Poor and marginalized rural women and girls are the greatest sufferers of climate change impacts, primarily because they are more dependent for their livelihood on natural resources that are threatened by climate change, and also because they face barriers that limit their coping capacity.

A case in point is the existing shortfalls in water resources. Climate change is predicted to aggravate these shortfalls, but the impact does not cut across the genders equally. A large proportion of rural women in South Asia live in water-stressed areas and are already bearing the burden of water shortages in terms of time spent on collecting water and increased exposure to water-borne diseases such as diarrhea. For young women time spent on fetching water can result in missing school (Denton, 2002).

The subject of unequal impact of climate change is true in case of other infectious diseases as well. The effects are modulated by social changes and population dynamics, like rapid growth of urban slum areas (Reiner et al., 2014). Crowding and poor infrastructure that can lead to flooding are likely to increase both diarrheal disease incidence (Reiner et al., 2014; Wu, Lu, Zhou, Chen, & Xu, 2016) as well as incidence of diseases caused by arthropod-borne viruses due to water stagnation following flooding (Githeko et al., 2000; Rasheed et al., 2014). Climate induced migration and population displacement (Hassani-Mahmooei & Parris, 2012; Islam & Hasan, 2016) are also likely to have an impact on the spread of infectious diseases, as human mobility and density are key drivers of disease dynamics. A study done in Chittagong hill tracts found that women are more vulnerable to malaria occurrence while pregnancy is a risk factor for asymptomatic *P. falciparum* infection development (Khan et al., 2014). Finally, the burden of infectious diseases often falls disproportionately on the young, the elderly, and the poor (Kunii et al., 2002). Understanding how climate may disproportionately affect disease burden among vulnerable populations is a key direction for future research.

Natural disasters also have indirect effects on the health and well-being of women and girls. Violation of women's rights becomes more prominent during disasters (Nasreen, 2008). According to the World Disaster Report, women and girls are at higher risk of sexual violence, sexual exploitation and abuse, trafficking, and domestic violence during natural disasters (Klynman, Kouppari, & Mukhier, 2007). In particular adolescent girls report especially high levels of sexual harassment and abuse in the aftermath of disasters and complain of the lack of privacy in emergency shelters (Bartlett, 2008). Natural disasters also exacerbate child marriage in the coastal areas of Bangladesh. Frequent flooding and river erosion means many families live with the constant threat of insecurity and increased poverty, which impacts decisions about schooling and marriage for girls. Both women and girls suffer more from shortages of food and economic resources in the aftermath of disasters (Neumayer & Plümper, 2007).

1.8 | Adaptation measures relevant to health

The health sector has an important role in protecting health from adverse effects of climate change. The current health system in Bangladesh is not designed to address the increasing burden of diseases that may result from climate change. Health and health care system response is inadequately addressed in the national adaptation measures in Bangladesh. There are gaps in

guidelines of execution and financing. Therefore, adaptation at different scales (individual to community level to institutional) of adaptation to the health impacts of climate change is crucial.

People diversify coping strategies to tackle climate related health consequences: from self-medication to traditional medicine to larger out of pocket expenditure (Haque et al., 2013; Haque, Louis, Phalkey, & Sauerborn, 2014). Perception studies suggests that people have a high awareness about climate related vulnerabilities (Kabir, Rahman, Smith, Lusha, & Milton, 2016) and in many cases perception matches with scientific evidence (Habiba, Shaw, & Takeuchi, 2012; Haque, Yamamoto, Malik, & Sauerborn, 2012). Bangladesh made significant progress on climate change adaptation planning and mainstreaming in the past decades (Ayers et al., 2014). It is one of the early practitioner countries of community-based adaptation (CBA), a bottom-up approach that has the promise of ensuring participation of the vulnerable population in decision making. In the wake of the devastating cyclone Sidr which ravaged coastal regions of the country in 2007, the Government of Bangladesh formulated a climate change strategy and action plan (BCCSAP) in the following year. The strategy identifies six major areas of action, a number of which overlap with direct and indirect health concerns (e.g., food-water security and disaster management). In addition, the Bangladesh government itself established a National Climate Change Fund. Policymakers and advisors emphasized the strategy as being "pro-poor" and one in alignment with the government's poverty reduction efforts. The Government of Bangladesh has also come forward with a National Adaptation Plan for Action (NAPA) for reducing the potential impacts of climate change. Currently, the nations with higher population growth are not the highest greenhouse gas (GHG) emitters, but it is expected that in 50 years' time countries with higher population and economic growth will become large emitters of GHGs (Woodward, Lindsay, & Singh, 2011). There is some discussion, albeit controversial, about family planning serving as a relatively cheaper adaptation option to combat climate change. Despite the link between population growth and climate change, the NAPA in Bangladesh did not recognize family planning as a part of their adaptation strategy—unlike many other countries who have adopted their own NAPA (Cost, 2009).

Some specific examples of adaptation measures include, but are not limited to, targeting the threat that climate change poses to water and food security. Measures such as rainwater harvesting (Khan, Ireson, et al., 2011), modified aquifer recharge (MAR) (Naser et al., 2017) and solar-based desalinization plants at household or at community level for providing safe water supplies in salinity affected coastal areas, development of crop varieties tolerant to flooding, drought and salinity, and crop diversification for food security are all being implemented to different extents. Several potential adaptation options specifically target the spread of infectious diseases. The aforementioned BCCSAP plans to implement extensive surveillance systems for existing and emerging diseases. Other adaptation measures aimed at a similar goal include the Oral Rehydration Solution (ORS), which is a type of fluid replacement used to prevent and treat dehydration, especially that due to diarrheal diseases, an innovation which has been successful in saving millions of lives from dehydration, and the distribution of insecticide treated mosquito bed nets to prevent malaria transmission (Bangladesh, 2005). While this issue remains controversial—migration from rural and coastal regions to urban areas have also been considered by some as an adaptation measure and others as a failure to adapt (Foster et al., 2012). In addition to the discussion regarding whether it even qualifies as an adaptation measure, there is also much to be said against its efficiency—as overcrowding and poor health in urban slums is another indirect effect of climate change (see above). Storm shelters installed by the local government have reduced mortality from cyclones (Adger, Huq, Brown, Conway, & Hulme, 2003). Nissan, Burkart, Coughlan de Perez, Aalst, and Mason (2017) tried to define and predict heat waves in Bangladesh and proposed an early warning system as an adaptation measure to the direct health impact of climate change. Tracking of different adaptation measures is important to check whether a certain measure is a good practice or a "mal-adaptation" leading to further vulnerability (Magnan et al., 2016).

1.9 | The main gaps and challenges in science, policy and in practice

Availability of data is one of the major requirements for evidence-based decision making. Relevant health data required to attribute health outcomes to climatic changes are limited in low and middle income countries, and Bangladesh is not an exception. In many cases, the quality of the data is questionable. Without ensuring the quality of the data, it is difficult to draw robust conclusions for many climate change induced public health problems.

In addition, many exploratory studies conducted on the topic thus far remain in the territory of gray literature. This brings up obvious concerns regarding lack of peer review as well as poor accessibility to global readership. The available studies usually have widely varying methodologies, and the heterogeneity makes it virtually impossible to compare results, much less construct meta-analyses or systematic reviews. This is particularly significant given the fact that there are enormous uncertainties in climate systems as well as in the causal link between climate and health (Stott et al., 2016). More concrete, peer reviewed and methodologically rigorous epidemiological studies are needed to fill this gap.

As far as the prevailing paradigm of public health research is concerned—health is always evaluated from the perspective of disease. However, in trying to investigate the nexus between climate change and health, we need to broaden this perspective. Health as a concept needs to be understood in terms of human well-being which subsumes myriad concepts like security, sense of place, satisfaction, absence of poverty, and other such concepts in addition to disease.

Scientific progress regarding the climate change-health nexus requires a multidisciplinary approach or even it requires trans-disciplinary research. This is because environmental and social systems are always interconnected, and focusing on only one issue would provide an overall poor understanding. What contributes to the aforementioned problems with data is the fact that research in Bangladesh in this regard has mostly been fragmented and sector-specific. Productive collaboration among disciplines and stakeholders is rarely seen. Moreover, there is also a tendency of hyper-specialization, which de-emphasizes a more holistic or systems-level approach which might aid in seeing the bigger picture. Lack of institutional capacity contributes to this issue. In Bangladesh as in many other countries, there are institutes which focus on climate, while others focus solely on health.

Science communication is another big challenge. The presence of uncertainties in the science means that scientists in the field often find it difficult to communicate their conclusions effectively. Political and social sensitivities make this an even thornier issue in the context in Bangladesh. The evidence of climatic impact on health has not necessarily translated into useable knowledge for development practitioners and key decision makers to identify their own needs and priorities.

2 | CONCLUSIONS AND FUTURE PROSPECTS

While climate change may be the biggest health threat of the century, tackling its impacts also presents us with the most important global health opportunity (Watts et al., 2015). Governments and community organizations around the world are increasingly allocating resources to prepare for tackling climate change and its adverse impacts on health and well-being (Boeckmann & Rohn, 2014). This provides an important justification for taking stock of the existing evidence and pointing out gaps in knowledge and understanding. That is what this review article accomplishes.

Climate change will have critical public health implications for Bangladesh through both direct and indirect pathways, in addition to being influenced by different socio-economic mediating factors. More research is needed to understand how climate will shape the future burden of illnesses, specifically taking into account local climatic variations, land use changes, population mobility, control efforts and other social drivers. Recent advancement in climate change modeling suggests significant increases in temperature and precipitation regimes in coming decades. This would result in increased heat stress, floods, drought, and storms, as well as increased morbidity and mortality among different subpopulations by age, sex, socio-economic status and location. The health impacts will likely be intensified through indirect pathways like spread of disease vectors, food and water insecurity, under-nutrition, displacement, etc. Increased incidences of waterborne (diarrhea, cholera, typhoid etc.), vector borne (malaria, dengue, kala-azar etc.) and other zoonotic diseases (leptospirosis, Nipah Virus encephalitis, etc.) were found to be associated with changes in temperature, precipitation, humidity, ENSO cycle and disasters like floods and cyclones. The situation is further complicated by certain features of social dynamics, like the differences in gender roles, dependence on natural resources in coastal areas, population density and migration to urban slums. These dynamics usually disproportionately affect women.

Two of the key scientific challenges facing climate change and health research in Bangladesh and beyond are the problems of attribution and communication. On one hand, it is often difficult to attribute health risks to climatic changes due to the complex and interconnected nature of climatic systems, shortfall of data and proper funding. On the other hand, it is partly because of this poor attributability that researchers hesitate to confidently communicate their conclusions to nonspecialists, including stakeholders. This underlines the importance of producing methodologically rigorous evidence to inform robust policy. On the whole, the health system in Bangladesh is yet to be prepared for the challenge of increasing disease burden from climate change, given its insufficient capacity to assess, generate and communicate research findings into policies and practices. There is also an urgent need to incorporate health concerns into the decisions and actions of different sectors.

The present review indicates that the impact of climate change can assume a large number of different modalities, and the cumulative impact is likely to have a wide-ranging effect on the public health of Bangladesh if the system is not made resilient for future challenges. However, there are important positive developments to consider as well. Bangladesh has already included health adaptation plans to climate change in different policy documents and program designs, although its impact is yet to be evaluated in reality. Measures taken for adaptation to climate change would result in cobenefits, enabling the country to achieve better health and well-being overall. Bangladesh offers exemplary lessons not only to low and middle income countries but also to high income nations as well. The importance of gender equity for positive health outcomes and how the

linkage between health intervention and socio-economic interventions (innovation, approaches and scaling up) can benefit the nation as a whole are all important lessons from Bangladesh to the world (Chowdhury et al., 2013). The dynamic pluralistic health system in Bangladesh challenged the static and antiquated WHO Health Systems Framework building block approach (Ahmed, Evans, Standing, & Mahmud, 2013). The need of the hour is to advance the knowledge with innovative scientific research, in order to achieve a climate resilient society.

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CONFLICT OF INTEREST

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