Regional Environmental Change (2018) 18:1535–1553
https://doi.org/10.1007/s10113-017-1271-9

REVIEW

Climate change research in Bangladesh: research gaps and implications for adaptation-related decision-making

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Received: 28 May 2016 / Accepted: 10 December 2017 / Published online: 12 February 2018

Abstract

In this paper, we present the results of a systematic literature review of climate change vulnerability-related research conducted in Bangladesh between 1994 and 2017 in order to identify trends and knowledge gaps. Our results identify interesting evolutions in the temporal and spatial scales of study and the nature of spatial and thematic associations, suggesting important knowledge gaps in the existing literature that likely limit understandings of scale-sensitive climate change impacts. We also observed a temporal mismatch between the published studies and policy-making processes focused on adaptation and mitigation and a bias towards the economic aspects of climate change, with less focus on social and environmental issues. Thematically, the climate change-related scholarship in Bangladesh would benefit from more integrative, cross-theme, and transdisciplinary studies, potentially drawing on the different theoretical constructs of vulnerability and adaptation. Such studies will be needed to better support evidence-based public policy and also to more accurately reflect the diversity of knowledge gaps and challenges concerning climatic stresses in Bangladesh at different scales and in different contexts.

Keywords Bangladesh · Climate change · Adaptation · Vulnerability · Systematic review · Knowledge synthesis

Introduction

The success of national climate change adaptation strategies largely depends on the capacity to generate appropriately contextualized information on climatic risks and adaptation opportunities at different scales through scientific research (Dilling and Lemos 2011; Ayers et al. 2014). Since adaptation-related decisions are closely related to a country's economic, social, environmental, and climatic characteristics, science can help to explain relationships likely to affect outcomes (Füssel 2007; Lemos et al. 2012). As a result, systematically analyzed and summarized knowledge from existing, often cross-scaler, scientific literature has been identified as being useful in assessing what is known, and what may need further research attention (Ford et al. 2012). According to Ford et al. (2010a, b, 2015), only a small number of studies have been conducted to better understand the overall effectiveness of adaptation actions taken at both local and national levels. This situation has the potential to result in policy bias, where particular geographic areas and specific sectors (e.g., livelihoods, health, natural resource management) may be emphasized due to greater research effort while other, equally important, areas and sectors may remain under-represented. Adger et al. (2003) acknowledged that some societies are more vulnerable to climate change than others and therefore may demand policy

Editor: Virginia Burkett.

Electronic supplementary material The online version of this article (https://doi.org/10.1007/s10113-017-1271-9) contains supplementary material, which is available to authorized users.

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privilege. However, when government and researchers are unaware of the vulnerability of certain communities and/or societies due to historical, cultural, or geographical issues, determining where best to direct limited resources becomes problematic.

This situation is often observed in developing countries, where available resources for adaptation actions are inadequate, and long-term investments are susceptible to uncertainties associated with the effectiveness of these investments (Fankhauser and Burton 2011). Efforts to synthesize existing knowledge are becoming increasingly common in developed nations (Arnell 2010; Tompkins et al. 2010; Ford et al. 2011; Ford and Pearce 2012). However, very little equivalent research has been done in the context of developing nations, particularly at national levels. For example, Bangladesh is both highly exposed to different climatic stresses (e.g., flood, storms, drought, over and under rainfall) and experiences high rates of poverty, social exclusion, marginalization and powerlessness in both urban and rural communities (Islam 2011; Rahman et al. 2015). While the national government has undertaken a number of important initiatives to foster local-level adaptation through different national-level policies and development plans, a high level of uncertainty surrounds the extent to which these initiatives are effective, equitable, and efficient (Huq and Khan 2006; Ayers 2011). In order to better bridge the information gaps facing policy-makers, there is a need to credibly summarize the climate change-related research advances made in Bangladesh with a view to informing future research and policy needs (Lemos et al. 2012). Focusing on the case of climate change adaptation research and policy in Bangladesh, one of the most climate-vulnerable countries in the world (Ayers and Forsyth 2009; Seneviratne et. al. 2012), this paper presents the results of a systematic literature review designed to answer the following questions: what is already known, what is not known, and what has been identified as being necessary to know about climate change vulnerability and adaptation in Bangladesh?

Methods

Research approach

We conducted a systematic literature review following a mixed method research approach. The application of systematic literature review is common in health science (Salmond and Holly 2012), and it has been adapted to climate change adaptation research fairly recently (Berrang-Ford et al. 2011). Systematic literature reviews aim to comprehensively synthesize, evaluate, and track down scientific literature on a certain topic of interest (Petticrew 2003; Lorenz et al. 2014; Berrang-Ford et al. 2015). As a literature review method, it has certain advantages over the more conventional narrative review technique where the literature search process is usually unreported (Ford and Pearce 2010). Further, the absence of a systematic management approach to literature may incur selection biases (Green et al. 2011). In contrast, systematic literature review has been designed to handle the growing amount of information available, considered to be the quality control standard of the review (Mulrow 1994) by following strictly defined inclusion and exclusion criteria, resulting in higher accuracy and consistency (McDowell et al. 2014; Ford et al. 2014; Berrang-Ford et al. 2015; McDowell et al. 2016).

The inclusion and exclusion criteria of a systematic review needs to be based on research objectives, along with a well-defined search protocol to locate primary studies. It also requires a clearly defined mechanism for assessing the risk and biases of primary studies, and finally, it needs to be presented following a systematic approach (Green et al. 2011). In addition, all research protocols need to be clearly stated in the synthesis to maximize research clarity and transparency (Green and Higgins 2011). However, the application of systematic review in climate change adaptation research is complex because of the adoption of both qualitative and quantitative research methods in primary studies. To overcome this problem, Ford et al. (2010a, b) have suggested applying a mixed method approach to data retrieval and analysis which involves placing equal emphasis on qualitative and quantitative approaches (Denscombe 2008; Bergman 2011).

Search protocol for primary studies

To conduct the review, we considered only peer reviewed research papers published between 1994 and April 2017. A keyword search using “climate change” and “Bangladesh” was conducted using the ISI Web of Knowledge (ISI) and Scopus electronic database to maximize our coverage of literature. A total of 535 published articles were subsequently identified using a set of inclusion and exclusion criteria, as follows: articles had to be peer reviewed and written in English; published in ISI and/or Scopus indexed journals; and focused on climate change vulnerability as their main research question (Table 1). Lavell et al (2012) defines vulnerability as the propensity of system elements (e.g., humans, livelihoods, assets) to be exposed to climatic stresses. More specifically, vulnerability is observed as the function of exposure, sensitivity, and adaptive capacity (Cardona et. al. 2012). We followed this definition when selecting the primary studies, which discussed at least one of the three elements of vulnerability in the context of a specific theme (e.g., livelihoods, biodiversity, natural resource management). In addition, cross-national comparative studies were excluded as they were likely to depend on relative comparison criteria which may not be directly relevant to the Bangladesh context. Following an initial review of title and abstract, a total of 363 papers were retained for full-text review and analysis (see Online resource 2 for the full list of papers included). The inclusion and exclusion criteria and the

Table 1 Inclusion and exclusion criteria of the studies

Inclusion	Exclusion
Research papers published in English	Paper published in languages other than English
Only peer reviewed articles	Non-peer reviewed research works such as books, non-peer reviewed book chapters, technical reports and working papers.
Climate change is the primary focus of research	Climate change issues appear as secondary or supporting elements
Studies that are fully devoted to exemplify the climate change issues of Bangladesh	Studies that have considered Bangladesh as one of two or more cases for the purpose of comparison

description of analytical categories are presented in Online resource 1 and 2, respectively.

Data retrieval

Data retrieval for this research involved both quantitative and qualitative methods. For quantitative data retrieval, we coded each paper according to the categories and sub-categories described in Table 2 using binary (paper falls under a category=1 and does not=0) and interval scales. The analytical categories included research scale, based on the sample selection and the geographic focus; temporal considerations, using the temporal distribution of published research; spatial considerations, based on the geographical connectedness of the research; and thematic considerations, based on the issue-focus of the research.

For systematic qualitative data retrieval, we developed a short questionnaire. Through a full-text review of each paper, we sought to answer five broad questions: (1) what is the main research question of a paper? (2) what are the outcomes? (3) what are the limitations of the paper identified by the authors? (4) what are the further research needs identified by the authors? and (5) what are the research gaps in each paper in terms of related current scholarship? Answers to each of these questions were then coded for further analysis.

Data analysis

All quantitative data from each paper were stored in an Excel spreadsheet for quantitative analysis. Basic descriptive statistics were used to identify the frequency and proportion of the existing studies covering each of the categories and sub-categories. After in-depth review of the articles, we distributed them among a total of 14 different climate change-related thematic areas and coded each paper using a binary scale (presence of a theme=1, absence of the theme=0). A detailed description of the themes has been given in Table 3. Importantly, one study may have had multiple themes due to the multidisciplinary approaches used in the study. To better understand the pattern of multidisciplinary approaches, we conducted factor analysis. Notably, factor analysis is used to reduce a large number of interrelated variables to a smaller number of latent or hidden dimensions (Tinsley and Tinsley 1987), which are then used to determine the "basic constructs making up the domains of interests" (Fabrigar and Wegener 2011). It therefore helps with determining which variables are influenced by a specific common factor. Factor analysis enabled us to identify the latent dimensions in order to help explain the pattern of maximum amount of common variance in the correlation matrix among the measured variables (i.e., research themes) (Fabrigar and Wegener 2011). Since we did not have any theoretical presumptions or constructs regarding the approaches of the reviewed studies, we conducted an exploratory factor analysis (Fabrigar and Wegener 2011) using the minimum residual method and applying the varimax rotation technique (Comrey and Ahmudu 1964; Comrey 1962), considered to be suitable for binary multivariate data (Kamata and Bauer 2008). Before conducting the analysis, we determined the appropriate number of common factors using parallel analysis, an eigenvalue-based technique, retaining the common factors which had an eigenvalue greater than 1 (Fabrigar and Wegener 2011). We tested the reliability of the analysis by calculating the Tucker Lewis Index of factoring reliability and the root mean square error of approximation values, which satisfy the standards of the tests (Taasoobshirazi and Wang 2016). We have also reported Cronbach's α values for each variable to show the internal consistency of our data, which are close to the standard value of 0.7.

Results and discussion

In what follows, we describe the results of the study in three sections: (1) the scale of research (e.g., local, sub-national, and local), (2) the trend and applicability of the studies, and (3) the spatial connectedness of different thematic studies. Each section begins with a brief description of related scholarship and ends with a discussion of the key research gaps.

Research scale

The scale at which research is conducted is important because environmental changes are cross-scale phenomena and,

Table 2 Analytical categories

Category	Description	Measurement scale
Research scale	*National* studies, which have been conducted at a national level, are considered under this category. In addition studies that have taken samples from all geographic locations are also taken under this category. *Sub-national* studies have samples from more than one geographic location but not from all locations, are considered. Again, for case study research, if a study takes more than one case from one or more geographic location it is also considered under this category. *Local* studies are single case study research from a single geographic location.	Binary
Temporal consideration	We examine the evolution of climate change research in Bangladesh over the time period between 1994 and 2014 under this analytical category.	Interval
Spatial consideration	*Northern part* falls under the Ganges-Brahmaputra river basin. This area is highly drought and flood prone; and particularly susceptible to seasonal hunger during the dry season. However, the establishment of embankment in the upper stream of the Ganges river under Indian territory is often responsible for drought. On the other hand, the overflow of river water during rainy season is responsible for flood. *Central part* falls under the Brahmaputra river basin, and is dominated by urban areas (e.g., Dhaka the capital of Bangladesh along with some other large cities are located in this part). This area is highly susceptible to flooding. Expanding urbanization and the destruction of wetlands and low laying areas has augmented flood risk in the area. *North-eastern part* falls under the upper Meghna river basin (also known as Surma-Kushiara river basin) and is highly dominated with wetlands ecosystem, and small hills. This part of the county receives the highest rainfall, and there are more than 22 trans-boundary rivers flowing across it. Along with rainfall, huge amounts of water flow from the upper stream territory of India. Consequently, most of this area remains under water for half of the year. However, over and under rainfall due to climatic variability significantly alter the livelihood activities and ecological structure. *Southern part* is dominated by coastal and estuarine ecosystems. Sea level rise, oceanic serge and tropical cyclone are the major climate change risks in the area. Recent cyclones have resulted in considerable loss of life and destruction of resources. Moreover, water stagnancy and saline water intrusion are responsible for land quality loss. Labor migration from this area is also higher than any other part of the country. *South-eastern part* is characterized by coastal and mountainous ecosystems. This area is highly exposed to tropical cyclones and saline water intrusion. Mountainous regions possess the lowest population density in the country, and several ethnic communities live in this region, practicing traditional agriculture with relatively low production. Consequently, poverty is a general scenario for these communities, which limits their capacity to adapt to a changing climate. On the other hand, plain land coastal communities are mostly farmers and fishers who encounter property loss due to cyclone events every year. In addition, saline water intrusion and stagnancy usually results in land and water quality loss.	Binary
Thematic consideration	The selected studies have been classified under 14 themes, which include: climatology, livelihood, health, policy and governance, food security, conservation, gender, agriculture, fisheries, livestock, forest, infrastructure, non-natural resource dependent economic activities and environmental quality. These studies have been conducted to understand the theme's exposure, sensitivity, adaptive capacity and adaptive change	Binary

therefore, require diverse knowledge to inform decision-making (Cash and Moser 2000). Gibson et al. (2000) suggested that scale-related thinking influences four aspects of scientific exploration. First, the pattern that exists at one level may not be found at higher or lower levels (Adger 2001). O'Brien et al. (2004) suggested that climate impact assessments are scale-specific and should not be generalized, although Adger et al. (2009) noted that scale-specific impacts are often connected and nested. Second, causal explanations are highly sensitive to scale because the variables in use are generally scale-specific, potentially resulting in an explanatory fallacy if not adequately recognized (Adger et al. 2005). Third, theoretical generalization is both difficult and costly because one set of variables used to explain a phenomenon at a particular spatial scale may not be found sufficient or even relevant at another scale (Wilbanks and Kates 1999). Therefore, Osbahr et al. (2008) have suggested that it may be more useful to observe cross-scale practices rather than focusing on a specific scale. According to Urwin and Jordan (2008) and Mastrandrea et al. (2010), two dominant approaches, including bottom-up and top-down scaling of scientific studies, may help to bridge the knowledge divides between scale-specific research through communication, collaboration, and co-learning.

Scale issues in the existing climate change scholarship in Bangladesh

We reviewed the scale-related aspects of the published papers from local, sub-national, and national perspectives (see Table 2 for definitions), which comprised 30.46 (total 111), 33.33 (total 121) and 36.21 (total 131)% of the sample, respectively. Based on our results, national-scale studies were mostly focused on two major areas: climatic risk and public policy. A number of studies also described the sensitivity of national agricultural production under a changing climate. Notably, almost all of the national-level studies had a specific thematic preference, where vulnerability or adaptation issues were the focus of discussion, with issues related to agriculture and health the most prominent. Exposure studies projected national climate change patterns using time-series data and identified that Bangladesh is one of the most climate-

Table 3 Definitions of research themes used in this study

Themes	Description of the themes
Health	Studies that discussed about climate induced health concerns including diseases exposure, diseases susceptibility due to climatic change and climate induced natural hazards, increasing health costs, adaptive responses from both community, non-government and government organizations.
Livelihood	According to Scoones (1998) livelihoods are the resources and activities undertaken by a community for their subsistence. We used this to identify the studies that focused on this issue. Therefore, the studies that discussed different types of livelihoods and their exposure to climatic change and stresses, loss of livelihood and resources, adaptation practices (e.g., technological and institutional innovations, migration for securing livelihood opportunities etc.) facelifted by the innovation of affected community members and external supports from government and non-government organizations were considered under this theme. Socio-economic discriminations based on ethnicity and marginalized social groups which have livelihood implications were also taken under this theme.
Climatology	The studies, which took at least one climatic variable for answering research questions that are related to long or short term climatic variability, future climate projection, studying climate stress patterns, and forecasting future climatic extremes like floods, storms and droughts, were listed under this theme. The studies, which used climatic variables for understanding the impact of that variable on another theme (e.g., agricultural, fisheries, infrastructure etc.) were also taken under this theme.
Policy and governance	Papers under this theme discussed about government policy making, institutional development at both international, national government and community level for supporting climate change adaptation and mitigation. Besides, studies covering issues that may influence policy and governance like climate awareness were also considered under this theme.
Food and food security	Studies that discuss the impacts of climate change on food availability, distribution and quality, and the adaptation of these issues to the climatic impacts were taken under this theme.
Wildlife and ecosystem conservation	Climate change impacts on and adaptation of wildlife, biodiversity, aquatic ecosystems including freshwater and marine, terrestrial ecosystems including agro-ecosystems, forest ecosystems, habitat conservation.
Gender	Climate impetus on gender discrimination including socio-economic marginalization, health facilities, gender sensitivity of adaptation actions (e.g., policy making, infrastructural development)
Agriculture	Climate impacts studies on agriculture as a production sector have been considered under this theme. Besides, studies that discussed agricultural production loss and its impacts on rural livelihoods, production and marketing processes, agricultural land loss due to climatic influences were also considered under this theme. Agricultural adaptation studies were also taken under this theme.
Fisheries	Fish production loss studies that identified climate change as one of main reasons of the loss were codified under this theme. Natural and non-natural fish habitat loss, fisheries as an adaptation practice and climatic challenges of shrimp cultivation are the studies under this theme.
Livestock	Climatic impacts on livestock production and the potential of livestock as an option for diversifying livelihood practices were considered under this theme.
Forest	Forest conservation, stock, growth, changing pattern of forest composition, forest expansion as an adaptation measure, carbon stock estimation and contribution of forest in trapping greenhouse gases related studies are considered under this theme.
Technology and infrastructure	Technological innovation for adaptation practices in both agricultural and non-agricultural production activities, carbon emission from industries, infrastructural development for stress impact reduction like water resource management infrastructures (e.g., embankment building, water compartmentalization, irrigation system management etc.), climate sensitive building development, energy consumption and technological innovation for renewable energy sources related studies were listed under this theme.
Non-natural resource economic activities	Impact of climate change on industrial sectors, urban migration and livelihood activities related studies were considered under this theme.
Environmental quality	Environmental pollution, quality loss as a consequence of greenhouse gas emission, sea level rise and saline water intrusion were listed under this theme.

vulnerable countries in the world. However, these studies also conclude that the vulnerability is heterogeneously distributed across different geographic locations, with specific impacts characterized by local social-ecological characteristics. Hence, despite having the ability to describe the country's status under different climate change scenarios, these national-level exposure studies are insufficient to meaningfully inform policy-makers concerning specific adaptation and transformation strategies. The national public policy-related studies primarily examined how climate change vulnerability and adaptation have been institutionalized and mainstreamed in Bangladesh through national development plans and policies, noting generally good progress.

We also identified five sub-national spaces based on their ecological distinctiveness and political boundaries, with existing studies reflecting this distinction. For example, coastal communities are dependent on both agriculture and fisheries which will be affected by changing salinity, sea level rise, and oceanic storms. Consequently, the studies conducted in this sub-national area investigate how communities have generated adaptive responses. While the wetland resource-using communities in a different sub-national area have similar resource-use behaviors (i.e., agriculture and fisheries), the adaptive learning insights derived from the coastal communities have very limited implications for wetland residents due to their identified climatic risks (e.g., flood, over and under rainfall), resource type (e.g., fresh water fisheries, rain-fed rice cultivation), and cultural practices. Since the government policies of Bangladesh are generally designed at the national scale, adaptation policy-related analyses were scarce in the sub-national studies, which instead focused heavily on ecosystem exposure to climatic risks, the sensitivity of

agricultural productivity (e.g., rice), the applicability of adaptive technologies, and the adaptive changes that have been undertaken at community levels.

Local studies were mostly case study-based with a relatively small sample size of communities and/or actors involved. Adger et al. (2009) suggested that such case-based studies do not provide in-depth understanding of cross-scalar causes and consequences of climate change and thus do not sufficiently contribute towards larger-scale generalization. As a result, some confusion remains regarding the contribution of these local-level studies to national-level policy. Ford et al. (2010a, b) argued that local-level studies are important for gaining the in-depth understanding of climate change impacts at local levels with a large number of variables which interact and co-vary (Gerring 2004). Consistent with these characteristics of case study research, the local-level studies conducted on climate change in Bangladesh provided more contextualized information and understandings. Such studies were particular- ly focused on household-level climate sensitivity and adaptive capacities, incorporating a wide number of variables and of- fering detailed descriptions. More specifically, these studies identified a range of ecosystem and society-specific climatic risks and resident community responses to explore community-level adaptation behaviors drawing on local knowledge and experiences (for further discussion see the "Cross-thematic research and spatial connectedness in Bangladesh" section). However, this research was generally not well-integrated with the existing government interventions in support of adaptation, formal decision-making processes, multi-scalar knowledge sharing initiatives, and larger-scale scientific research programs.

Research gaps

Our results revealed the presence of both top-down and bottom-up approaches to climate change research in Bangladesh. However, it remains unclear how national government actions are contributing to sub-national and local scales of operation, and to what extent the local and sub-national understandings of issues are reflected in national policy. This suggests that climate change research in Bangladesh tends towards being authoritative and technocratic (Ayers et al. 2014), with local-level information generally insufficient to help understand local climate change patterns, impacts, and responses. Another research gap that appears through our analysis relates to the consideration of scale in the multi-level decision-making processes affecting adaptation (Gibson et al. 2000). We observed little-to-no research that identified the appropriate scale of decision-making for different climate change-related issues and a scarcity of cross-scaler studies in Bangladesh. As a result, there is likely a mismatch between local and sub-national conditions and national-level policy responses (Juhola and Westerhoff 2011; Osbahr et al. 2008). Moreover, questions related to fairness and equity in the adaptation-related decision-making processes occurring through multi-scaler network governance remain under-researched in the context of Bangladesh (Adger et al. 2005).

Temporal applicability

Equipped with theoretical grounding (e.g., Kelly and Adger 2000; O'Brien and Leichenko 2000; Burton et al. 2002; Füssel and Klein 2004; O'Brien et al. 2007), conceptual framing (e.g., Turner et al. 2003; Smit and Wandel 2006; Gallopín 2006; Füssel 2007), and methodological specifics (e.g., Sullivan 2011; Brooks et al. 2005; Polsky et al. 2007; Hinkel 2011; Cinner et al. 2012), climate change vulnerability and adaptation research has been evolving and aiming to contribute to policy process with more holistic and "usable" scientific knowledge. However, McNie (2007) suggested that in order for scientific research to effectively inform public policy, issues related to the salience, credibility, and legitimacy of the research become important, with salience related to the timeliness of findings (Ford et al. 2013; Lemos and Morehouse 2005), credibility indicating reliability of knowledge and legitimacy closely related to the degree of engagement with local policy actors and affected stakeholders (Dilling 2007; Lemos et al. 2012). Ultimately, scientific research is most useful when key decisions have yet to be made and when the findings are appropriately contextualized for the relevant decision-makers (Lemos and Morehouse 2005; Ford et al. 2013; Lemos et al. 2012; Lalor and Hickey 2014).

Trends in climate change research in Bangladesh

Climate change research in Bangladesh has been increasing (Fig. 1) following global trends (McDowell et al. 2016). Initially focused on understanding the national climatic risks and their influence on economic activities like agriculture (e.g., Ortiz 1994; Mahmood 1997, 1998), the scientific understanding of climate change in Bangladesh has been moving towards the exploration of socio-economic and social-ecological system-based understandings of climatic vulnerability involving stakeholders from different scales and giving more credibility and legitimacy to the scientific process (e.g., Ahammad et al. 2014; Anwar and Takewaka 2014; Ayers et al. 2014). Initial studies mostly pointed to climate change impacts which significantly contributed to improving national political consensus on the need for action. Sea level rise and its consequential land loss in the southern coastal region, flood propensity, temperature rise, and irregular rainfall along with corresponding agricultural production losses have been the main focus of these studies (e.g., Faisal and Parveen 2004; Khan et al. 2000). Such studies have supported the government in developing climate-sensitive action plans (e.g., NAPA 2005) and Bangladesh Climate Change Strategy and Action Plan (BCCSAP 2009), and have provided a scientific basis from which the

government could assess and communicate the country's vulnerability in different international fora.

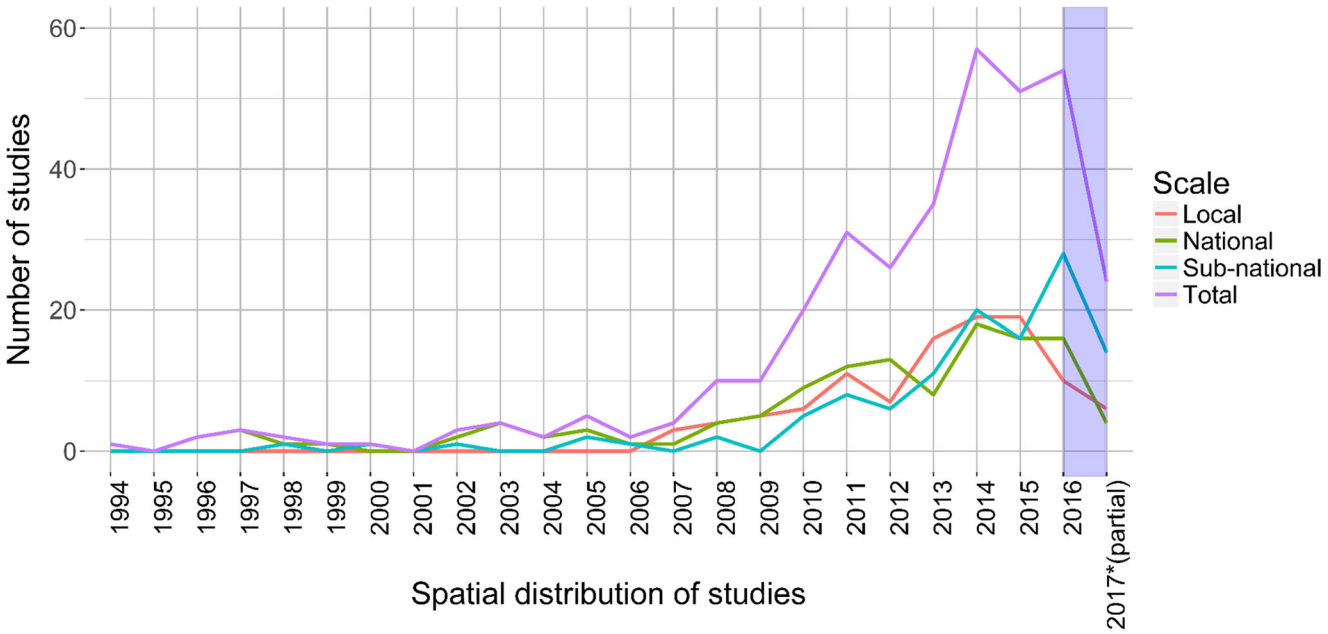
Research into the socio-economic factors related to climate change was heterogeneously distributed in different geographic locations, with sub-national and local studies increasing through time. Along with the increasing identification of locally embedded vulnerability, more recent studies have attempted to identify the innovativeness and gradual progress of communities in the face of climate-related shocks. Noticeably, most of these studies were conducted after the release of the latest national climate action plan (BCCSAP 2009), meaning that both the NAPA (2005) and BCCSAP (2009) likely do not well-reflect vulnerability-based approaches to climate change impact assessment. As a result, many of these studies criticize the existing policy plans rather contributing to new policy proposals, raising questions concerning the salience of existing research to policy-making processes. In contrast, our literature review also suggests that public participation in research has been increasing over time, opening opportunities to better consider community innovations, informal adaptive actions based on indigenous and local knowledge, and social networks—potentially increasing the legitimacy of research findings.

Research gap

Although impact and vulnerability-based research approaches are common in the Bangladesh-focused climate change literature, relatively little formal attention has been paid to bridging gaps between science and policy and science and society. For example, no published study has synthesized the existing knowledge available at different scales. Other research gaps include studies on Bangladesh climate research credibility and methodological appropriateness (Lemos et al. 2012) and the longitudinal socio-economic changes occurring through adaptation actions. Based on our review, the effectiveness of adaptation has not yet been sufficiently assessed to meaningfully inform Bangladesh policy processes.

Spatial and thematic connectedness

Climatic impacts are not only multi-scaler but also multi-sectoral. For example, agriculture is a climate-vulnerable sector that can be studied to better understand production risks arising from potential future climatic uncertainties using agricultural productivity and climatic variables. However, as a livelihood opportunity and potential area for adaptation, agriculture also needs to be studied using socio-economic and policy variables. While each type of study on the same sector will likely produce different interpretations regarding vulnerability and adaptation, all are potentially important for adaptation decision-making at various scales. In what follows, we consider each major research theme raised in the literature (e.g., agriculture, climate, fisheries) and assume that the underlying associations among these themes can generate indications of



*Four months only. Data reflects publications to 30 April 2017.

Note: The number of studies depicted exceeds the total number of studies reviewed because of inter sub-national and national level studies.

Fig. 1 Temporal trends in the published papers focusing on climate change in Bangladesh as indexed in ISI and Scopus (1994 to May 2017) (n=348)

what has been studied, to what degree, and what may benefit from receiving more research focus (see Table 4 for summary of findings).

Cross-thematic research and spatial connectedness in Bangladesh

Figure 2 shows that the climate change studies were heterogeneously distributed across the national and sub-national levels (e.g., central, north-eastern, northern, south-eastern, and southern), with variability in the thematic issue areas covered. For example, the Southern region has been most widely studied with the broadest thematic coverage likely because of the area's exposure to destructive climatic stresses and disasters such as severe storms, oceanic surge, and saline water intrusion. National, South-Eastern, and Central regions each appears to have been studied to a similar degree with generally broad thematic coverage, while comparatively less research has been published in the Northern region. Importantly, the North-Eastern region clearly stands out as the most understudied area of Bangladesh with very limited thematic coverage. This result is likely due to poor research infrastructure and the absence of a centralized scientific research administration in Bangladesh. Such large regional variation in the availability of climate change-related evidence has the potential to lead to policy biases that may perpetuate or exacerbate the knowledge gaps.

The results of our factor analysis (Online resource 1) further reveal the broad themes of the available studies to help draw a clearer picture of the scientific knowledge base. We found that six factors (Online resource 1a) describe almost 50% of the total data variability, broadly classified as environmental conservation, socio-economy, policy response, technological innovation, and environmental risk, impacts on health, and impacts on fish resources (see Online resource 1b). We now provide a more detailed description of these findings in each sub-national region.

Central region Eighty-two studies (23% of total sample) were conducted on the central region, focused primarily on understanding the vulnerability of both urban (particularly the capital city Dhaka) and rural areas to climatic impacts. Climatic exposure studies predict that annual daily maximum rainfall may become equal to, or more than, 200 mm with a return period of 12 years between 2010 and 2066, observing that rainfall trends are increasing at a rate of 4.54 mm per year (Ahammad et al. 2014). Gain and Hoque (2013) show that agricultural land use is highly vulnerable to climate change, although it is predicted that such land use will be altered in coming years through rapid urban expansion (Molla et al. 2014). Khan et al. (2014), Mynett and Vojinovic (2009), and Alam and Rabbani (2007) suggest that prolonged water stagnancy is having the largest negative impact on the poorest residents of the city who live in slums. Barua and van Ast (2011) identify that poor and inefficient infrastructural developments, accompanied by inefficient institutional and planning process, are the potential causes of water stagnancy. In addition, residents of slums are generating adaptation actions to climatic impacts, particularly related to flood and water stagnancy (Jabeen et al. 2010; Jabeen and Guy 2015), which largely depend on the level of household capital assets and social networks (Braun and Aßheuer 2011; Rotberg 2013). In addition, changing climatic variables including temperature, rainfall, and flood frequency increment are projected to increase the risk of diseases like Dengue and Cholera, and will likely increase the health care costs, particularly for people living in slums (Banu et al. 2014; Khan et al. 2014; Burkart et al. 2011; Matsuda et al. 2008).

Water scarcity appears as an important climatic consequence in rural areas, particularly during the dry season, and water flows are predicted to increase during wet seasons resulting in flood (Gain and Wada 2014; Gain et al. 2013). Both of these factors are expected to reduce agricultural productivity in the region, resulting in rural livelihood insecurity despite farm-level adaptation actions (Mahmood 1998; Younus 2015; Younus and Harvey 2014). This is likely to lead to increasing rural-urban migration (Martin et al. 2014), which largely depends on the social networks of the affected community members. However, these migrants are also likely to encounter urban climatic exposure in their new locations suggesting that migration, as a climate change adaptation, will not be sufficient (Adri and Simon 2017).

North-eastern floodplain The north-eastern floodplain is the most understudied area in the country with only 25 (6.9%) published studies appearing in our systematic review. After studying rainfall and temperature patterns, Nowreen et al. (2014) and Nury et al. (2017) indicate that annual average temperatures will increase by almost 3 °C by 2080 from the base year 1980 in the region. Using rainfall and river water discharge data, Nowreen et al. (2014) forecast that average annual rainfall will increase by 2 mm/day, while Masood and Takeuchi (2016) predict river water discharge will increase from 25 to 104% in the long run resulting in higher potential for flash flooding, the most destructive climatic impact facing the rural economy and household livelihood practices. In contrast, Anik and Khan (2012) found that despite the increasing climatic threat, community members are generating adaptive capacities by innovating and practicing new technologies, while Pavel et al. (2014) estimated the financial efficacy of these practices. Beyond impacts on socio-economic activities, Rahman et al. (2017), Sohel et al. (2017), and Deb et al. (2016) identify climatic impacts on the growth and distribution of different forest plant species.

Table 4 Description of synthesized knowledge and potential future research questions

Analytical considerations	Considerations for synthesizing knowledge		
	What's needed	What's known	What's not known
Spatial scale	• Characterizing vulnerability at different scales and their interconnectivity (O'Brien et al. 2004) • Identifying appropriate scale of managing vulnerability (Haarstad 2014) • Scale specific knowledge domains that describe socio-economic and biophysical dynamics (Füssel, 2007) • Policy implications of scale specific knowledge	• Scale specific vulnerability knowledge • Place based biophysical and socio-economic property based assessment of vulnerability • Where, why and how climate impacts interact with locally specific socio-economic properties	• Cross scaler vulnerability assessment • Scale specific actions for governing adaptation practices • Implications of local case studies to national scale policy making
Temporal usability	• What knowledge is needed and when should it be generated (Ford et al. 2013) • When and from where the knowledge should come (Ford et al. 2013) • Identifying knowledge necessities from policy makers and affected people (Moser 2010)	• Knowledge generated from different scales in a discrete way • Initial knowledge focused on national scale and more emphasize has been given on sub-national and local scales recently • Multiple stakeholder engagement has been prioritized in contemporary studies	• Finding options for bridging science-policy and science-society divide • Identifying key areas of innovation necessities for future policy making and implementation
Cross-thematic and geographic connectivity	• What are the future trajectories of climatic change (Burton et al. 2002) • What are the potential future climatic stresses (Burton et al. 2002) • What are the geographic associations of different climatic stresses (Simelton et al. 2009) • Which sectors and societal sects are more exposed to these stresses (Adger et al. 2005) • To what extent these sectors (in terms of productivity, stability and potential) and society (in terms of life and livelihood opportunities) are either positively or negatively affected by the stresses (Patwardhan et al. 2009) • What non-climatic factors are associated with these stresses (O'Brien and Leichenko 2000) • How do the non-climatic factors operate and intensify the stress impacts (Füssel and Klein 2004) • How do the affected communities perceive climatic stress and their impacts for adaptation decision making (Adger 2006; Adger et al. 2009) • How do the affected community members intervene adaptation actions through technological innovations, creating livelihood opportunities and institutional and governance modifications (Adger et al. 2009) • To what extent national and international policy making contribute to supporting local level adaptation actions (Füssel 2007) • What is the nature of multilevel and multi-scaler interplay of adaptation governance (Adger et al. 2005) • Does the national adaptation policy making reflect local level adaptation demand (Smit and Wandel 2006)	• Future climate forecast at different scales • Climate impacts on local level bio-physical properties (e.g., social property, salinity level, water availability) • Future impacts on water resource and potential future demand • Future impacts of climate change in different sectors (e.g., agriculture, health, fisheries) • Socio-economic drivers of vulnerability • Climate impacts on livelihood activities • Constraints on livelihood adaptation actions • Climate impacts in large urban areas • Nature of climate change induced rural-urban migration • Community based adaptation actions, local innovation and adoption of new-technologies • Level of policy support to community based adaptation actions	• Community perceptions regarding climatic stresses • Coupled social-ecological system based vulnerability assessments • Identification of local bio-physical properties that can intensify climatic impacts • Gender aspects of climate change impacts • Vulnerability of socially, politically and economically marginalized communities like ethnic minorities • Vulnerability and adaptation of extremely natural resource dependent communities like north-eastern wetland and south-eastern hill forest dependent communities • Interactions of socio-economic and socio-political issues with health sector • Human vulnerability in small and peri-urban areas • Vulnerability of built environment in coastal and hilly regions • Climate induced ecosystem conservation risks • Multi-level institutional linkage for governing adaptation actions • Synthesis of existing knowledge in terms of sectoral, scaler and geographic connectedness for policy incorporation

Northern region This area was the focus of 56 studies (15.4% of the total). This region is particularly susceptible to seasonal flooding and drought. Upstream river flow reduction and low rainfall are the main causes of drought in the area (Shahid 2011a; Etzold et al. 2014). Ahamad et al. (2013) identify these factors as the cause of seasonal food insecurity, with rural poor smallholders being the worst affected, locally known as *Monga* (seasonal famine). Existing climatologic studies indicate that annual rainfall will increase by between 1 and 5% over the next 20 years, with pre-monsoon rainfall increasing between 1 and 3% and post-monsoon rainfall increasing between 3 and 5% during the same time period (Kumar et al. 2014). Gain et al. (2013) and Gain et al. (2011) suggest that severe flooding due to higher levels of upstream river flow will occur with a 10-year return period. However, Gain and Wada (2014) identify that water scarcity during dry spells will

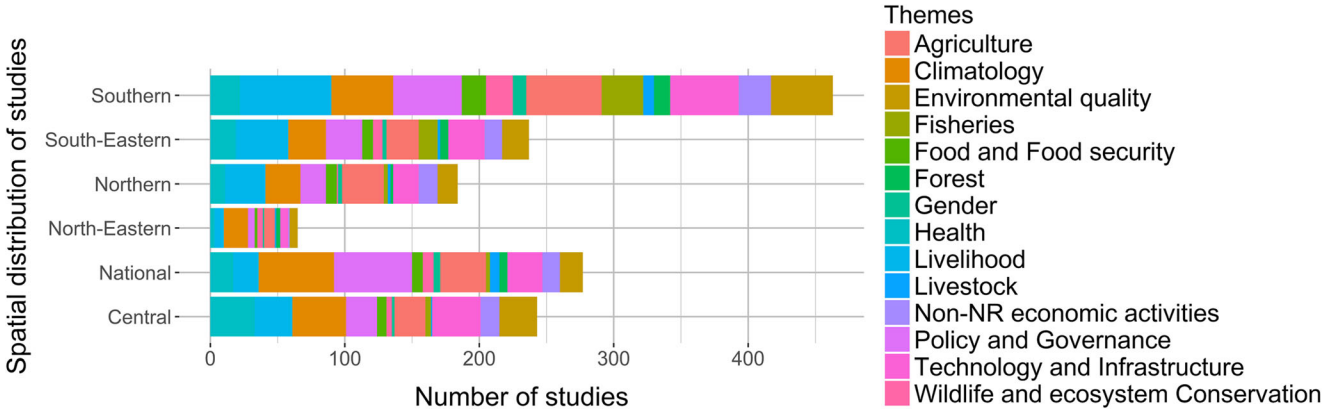


Fig. 2 Spatial and thematic aspects of the published papers focusing on climate change in Bangladesh as indexed in ISI and Scopus (1994 to May 2017) (n=363). The number of studies exceeds total n as many papers covered more than one theme

significantly increase in the coming years, which will affect local socio-economic and ecosystem function.

To escape this situation, affected communities are adopting different techniques and practices for different sectors. For example, cropping diversity, intercropping practices, and small scale irrigation systems are some common practices identified in agricultural adaptation (Kabir et al. 2017; Hossain et al. 2016), although Habiba et al. (2014); Etzold et al. (2014), and Shahid (2011a) note that excessive ground water harvesting may lead to maladaptation. However, in a recent study, Acharjee et al. (2017) note that climate change may not always intensify agricultural water use and may instead reduce water demand in northern region. Enhancing livelihood diversity through migration is another common practice among the rural poor of the region (Martin et al. 2014). However, this practice requires some degree of social capital in order to facilitate mobilization and adequate housing. In another study Khan et al. (2014) identify that knowledge and the use of traditional medicine play a crucial role in health-related adaptation practices. Notably, Coirolo and Rahman (2014) suggest that the adoption of adaptation practices in this region may be challenged by socially embedded power differentials and disproportionate access to resources among different socio-economic groups, and thus, call for cross-level institutional linkages and greater policy support.

Southern region This is the most widely studied region with a total of 121 published studies (33.3% of the total). It is regarded as the most climate-vulnerable area of Bangladesh, exposed to tropical cyclones, oceanic surge, coastal flooding, sea level rise, saline water intrusion, and land erosion. After conducting extreme value analysis, Lee (2013) suggested that extreme sea levels in 2050 due to oceanic surge and sea level rise, with 100-year return period, will be 2.09 m. Khan et al. (2000) note that sea surface temperature rise during the summer season is responsible for the increasing number of tropical cyclones in the area. On the other hand, Karim and Mimura (2008) identify that sea surface temperature and sea level rise are jointly responsible for oceanic surge and coastal flooding. They also predict that a 2 °C sea surface temperature and 0.3-m sea level rise will increase coastal flood risk by 15.3% from the present risk, which is responsible for coastal erosion. However, Sarwar and Woodroffe (2013) observed that there is no overall significant change in landform because of dynamic and active land erosion and accretion characteristics across the coastline. Despite this shoreline feature, the resident communities, infrastructures, and settlements are highly exposed to climatic influences due to these dynamics (Dasgupta et al. 2014), and thus, Hossain et al. (2017) conclude that potential climatic and socio-economic change will limit future local adaptation capacity.

In addition, Mallick et al. (2011) point to the inadequacy of infrastructure development for disaster protection. They note that poverty, natural resource-dependent livelihood activities, and poor institutional empowerment curtail the capacity of rural smallholders to adapt to disaster and post-disaster situations. Similarly, inadequate adaptive capacity significantly enhances livelihood insecurity and consequently influences household economic structures. For instance, Mottaleb et al. (2013) found that rural agrarian households spent the least on child education during stress periods because of income loss. Disasters cause internal displacement or forced migration for the extreme poor and rural smallholders (e.g., post Aila situation). In addition, they are forced to experiment with new business approaches without having adequate capital assets (Kartiki 2011; Martin et al. 2014).

Beyond disaster events, slow changes in environmental factors (e.g., water and soil salinity) have multi-sectoral influences. For instance, high saline concentration lowers land productivity, which is being gradually converted to shrimp ponds (Pouliotte et al. 2009). However, poorer people have limited access to these ponds because shrimp cultivation is labor and

cost intensive. In addition, production losses due to oceanic surges, cyclones, and any climatic factors (e.g., rainfall, drought, water temperature) may destroy partial or total investment (Kartiki 2011; Ahmed et al. 2013). Although Ahmed and Diana (2015) and Ahmed and Glaser (2016) have identified adaptive techniques, Paprocki and Huq (2017) have criticized the expansion of shrimp cultivation since it shrinks locally available livelihood opportunities for poorer smallholders. Additional multi-scalar governance, policy, planning, and technological and socio-economic constraints are also identified as being responsible for limiting the adaptive capacity of poorer smallholders (Islam et al. 2014).

Salinity has been found to affect public health, although a limited number of studies have sought to understand this issue. Khan et al. (2011a) identify that salinity in drinking water is increasing the level of salt consumption by the rural people, leading to mental health issues. They note weak responses both from the community and government in order to adapt to this changing scenario.

South-eastern region The south-eastern region was the focus of 68 published studies (18.7% of the total). The type and nature of climatic exposure in the south-eastern region is similar to the southern region because this area falls under the coastal territory of the country. Consequently, oceanic storms, sea level rise, salinity increment, and shoreline changes are the major threats. Studies reveal that, like the other parts of the country, farmers and fishers are the two most vulnerable livelihood groups in the south-eastern rural areas. Sea surface temperature rise combined with sea level rise are considered to be responsible for the increasing trend of cyclones and oceanic surges in the area (Karim and Mimura 2008). Landslides resulting from high rainfall and deforestation in the upland areas of the region are increasing siltation in the estuaries, responsible for environmental quality degradation (Lara et al. 2009). To reduce the level of exposure of coastal communities to saline water intrusion, the government of Bangladesh has intervened with structural development (e.g., polders) along the coastline. However, these establishments have little effect on protecting agricultural lands from saline water intrusion because this part of the country has the highest level of inundation risk. Consequently, it has been observed that coastal polders will likely be overtopped in several areas (Dasgupta et al. 2014). Moreover, socio-economic and socio-cultural features in this area are augmenting the potential vulnerability of resident communities. Therefore, Ahmed and Cokinos (2017) suggest that institutional innovation can directly influence vulnerability, although Younus (2017) notes that corruption limits the effectiveness of institutional process.

The unique feature of this area is that migrant landless households living in small islands and estuarine isles are highly exposed to the threat of oceanic surges due to their remoteness from cyclone shelters (Alam and Collins 2010). However, they have also noted that these people have developed their own adaptive learning mechanisms which support them in pre-disaster adaptation actions, observing that these actions help support their survival during the disaster period. These actions involve the establishment of small raised embankments around the households and migration from the islands to the mainland (Islam et al. 2014). However, both these actions are cost intensive and are primarily available to financially secure households. Mainland communities are also vulnerable to these risks due to socio-economic structures, markets, and resource managing institutions (Islam et al. 2014).

National-level studies National-level studies comprised 126 (34.7%) of the total 363 studies. National-level studies can be broadly classified as focusing on exposure or policy questions. The exposure studies are mainly oriented towards assessing the sensitivity of national agricultural production. Reviewing different extreme climatic impacts in Bangladesh, Dastagir (2015) concludes that the frequency of climate-induced extreme events has been increasing in Bangladesh, while Mirza et al. (2003) earlier identify that flooding is the main climatic disturbance for the country because it occurs in all region in various forms including flash, riverine, rain-fed, and storm-surge. Other national-level climatic disturbances are sea level rise and tropical cyclones. Mirza (2003), Shahid (2011b), and Prasanna et al. (2014) also describe that extreme rainfall in the upper tributaries of Ganges-Meghna-Brahmaputra (GMB) river basins and also water from melting glaciers from the Himalayan mountain range cause flash flood every year. Again, inland extreme rainfall also significantly contributes to rain-fed flooding during monsoon and post-monsoon periods, observed in flooding events that took place in 1998 and 2007 (Mirza et al. 2003; Prasanna et al. 2014). In addition, after studying long-term rainfall data, Shahid (2010a) and Rahman et al. (2013) identify that both pre- and during monsoon, rainfall is increasing, which may contribute to early floods, and may significantly affect rice production (Amin et al. 2015) and crop selection (Maniruzzaman et al. 2015). More specifically, Karim et al. (1996) predicted that temperature fluctuation and CO_2 concentration would reduce wheat and rice production, something that has been felt in almost all parts of the country for all rice crops (e.g., Aus, Aman, and Boro) (for detail, see Sarker et al. 2013; Sarker et al. 2012; Thurlow et al. 2012). Mahmood (1998) suggests that a 1 °C reduction in air temperature will increase evapotranspiration by 5% for Boro rice (winter rice) and will result in increasing irrigation demand. Another study suggests that over and under rainfall during the monsoon period significantly reduces Aman rice production (Mahmood et al. 2003; Mahmood et al. 2004). Again, production reduction has been observed for Aus (pre-

monsoon rice) because of temperature increases in the monsoon season (Sarker et al. 2013). Faisal and Parveen (2004) further suggest that after 2050, there will be significant freshwater deficiency for both agriculture and non-agricultural uses, although sufficient amounts of water are expected to be available until 2030. Therefore, they conclude that this situation will threaten the food security of the country in the long run. However, they also identify that national rice production is increasing due to the planting of high yielding salt and drought tolerant varieties.

Mirza (2002) observes that climate change will have negative implications for national development. Following this observation, most of the later studies have mainly focused on the influence of climate change on agriculture, health, and community displacement due to livelihood losses and disaster-related destruction (Rahman 2008; Thurlow et al. 2012; Gray and Mueller 2012). Contradictory findings emerged from two extensive and robust studies seeking to understand the consequences of disaster occurrence and crop loss on livelihood security at the national level. Hassani-Mahmooei and Parris (2012) developed an agent-based model for the migration pattern of disaster-affected communities and predicted that 3–10 million internal migrations will take place in the next 40 years based on the severity of disaster. In contrast, Gray and Mueller (2012) suggested that most of the internal migration is taking place as a consequence of crop loss rather than disaster occurrences because labor demand remains high during the post-disaster situation. Both of these observations have significant implications for adaptation-related decision-making in government and require further research.

Rahman (2008) observed that climate change impacts on health are generally under-explored in Bangladesh, with most of the existing research focused on the potential for changes in the incidence of diarrhea and cholera due to climate change (e.g., Cash et al. 2008, 2009; Ohtomo et al. 2010). Exceptions include Burkart et al. (2014) and Nahar et al. (2014), who reported that heat effects have negative impacts on human health, particularly on urban elderly residents, and post-disaster trauma will be particularly evident for rural women, who are often the worst affected by natural disasters. Here, Nelson (2003) identifies the direct disaster impact on affected communities and observes that socio-economic status and high population density have intensified climate-induced health risks. Moreover, Shahid (2010b) and Khan et al. (2011b) describe some indirect impacts of climate change related to groundwater withdrawal, which intensifies arsenic contamination, and saline water intrusion, which pollutes freshwater and creates favorable conditions for infectious diseases.

A large number of studies have also focused on national climate change policy-making processes in support of building adaptive capacity through institutional development and innovation. For example, Ayers et al. (2014) acknowledge the advancement of climate-sensitive adaptation planning in Bangladesh, identifying the National Adaptation Plan for Action as one of the first. They also identify Bangladesh as an example of "adaptation mainstreaming" through deliberative adaptation planning. Huq (2011) suggests that Bangladesh has achieved significant success in adaptive knowledge management and dissemination, while the country has a high potential to incorporate mitigation strategies along with its adaptation planning (Ayers and Huq 2009). Hence, the disaster management interventions of Bangladesh offer an example for many other similarly climate-vulnerable countries (Huq 2011), although the disaster losses, particularly in infrastructure, will cause additional cost burdens for the country (Dasgupta et al. 2011). Huq and Rabbani (2011) have provided a detailed description of institutional development and financial mechanisms for bearing the costs of adaptation. Some other studies have identified concerns and issues which may reduce the effectiveness of national adaptation practices. For instance, Coirolo et al. (2013) identify that the objectives of the existing social protection programs designed to support affected community members has not been sufficiently realized due to information gaps between community members and government officials, and the embedded corruption within the administration. Information gaps also remain in adaption planning processes which, despite requiring participatory and inclusive approaches, often suffer from vague and inadequate community representation due to elite capture (Ayers 2011). Moreover, institutionalized policy and political marginalization of certain community groups (e.g., urban slum dwellers; women; minority ethnic communities) also play a crucial role in excluding them from the policy process (Alam et al. 2011; Banks et al. 2011; Sultana 2010). Ayers et al. (2014) identify this feature as an obstacle to deliberative adaptation planning in Bangladesh.

Research gap

Reviewing the existing literature, we observe that climatic exposure at both the national and sub-national scales have been widely studied using time-series data following a scientific framing. However, most of these studies rely on the historical trends of climatic variables in order to predict the future scenario providing us with "outcome"-based vulnerability assessments. Comparatively, few studies have been conducted to understand how the existing climatic changes are perceived by the affected communities in Bangladesh. Perception is an individual construct, and largely depends on the level or capacity to adapt, and thus can inform residual vulnerability, which Kelly and Adger (2000) defined as "end-point" vulnerability. Perception-based understandings could therefore help inform questions such as what the level of adaptation is, and where to invest for short and long-term preparedness at both finer and coarser scales? (Parry 2007; Moser 2010). Other studies aim to

evaluate the influences of climatic events on production sectors (e.g., agriculture, fisheries) (Harrison et al. 2013). Patwardhan et al. (2009) called for more in-depth understanding of sector-specific vulnerability across scales through multi-sectoral and multidisciplinary research. This is particularly relevant to the case of Bangladesh due to the sometimes contrasting observations made at national and sub-national studies, for example, in the case of irrigation demand for winter crops (Mahmood 1998; Acharjee et al. 2017) (for detail see national and northern region study summaries).

Beyond identifying the nature and extent of climatic stresses, it is also important to understand the non-climatic stresses that have the potential to intensify climatic stresses. Cross-scaler institutional dynamics, market globalization, power, and socio-economic differentials are some examples of non-climatic stresses (Rodima-Taylor et al. 2012; Devine-Wright 2013; Osbahr et al. 2008; Chapin et al. 2016; Adger et al. 2012). While most contemporary research in Bangladesh has characterized power and socio-economic differentials at local scales (e.g., through end-point and focal-point vulnerability studies), we did not identify any study that reveals cross-scaler vulnerability dynamics or market globalization influences on local vulnerability. Notably, issues facing ethnic minorities, women, and youth have not been adequately studied with potential implications for adaptation policy. Further system-based research (Nelson et al. 2007) designed and implemented through local participation may have greater applicability to adaptation-related decision-making (Smit and Wandel 2006; Patwardhan et al. 2009; Ford et al. 2013). Here, understanding how people generate and share adaptation-related knowledge at different levels and how adaptation actions are organized through formal and informal institutions along with their horizontal and vertical interplay would be valuable (Cash et al. 2006; Devine-Wright 2013; Temby et al. 2017; Juhola and Westerhoff 2011; Ford and King 2015).

Conclusion

Synthesizing scientific information has multiple implications for climate change-related policy-making and practice and can help to understand what we know and what we need to know. In this paper, we systematically reviewed climate change research in Bangladesh over a 23-year period based on three broad aspects: spatial distribution, temporal trends, and thematic area, observing research trends and gaps. More specifically, we concentrated on the spatial connectedness, temporal evolution, and thematic specifications of the studies, observing that there remains a wide range of research gaps in existing scholarship. We observed that diverse perspectives of vulnerability have been used to examine climate change-related issues in Bangladesh, with significant regional variation in the number of published studies and the nature of the research conducted. Efforts to adopt more participatory and decentralized approaches to climate change-related research in Bangladesh will likely assist with better understanding how different climatic stresses are influencing the socio-economic and social-ecological conditions at different scales. Also, more locally based studies designed to understand the capacity of affected people to respond to climatic impacts through their innovation and available resources can help inform public policy. Thematically, the climatic scholarship in Bangladesh would benefit from more multidisciplinary studies involving cross-sectoral knowledge integration. Such studies could benefit from drawing on the large and growing climate change literature that draws on multi-level systems thinking. This paper seeks to support more evidence-based public policy and also to more accurately reflect the diversity of knowledge gaps and challenges concerning climatic stresses in Bangladesh at different scales and in different contexts.

Funding information We would like to acknowledge the Prince Albert II of Monaco Foundation and IPCC for their financial support to conduct the research. Additional funding support was provided by the William Dawson Scholar Award, McGill University.

Compliance with ethical standards

Disclaimer The comments of the paper are solely the responsibility of the authors and under no circumstances may be considered as a reflection of the position of the Prince Albert II of Monaco Foundation and/or the IPCC.

References

Acharjee TK, Halsema G, Ludwig F, Hellegers P (2017) Declining trends of water requirements of dry season Boro rice in the north-west Bangladesh. Agric Water Manag 180:148–159. https://doi.org/10.1016/j.agwat.2016.11.014

Adger WN (2001) Scales of governance and environmental justice for adaptation and mitigation of climate change. J Int Dev 13(7):921–931. https://doi.org/10.1002/jid.833

Adger W, Huq S, Brown K (2003) Adaptation to climate change in the developing world. Prog Dev Stud 3:179–195. https://doi.org/10.1191/1464993403ps060oa

Adger WN, Arnell NW, Tompkins EL (2005) Successful adaptation to climate change across scales. Glob Environ Chang 15(2):77–86. https://doi.org/10.1016/j.gloenvcha.2004.12.005

Adger WN, Paavola J, Huq S, Mace MJ (2006) Toward justice in adaptation to climate change. In: Adger WN, Paavola J, Huq S, Mace MJ (ed) Fairness in adaptation to climate change. MIT Press, London, pp 1–19

Adger WN, Eakin H, Winkels A (2009) Nested and teleconnected vulnerabilities to environmental change. Front Ecol Environ 7(3):150–157. https://doi.org/10.1890/070148

Adger WN, Barnett J, Brown K, Marshall N, O'Brien K (2012) Cultural dimensions of climate change impacts and adaptation. Nat Clim Chang 3(2):112–117. https://doi.org/10.1038/nclimate1666

Adri N, Simon D (2017) A tale of two groups: focusing on the differential vulnerability of "climate-induced" and "nonclimate-induced" migrants in Dhaka City. Clim Dev. https://doi.org/10.1080/17565529.2017.1291402

Ahamad MG, Khondker RK, Ahmed ZU, Tanin F (2013) Seasonal food insecurity in Bangladesh: evidences from northern areas. Mit Adapt Strateg Glob Chang 18(7): 1077–1088. https://doi.org/10.1007/s11027-012-9408-0

Ahammad R, Hossain MK, Husnain P (2014) Governance of forest conservation and co-benefits for Bangladesh under changing climate. J For Res 25(1):29–36. https://doi.org/10.1007/s11676-014-0430-9

Ahmed S, Cokinos C (2017) How does ecological modernization explain agriculture adaptation in coastal Bangladesh? A critical discussion. Environ Hazards 16:133–148. https://doi.org/10.1080/17477891.2017.1279047

Ahmed N, Diana JS (2015) Coastal to inland: expansion of prawn farming for adaptation to climate change in Bangladesh. Aquac Reports 2:67–76. https://doi.org/10.1016/j.aqrep.2015.08.001

Ahmed N, Glaser M (2016) Coastal aquaculture, mangrove deforestation and blue carbon emissions: is REDD+ a solution? Mar Policy 66: 58–66. https://doi.org/10.1016/j.marpol.2016.01.011

Ahmed N, Occhipinti-Ambrogi A, Muir JF (2013) The impact of climate change on prawn post larvae fishing in coastal Bangladesh: socio-economic and ecological perspectives. Mar Pol 39:224–233. https://doi.org/10.1016/j.marpol.2012.10.008

Alam E, Collins AE (2010) Cyclone disaster vulnerability and response experiences in coastal Bangladesh. Disasters 34(4):931–954. https://doi.org/10.1111/j.1467-7717.2010.01176.x

Alam M, Rabbani MDG (2007) Vulnerabilities and responses to climate change for Dhaka. Environ Urban 19(1):81–97. https://doi.org/10.1177/0956247807076911

Alam K, Shamsuddoha M, Tanner T, Sultana M, Huq MJ, Kabir SS (2011) The political economy of climate resilient development planning in Bangladesh. IDS Bull 42(3):52–61. https://doi.org/10.1111/j.1759-5436.2011.00222.x

Amin RM, Zhang J, Yang M (2015) Effects of climate change on the yield and cropping area of major food crops: a case of Bangladesh. Sustain 7:898–915. https://doi.org/10.3390/su7010898

Anik SI, Khan MASA (2012) Climate change adaptation through local knowledge in the north eastern region of Bangladesh. Mitig Adapt Strateg Glob Chang 17(8):879–896. https://doi.org/10.1007/s11027-011-9350-6

Anwar MS, Takewaka S (2014) Analyses on phenological and morphological variations of mangrove forests along the southwest coast of Bangladesh. J Coast Conserv 18:339–357. https://doi.org/10.1007/s11852-014-0321-4

Arnell NW (2010) Adapting to climate change: an evolving research programme. Clim Chang 100(1):107–111. https://doi.org/10.1007/s10584-010-9839-0

Ayers J (2011) Resolving the adaptation paradox: exploring the potential for deliberative adaptation policy-making in Bangladesh. Glob Environ Polit 11(1):62–88. https://doi.org/10.1162/GLEP_a_00043

Ayers J, Forsyth T (2009) Community-based adaptation to climate change. Environ Sci Pol Sustain Dev 51(4):22–31. https://doi.org/10.3200/ENV.51.4.22-31

Ayers JM, Huq S (2009) Supporting adaptation to climate change: what role for official development assistance? Dev Policy Rev 27(6):675–692. https://doi.org/10.1111/j.1467-7679.2009.00465.x

Ayers JM, Huq S, Faisal AM, Hussain ST (2014) Mainstreaming climate change adaptation into development: a case study of Bangladesh. Wiley Interdiscip Rev Clim Chang 5(1):37–51. https://doi.org/10.1002/wcc.226

Banks N, Roy M, Hulme D (2011) Neglecting the urban poor in Bangladesh: research, policy and action in the context of climate change. Environ Urban 23(2):487–502. https://doi.org/10.1177/0956247811417794

Banu S, Hu W, Guo Y, Hurst C, Tong S (2014) Projecting the impact of climate change on dengue transmission in Dhaka, Bangladesh. Environ Int 63:137–142. https://doi.org/10.1016/j.envint.2013.11.002

Barua S, van Ast J (2011) Towards interactive flood management in Dhaka, Bangladesh. Water Pol 13(5):693–716. https://doi.org/10.2166/Wp.2011.020

BCCSAP (2009) Bangladesh climate change strategy and action plan. Ministry of Environment and Forest. Government of the People's Republic of Bangladesh, Dhaka https://www.iucn.org/downloads/bangladesh_climate_change_strategy_and_action_plan_2009.pdf. Accessed 3 April 2015

Bergman MM (2011) The good, the bad, and the ugly in mixed methods research and design. J Mix Methods Res 5(4):271–275. https://doi.org/10.1177/1558689811433236

Berrang-Ford L, Ford JD, Paterson J (2011) Are we adapting to climate change? Glob Environ Chang 21(1):25–33. https://doi.org/10.1016/j.gloenvcha.2010.09.012

Berrang-Ford L, Pearce T, Ford JD (2015) Systematic review approaches for climate change adaptation research. Reg Environ Chang 15(5): 755–769. https://doi.org/10.1007/s10113-014-0708-7

Braun B, Aßheuer T (2011) Floods in megacity environments: vulnerability and coping strategies of slum dwellers in Dhaka/Bangladesh. Nat Hazards 58:771–787. https://doi.org/10.1007/s11069-011-9752-5

Brooks N, Adger WN, Kelly PM (2005) The determinants of vulnerability and adaptive capacity at the national level and the implications for adaptation. Glob Environ Chang 15:151–163. https://doi.org/10.1016/j.gloenvcha.2004.12.006

Burkart K, Schneider A, Breitner S, Khan MH, Krämer A, Endlicher W (2011) The effect of atmospheric thermal conditions and urban thermal pollution on all-cause and cardiovascular mortality in Bangladesh. Environ Pollut 159(8–9):2035–2043. https://doi.org/10.1016/j.envpol.2011.02.005

Burkart K, Breitner S, Schneider A, Khan MM, Kramer A, Endlicher W (2014) An analysis of heat effects in different subpopulations of Bangladesh. Int J Biometeorol 58(2):227–237. https://doi.org/10.1007/s00484-013-0668-5

Burton I, Huq S, Lim B, Pilifosova O, Schipper EM (2002) From impacts assessment to adaptation priorities: the shaping of adaptation policy. Clim Pol 2(2–3):145–159. https://doi.org/10.3763/cpol.2002.0217

Cardona OD, van Aalst MK, Birkmann J, Fordham M, McGregor G, Perez R et. al., (2012) Determinants of risk: exposure and vulnerability. In: Field CB, Barros V, Stocker TF, Qin D, Dokken DJ, Ebi KL et. al., (eds) Managing the risks of extreme events and disasters to advance climate change adaptation A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change (IPCC). Cambridge University Press, Cambridge, pp. 25–64

Cash DW, Moser SC (2000) Linking global and local scales: designing dynamic assessment and management processes. Glob Environ Chang 10(2):109–120. https://doi.org/10.1016/S0959-3780(00)00017-0

Cash DW, Adger WN, Berkes F, Garden P, Lebel L, Olsson P, Pritchard L, Young O (2006) Scale and cross-scale dynamics: governance and information in a multilevel world. Ecol Soc 11(2):8 http://www.ecologyandsociety.org/vol11/iss2/art8/. Accessed 15 May 2015

Cash BA, Rodó X, Kinter JL (2008) Links between Tropical Pacific SST and Cholera incidence in Bangladesh: role of the Eastern and Central Tropical Pacific. J Clim 21(18):4647–4663. https://doi.org/10.1175/2007JCLI2001.1

Cash BA, Rodó X, Kinter JL (2009) Links between Tropical Pacific SST and Cholera incidence in Bangladesh: role of the Eastern and Central Tropical Pacific. J Clim 21(18):4647–4663. https://doi.org/10.1175/2007JCLI2001.1

Chapin FS, Knapp CN, Brinkman TJ, Bronen R, Cochran P (2016) Community-empowered adaptation for self-reliance. Curr Opin Environ Sustain 19:67–75. https://doi.org/10.1016/j.cosust.2015.12.008

Cinner JE, McClanahan TR, Graham NAJ, Daw TM, Maina J, Stead SM, Wamukota A, Brown K, Bodin O (2012) Vulnerability of coastal communities to key impacts of climate change on coral reef

fisheries. Glob Environ Chang 22:12–20. https://doi.org/10.1016/j.gloenvcha.2011.09.018
Coirolo C, Rahman A (2014) Power and differential climate change vulnerability among extremely poor people in Northwest Bangladesh: lessons for mainstreaming. Clim Dev 6:336–344. https://doi.org/10.1080/17565529.2014.934774
Coirolo C, Commins S, Haque I, Pierce G (2013) Climate change and social protection in Bangladesh: are existing programmes able to address the impacts of climate change? Dev Policy Rev 31:74–90. https://doi.org/10.1111/dpr.12040
Comrey AL (1962) The minimum residual method of factor analysis. Psychol Rep 11:15–18. https://doi.org/10.2466/pr0.1962.11.1.15
Comrey AL, Ahmudu A (1964) An improved procedure and program for minimum residual factor analysis. Psychol Rep 15:91–96. https://doi.org/10.2466/pr0.1964.15.1.91
Dasgupta S, Huq M, Zahirul HK, Masud MS, Ahmed MMZ, Mukherjee N, Pandey K (2011) Climate proofing infrastructure in Bangladesh: the incremental cost of limiting future flood damage. J Environ Dev 20(2):167–190. https://doi.org/10.1177/1070496511408401
Dasgupta S, Huq M, Khan ZH, Ahmed MMZ, Mukherjee N, Khan MF, Pandey K (2014) Cyclones in a changing climate: the case of Bangladesh. Clim Dev 6(2):96–110. https://doi.org/10.1080/17565529.2013.868335
Dastagir MR (2015) Modeling recent climate change induced extreme events in Bangladesh: a review. Weather Clim Extrem 7:49–60. https://doi.org/10.1016/j.wace.2014.10.003
Deb JC, Rahman HMT, Roy A (2016) Freshwater swamp forest trees of Bangladesh face extinction risk from climate change. Wetlands 36:323–334. https://doi.org/10.1007/s13157-016-0741-z
Denscombe M (2008) Communities of practice: a research paradigm for the mixed methods approach. J Mix Methods Res 2(3):270–283. https://doi.org/10.1177/1558689808316807
Devine-Wright P (2013) Think global, act local? The relevance of place attachments and place identities in a climate changed world. Glob Environ Chang 23(1):61–69. https://doi.org/10.1016/j.gloenvcha.2012.08.003
Dilling L (2007) Towards science in support of decision making: characterizing the supply of carbon cycle science. Environ Sci Pol 10(1):48–61. https://doi.org/10.1016/j.envsci.2006.10.008
Dilling L, Lemos MC (2011) Creating usable science: opportunities and constraints for climate knowledge use and their implications for science policy. Glob Environ Chang 21(2):680–689. https://doi.org/10.1016/j.gloenvcha.2010.11.006
Etzold B, Ahmed AU, Hassan SR, Neelormi S (2014) Clouds gather in the sky, but no rain falls. Vulnerability to rainfall variability and food insecurity in Northern Bangladesh and its effects on migration. Clim Dev 6(1):18–27. https://doi.org/10.1080/17565529.2013.833078
Fabrigar LR, Wegener DT (2011) Exploratory factor analysis. Oxford University Press, New York. https://doi.org/10.1093/acprof:osobl/9780199734177.001.0001
Faisal IM, Parveen S (2004) Food security in the face of climate change, population growth, and resource constraints: implications for Bangladesh. Environ Manag 34(4):487–498. https://doi.org/10.1007/s00267-003-3066-7
Fankhauser S, Burton I (2011) Spending adaptation money wisely. Clim Pol 11(3):1037–1049. https://doi.org/10.1080/14693062.2011.582389
Ford JD, King D (2015) A framework for examining adaptation readiness. Mitig Adapt Strateg Glob Chang 20(4):505–526. https://doi.org/10.1007/s11027-013-9505-8
Ford JD, Pearce T (2010) What we know, do not know, and need to know about climate change vulnerability in the western Canadian Arctic: a systematic literature review. Environ Res Lett 5(1):014008. https://doi.org/10.1088/1748-9326/5/1/014008
Ford JD, Pearce T (2012) Climate change vulnerability and adaptation research focusing on the Inuit subsistence sector in Canada: directions for future research. Can Geogr 56(2):275–287. https://doi.org/10.1111/j.1541-0064.2012.00418.x
Ford JD, Berrang-Ford L, King M, Frugal C (2010a) Vulnerability of aboriginal health systems in Canada to climate change. Glob Environ Chang 20(4):668–680. https://doi.org/10.1016/j.gloenvcha.2010.05.003
Ford JD, Keskitalo ECH, Smith T, Pearce T, Berrang-Ford L, Duerden F, Smit B (2010b) Case study and analogue methodologies in climate change vulnerability research. Wiley Interdiscip Rev Clim Chang 1(3):374–392. https://doi.org/10.1002/wcc.48
Ford JD, Berrang-Ford L, Paterson J (2011) Are we adapting to climate change? Glob Environ Chang 21(1):25–33. https://doi.org/10.1016/j.gloenvcha.2010.09.012
Ford JD, Bolton KC, Shirley J, Pearce T, Tremblay M, Westlake M (2012) Research on the human dimensions of climate change in Nunavut, Nunavik, and Nunatsiavut: a literature review and gap analysis. Arctic 65(3):289–304 http://www.jstor.org/stable/41758936. Accessed 15 May 2015
Ford JD, Knight M, Pearce T (2013) Assessing the "usability" of climate change research for decision-making: a case study of the Canadian international polar year. Glob Environ Chang 23(5):1317–1326. https://doi.org/10.1016/j.gloenvcha.2013.06.001
Ford JD, McDowell G, Jones J (2014) The state of climate change adaptation in the Arctic. Environ Res Lett 9(10):104005. https://doi.org/10.1088/1748-9326/9/10/104005
Ford JD, Berrang-Ford L, Bunce A, McKay IM, Pearce T (2015) The status of climate change adaptation in Africa and Asia. Reg Environ Chang 15(5):801–814. https://doi.org/10.1007/s10113-014-0648-2
Füssel HM (2007) Adaptation planning for climate change: concepts, assessment approaches, and key lessons. Sustain Sci 2(2):265–275. https://doi.org/10.1007/s11625-007-0032-y
Füssel H, Klein RJT (2004) Climate change vulnerability assessments: an evolution of conceptual thinking. Clim Chang 75(3):301–329. https://doi.org/10.1007/s10584-006-0329-3
Gain AK, Hoque MM (2013) Flood risk assessment and its application in the eastern part of Dhaka City, Bangladesh. J Flood Risk Manag 6(3):219–228. https://doi.org/10.1111/jfr3.12003
Gain AK, Wada Y (2014) Assessment of future water scarcity at different spatial and temporal scales of the Brahmaputra River Basin. Water Resour Manag 28(4):999–1012. https://doi.org/10.1007/s11269-014-0530-5
Gain AK, Immerzeel WW, Weiland FCS, Bierkens MFP (2011) Impact of climate change on the stream flow of the lower Brahmaputra: trends in high and low flows based on discharge-weighted ensemble modelling. Hydrol Earth Syst Sci 15(5):1537–1545. https://doi.org/10.5194/hess-15-1537-2011
Gain AK, Apel H, Renaud FG, Giupponi C (2013) Thresholds of hydrologic flow regime of a river and investigation of climate change impact—the case of the lower Brahmaputra river basin. Clim Chang 120:463–475. https://doi.org/10.1007/s10584-013-0800-x
Gallopín GC (2006) Linkages between vulnerability, resilience, and adaptive capacity. Glob Environ Chang 16(3):293–303. https://doi.org/10.1016/j.gloenvcha.2006.02.004
Gerring J (2004) What is a case study and what is it good for? Am Polit Sci Rev 98(02):341–354. https://doi.org/10.1017/S0003055404001182
Gibson CC, Ostrom E, Ahn TK (2000) The concept of scale and the human dimensions of global change: a survey. Ecol Econ 32(2):217–239. https://doi.org/10.1016/S0921-8009(99)00092-0
Gray CL, Mueller V (2012) Natural disasters and population mobility in Bangladesh. Proc Natl Acad Sci 109(16):6000–6005. https://doi.org/10.1073/pnas.1115944109
Green S, Higgins JPT (2011) Preparing a Cochrane review. In: Higgins JPT, Greenm S (eds) Cochrane handbook for systematic reviews of interventions: Cochrane book series. John Willey and Sons, Sussex, pp 11–29. https://doi.org/10.1002/9780470712184

Green S, Higgins JPT, Alderson P, Clarke M, Mulrow CD, Oxman AD (2011) Introduction. In: Higgins JPT, Greenm S (eds) Cochrane handbook for systematic reviews of interventions: Cochrane book series. John Willey and Sons, Sussex, pp 3–9. https://doi.org/10.1002/9780470712184

Haarstad H (2014) Climate Change, Environmental Governance and the Scale Problem: The Scale Problem. Geogr Compass 8:87–97. https://doi.org/10.1111/gec3.12111

Habiba U, Shaw R, Takeuchi Y (2014) Farmers' adaptive practices for drought risk reduction in the northwest region of Bangladesh. Nat Hazards 72:337–359. https://doi.org/10.1007/s11069-013-1011-5

Harrison PA, Holman IP, Cojocaru G, Kok K, Kontogianni A, Metzger MJ, Gramberger M (2013) Combining qualitative and quantitative understanding for exploring cross-sectoral climate change impacts, adaptation and vulnerability in Europe. Reg Environ Chang 13(4): 761–780. https://doi.org/10.1007/s10113-012-0361-y

Hassani-Mahmooei B, Parris BW (2012) Climate change and internal migration patterns in Bangladesh: an agent-based model. Environ Dev Econ 17(06):763–780. https://doi.org/10.1017/S1355770X12000290

Hinkel J (2011) "Indicators of vulnerability and adaptive capacity": towards a clarification of the science–policy interface. Glob Environ Chang 21:198–208. https://doi.org/10.1016/j.gloenvcha.2010.08.002

Hossain MN, Chowdhury S, Paul SK (2016) Farmer-level adaptation to climate change and agricultural drought: empirical evidences from the Barind region of Bangladesh. Nat Hazards 83:1007–1026. https://doi.org/10.1007/s11069-016-2360-7

Hossain MS, Dearing JA, Eigenbrod F, Johnson FA (2017) Operationalizing safe operating space for regional social-ecological systems. Sci Total Environ 584-585:673–682. https://doi.org/10.1016/j.scitotenv.2017.01.095

Huq S (2011) Lessons of climate change, stories of solutions: Bangladesh: adaptation. Bull At Sci 67(1):56–59. https://doi.org/10.1177/0096340210393925

Huq S, Khan MR (2006) Equity in National Adaptation Programs of Action (NAPAs): the case study of Bangladesh. In: Adger WN, Paavola J, Huq S, Mace MJ (eds) Fairness in adaptation to climate change. The MIT Press, Cambridge, pp 181–200

Huq S, Rabbani G (2011) Climate change and Bangladesh: policy and institutional development to reduce vulnerability. J Ban Stud 13:1–10. https://www.researchgate.net/profile/Rabbani/publication/251571877_Climate_Change_and_Bangladesh_Policy_and_Institutional_Development_to_reduce_vulnerability/links/0046351f0fc3387310000000/Climate-Change-and-Bangladesh-Policy-and-Institutional-Development-to-reduce-vulnerability.pdf. Accessed 15 May 2015

IPCC (2012) Managing the risks of extreme events and disasters to advance climate change adaptation. Cambridge University Press, Cambridge, New York https://www.ipcc.ch/pdf/special-reports/srex/SREX_Full_Report.pdf. Accessed 15 May 2015

IPCC (2014) Climate change 2014: impacts, adaptation, and vulnerability. Part A: global and sectoral aspects. Cambridge University Press, Cambridge http://www.ipcc.ch/report/ar5/wg2/. Accessed 16 May 2015

Islam SMF (2011) Decision support system for ex ante cost-benefit assessment of new agro-technology in the context of climate change. Int J Sustain Soc 3(1):82–106. https://doi.org/10.1504/IJSSoc.2011.038479

Islam M, Sallu S, Hubacek K, Paavola J (2014) Migrating to tackle climate variability and change? Insights from coastal fishing communities in Bangladesh. Clim Chang 124(4):733–746. https://doi.org/10.1007/s10584-014-1135-y

Jabeen H, Guy S (2015) Fluid engagements: responding to the co-evolution of poverty and climate change in Dhaka, Bangladesh. Habit Int 47:307–314. https://doi.org/10.1016/j.habitatint.2015.02.005

Jabeen H, Johnson C, Allen A (2010) Built-in resilience: learning from grassroots coping strategies for climate variability. Environ Urban 22(2):415–431. https://doi.org/10.1177/0956247810379937

Juhola S, Westerhoff L (2011) Challenges of adaptation to climate change across multiple scales: a case study of network governance in two European countries. Environ Sci Pol 14(3):239–247. https://doi.org/10.1016/j.envsci.2010.12.006

Kabir MJ, Alauddin M, Crimp S (2017) Farm-level adaptation to climate change in Western Bangladesh: an analysis of adaptation dynamics, profitability and risks. Land Use Policy 64:212–224. https://doi.org/10.1016/j.landusepol.2017.02.026

Kamata A, Bauer DJ (2008) A note on the relation between factor analytic and item response theory models. Struc Equ Model 15:136–153. https://doi.org/10.1080/10705510701758406

Karim M, Mimura N (2008) Impacts of climate change and sea-level rise on cyclonic storm surge floods in Bangladesh. Glob Environ Chang 18(3):490–500. https://doi.org/10.1016/j.gloenvcha.2008.05.002

Karim Z, Hussain SG, Ahmed M (1996) Assessing impacts of climatic variations on food grain production in Bangladesh. Water Air Soil Pollut 92(1–2):53–62. https://doi.org/10.1007/BF00175552

Kartiki K (2011) Climate change and migration: a case study from rural Bangladesh. Gend Dev 19:23–38. https://doi.org/10.1080/13552074.2011.554017

Kelly PM, Adger WN (2000) Theory and practice in assessing vulnerability to climate change and facilitating adaptation. Clim Chang 47: 325–352. https://doi.org/10.1023/A:1005627828199

Khan TMA, Singh OP, Rahman MS (2000) Recent sea level and sea surface temperature trends along the Bangladesh coast in relation to the frequency of intense cyclones. Mar Geod 23(2):103–116. https://doi.org/10.1080/01490410050030670

Khan AE, Ireson A, Kovats S, Mojumder SK, Khusru A, Rahman A, Vineis P (2011a) Drinking water salinity and maternal health in coastal Bangladesh: implications of climate change. Environ Health Perspect 119:1328–1332. https://doi.org/10.1289/ehp.1002804

Khan AE, Xun WW, Ahsan H, Vineis P (2011b) Climate change, sea-level rise, and health impacts in Bangladesh. Environ Sci Policy Sustain Dev 53(5):37–41. https://doi.org/10.1080/00139157.2011.604008

Khan MMH, Gruebner O, Kraemer A (2014) Is area affected by flood or stagnant water independently associated with poorer health outcomes in urban slums of Dhaka and adjacent rural areas? Nat Hazards 70(1): 549–565. https://doi.org/10.1007/s11069-013-0829-1

Kumar D, Arya DS, Murumkar AR, Rahman MM (2014) Impact of climate change on rainfall in Northwestern Bangladesh using multi-GCM ensembles. Int J Climatol 34(5):1395–1404. https://doi.org/10.1002/joc.3770

Lalor BM, Hickey GM (2014) Strengthening the role of science in the environmental decision-making processes of executive government. Organ Environ 27(2):161–180. https://doi.org/10.1177/1086026614525641

Lara RJ, Neogi SB, Islam MS, Mahmud ZH, Yamasaki S, Nair GB (2009) Influence of catastrophic climatic events and human waste on Vibrio distribution in the Karnaphuli estuary, Bangladesh. EcoHealth 6(2):279–286. https://doi.org/10.1007/s10393-009-0257-6

Lavell A, Oppenheimer M, Diop C, Hess J, Lempert R, Li J et. al., (2012) Climate change: new dimensions in disaster risk, exposure, vulnerability, and resilience. In: Field CB, Barros V, Stocker TF, Qin D, Dokken DJ, Ebi KL et. al., (eds) Managing the risks of extreme events and disasters to advance climate change adaptation A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change (IPCC). Cambridge University Press, Cambridge, pp. 25–64

Lee HS (2013) Estimation of extreme sea levels along the Bangladesh coast due to storm surge and sea level rise using EEMD and EVA. J Geophys Res Ocean 118(9):4273–4285. https://doi.org/10.1002/jgrc.20310

Lemos MC, Morehouse BJ (2005) The co-production of science and policy in integrated climate assessments. Glob Environ Chang 15(1):57–68. https://doi.org/10.1016/j.gloenvcha.2004.09.004

Lemos MC, Kirchhoff CJ, Ramprasad V (2012) Narrowing the climate information usability gap. Nat Clim Chang 2(11):789–794. https://doi.org/10.1038/nclimate1614

Lorenz S, Berman R, Dixon J, Lebel S (2014) Time for a systematic review: a response to Bassett and Fogelman's "Déjà vu or something new? The adaptation concept in the climate change literature". Geoforum 51:252–255. https://doi.org/10.1016/j.geoforum.2013.10.003

Mahmood R (1997) Impacts of air temperature variations on the boro rice phenology in Bangladesh: implications for irrigation requirements. Agric For Meteorol 84:233–247. https://doi.org/10.1016/S0168-1923(96)02360-X

Mahmood R (1998) Air temperature variations and rice productivity in Bangladesh: a comparative study of the performance of the YIELD and the CERES-Rice models. Ecol Model 106:201–212. https://doi.org/10.1016/S0304-3800(97)00192-0

Mahmood R, Meo M, Legates DR, Morrissey ML (2003) The CERES-rice model-based estimates of potential monsoon season rainfed rice productivity in Bangladesh. Prof Geogr 55(2):259–273. https://doi.org/10.1111/0033-0124.5502013

Mahmood R, Legates DR, Meo M (2004) The role of soil water availability in potential rainfed rice productivity in Bangladesh: applications of the CERES-Rice model. Appl Geogr 24(2):139–159. https://doi.org/10.1016/j.apgeog.2004.03.001

Mallick B, Rahaman KR, Vogt J (2011) Coastal livelihood and physical infrastructure in Bangladesh after cyclone Aila. Mitig Adapt Strateg Glob Chang 16(6):629–648. https://doi.org/10.1007/s11027-011-9285-y

Maniruzzaman M, Talukder MSU, Khan MH, Biswas JC, Nemes A (2015) Validation of the AquaCrop model for irrigated rice production under varied water regimes in Bangladesh. Agric Water Manag 159:331–340. https://doi.org/10.1016/j.agwat.2015.06.022

Martin M, Billah M, Siddiqui T, Abrar C, Black R, Kniveton D (2014) Climate-related migration in rural Bangladesh: a behavioural model. Popul Environ 36(1):85–110. https://doi.org/10.1007/s11111-014-0207-2

Masood M, Takeuchi K (2016) Climate change impacts and its implications on future water resource management in the Meghna Basin. Futures 78-79:1–18. https://doi.org/10.1016/j.futures.2016.03.001

Mastrandrea MD, Heller NE, Root TL, Schneider SH (2010) Bridging the gap: linking climate-impacts research with adaptation planning and management. Clim Chang 100(1):87–101. https://doi.org/10.1007/s10584-010-9827-4

Matsuda F, Ishimura S, Wagatsuma Y, Higashi T, Hayashi T, Faruque ASG, Sack DA, Nishibuchi M (2008) Prediction of epidemic cholera due to Vibrio cholera O1 in children younger than 10 years using climate data in Bangladesh. Epidemiol Infect 136(1):73–79. https://doi.org/10.1017/S0950268807008175

McDowell G, Stephenson E, Ford J (2014) Adaptation to climate change in glaciated mountain regions. Clim Chang 126(1–2):77–91. https://doi.org/10.1007/s10584-014-1215-z

Mcdowell G, Ford J, Jones J (2016) Community-level climate change vulnerability research: trends, progress, and future directions. Environ Res Lett 11(3):033001. https://doi.org/10.1088/1748-9326/11/3/033001

McNie EC (2007) Reconciling the supply of scientific information with user demands: an analysis of the problem and review of the literature. Environ Sci Pol 10(1):17–38. https://doi.org/10.1016/j.envsci.2006.10.004

Mirza MMQ (2002) Global warming and changes in the probability of occurrence of floods in Bangladesh and implications. Glob Environ Chang 12(2):127–138. https://doi.org/10.1016/S0959-3780(02)00002-X

Mirza MMQ (2003) Climate change and extreme weather events: can developing countries adapt? Clim Pol 3(3):233–248. https://doi.org/10.1016/S1469-3062(03)00052-4

Mirza MMQ, Warrick RA, Ericksen NJ (2003) The implications of climate change on floods of the Ganges, Brahmaputra and Meghna rivers in Bangladesh. Clim Chang 57(3): 287–318. https://doi.org/10.1023/A:1022825915791

Molla NA, Mollah KA, Fungladda W, Ramasoot P (2014) Multidisciplinary household environmental factors: influence on DALYs lost in climate refugees community. Environ Dev 9:1–11. https://doi.org/10.1016/j.envdev.2013.09.006

Moser SC (2010) Now more than ever: the need for more societally relevant research on vulnerability and adaptation to climate change. Appl Geogr 30(4):464–474. https://doi.org/10.1016/j.apgeog.2009.09.003

Mottaleb KA, Mohanty S, Hoang HTK, Rejesus RM (2013) The effects of natural disasters on farm household income and expenditures: a study on rice farmers in Bangladesh. Agric Syst 121:43–52. https://doi.org/10.1016/j.agsy.2013.06.003

Mulrow CD (1994) Rationale for systematic reviews. BMJ 309(6954): 597–599 https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2541393/pdf/bmj00455-0051.pdf. Accessed 18 May 2015

Mynett AE, Vojinovic Z (2009) Hydroinformatics in multi-colours—part red: urban flood and disaster management. J Hydroinf 11:166–180. https://doi.org/10.2166/hydro.2009.027

Nahar N, Blomstedt Y, Wu B, Kandarina I, Trisnantoro L, Kinsman J (2014) Increasing the provision of mental health care for vulnerable, disaster-affected people in Bangladesh. BMC Public Health 14(1): 708. https://doi.org/10.1186/1471-2458-14-708

NAPA (2005) National adaptation program of action. Ministry of Environment and Forest. Government of the People's Republic of Bangladesh, Dhaka https://unfccc.int/resource/docs/napa/ban01.pdf. Accessed 18 May 2015

Nelson DI (2003) Health impact assessment of climate change in Bangladesh. Environ Impact Assess Rev 23(3):323–341. https://doi.org/10.1016/S0195-9255(02)00102-6

Nelson DR, Adger WN, Brown K (2007) Adaptation to environmental change: contributions of a resilience framework. Annu Rev Environ Resour 32(1):395–419. https://doi.org/10.1146/annurev.energy.32.051807.090348

Nowreen S, Murshed SB, Islam AKMS, Bhaskaran B, Hasan MA (2014) Changes of rainfall extremes around the haor basin areas of Bangladesh using multi-member ensemble RCM. Theor Appl Climatol 119(1–2):363–377. https://doi.org/10.1007/s00704-014-1101-7

Nury AH, Hasan K, Alam MAB (2017) Comparative study of wavelet-ARIMA and wavelet-ANN models for temperature time series data in northeastern Bangladesh. J King Saudi Uni – Sci 29:47–61. https://doi.org/10.1016/j.jksus.2015.12.002

O'Brien KL, Leichenko RM (2000) Double exposure: assessing the impacts of climate change within the context of economic globalization. Glob Environ Chang 10:221–232. https://doi.org/10.1016/S0959-3780(00)00021-2

O'Brien KL, Leichenko R, Kelkar U, Venema H, Aandahl G, Tompkins H, Javed A, Bhadwal S, Barg S, Nygaard L, West J (2004) Mapping vulnerability to multiple stressors: climate change and globalization in India. Glob Environ Chang 14:303–313. https://doi.org/10.1016/j.gloenvcha.2004.01.001

O'Brien K, Eriksen S, Nygaard LP, Schjolden A (2007) Why different interpretations of vulnerability matter in climate change discourses. Clim Pol 7(1):73–88. https://doi.org/10.1080/14693062.2007.9685639

Ohtomo K, Kobayashi N, Sumi A, Ohtomo N (2010) Relationship of cholera incidence to El Niño and solar activity elucidated by time-series analysis. Epidemiol Infect 138(1):99–107. https://doi.org/10.1017/S0950268809990203

Ortiz CAC (1994) Sea-level rise and its impact on Bangladesh. Ocean Coast Manag 23(3):249–270. https://doi.org/10.1016/0964-5691(94)90022-1

Osbahr H, Twyman C, Adger WN, Thomas DSG (2008) Effective livelihood adaptation to climate change disturbance: scale dimensions of practice in Mozambique. Geoforum 39(6):1951–1964. https://doi.org/10.1016/j.geoforum.2008.07.010

Paprocki K, Huq S (2017) Shrimp and coastal adaptation: on the politics of climate justice. Clim Dev 0:1–3. https://doi.org/10.1080/17565529.2017.1301871

Parry M (2007) Viewpoint climate change: where should our research priorities be? Glob Environ Chang 11(2001):257–260. https://doi.org/10.1016/S0959-3780(01)00012-7

Patwardhan A, Downing T, Leary N, Wilbanks T (2009) Towards an integrated agenda for adaptation research: theory, practice and policy. Strategy paper. Curr Opin Environ Sustain 1(2):219–225. https://doi.org/10.1016/j.cosust.2009.10.010

Pavel MAA, Chowdhury MA, Mamun MAA (2014) Economic evaluation of floating gardening as a means of adapting to climate change in Bangladesh. Int J Environ Stud 71(3):261–269. https://doi.org/10.1080/00207233.2014.911406

Petticrew M (2003) Why certain systematic reviews reach uncertain conclusions. BMJ 326(7392):756–758. https://doi.org/10.1136/bmj.326.7392.756

Polsky C, Neff R, Yarnal B (2007) Building comparable global change vulnerability assessments: the vulnerability scoping diagram. Glob Environ Chang 17:472–485. https://doi.org/10.1016/j.gloenvcha.2007.01.005

Pouliotte J, Smit B, Westerhoff L (2009) Adaptation and development: livelihoods and climate change in Subarnabad, Bangladesh. Clim Dev 1(1):31–46. https://doi.org/10.3763/cdev.2009.0001

Prasanna V, Subere J, Das DK, Govindarajan S, Yasunari T (2014) Development of daily gridded rainfall dataset over the Ganga, Brahmaputra and Meghna river basins. Meteorol Appl 21(2):278–293. https://doi.org/10.1002/met.1327

Rahman A (2008) Climate change and its impact on health in Bangladesh. Forum Am Bar Assoc 12(1):16–26 http://ngof.org/wdb_new/sites/default/files/Climate%20change%20and%20its%20Impact%20on%20Health%20in%20Bangladesh.pdf. Accessed 18 November 2015

Rahman MM, Rafiuddin M, Alam MM, Kusunoki S, Kitoh A, Giorgi F (2013) Summer monsoon rainfall scenario over Bangladesh using a high-resolution AGCM. Nat Hazards 69(1):793–807. https://doi.org/10.1007/s11069-013-0734-7

Rahman HMT, Hickey GM, Sarker SK (2015) Examining the role of social capital in community collective action for sustainable wetland fisheries in Bangladesh. Wetlands 35(3):487–499. https://doi.org/10.1007/s13157-015-0635-5

Rahman M, Islam R, Islam M (2017) Long-term growth decline in Toona ciliata in a moist tropical forest in Bangladesh: impact of global warming. Acta Oecol 80:8–17. https://doi.org/10.1016/j.actao.2017.02.004

Rodima-Taylor D, Olwig MF, Chhetri N (2012) Adaptation as innovation, innovation as adaptation: an institutional approach to climate change. Appl Geogr 33(1):107–111. https://doi.org/10.1016/j.apgeog.2011.10.011

Rotberg FJY (2013) Social networks, brokers and climate change adaptation: a Bangladeshi case. J Int Dev 25:599–608. https://doi.org/10.1002/jid.2857

Salmond SW, Holly C (2012) Systematic review as the basis for evidence-based practice. In: Holly C, Salmond SW, Saimbert M (eds) Comprehensive systematic review for advanced nursing practice. Springer, New York, pp 3–12

Sarker MAR, Alam K, Gow J (2012) Exploring the relationship between climate change and rice yield in Bangladesh: an analysis of time series data. Agric Syst 112:11–16. https://doi.org/10.1016/j.agsy.2012.06.004

Sarker MAR, Alam K, Gow J (2013) How does the variability in aus rice yield respond to climate variables in Bangladesh? J Agron Crop Sci 199:189–194. https://doi.org/10.1111/jac.12011

Sarwar MGM, Woodroffe CD (2013) Rates of shoreline change along the coast of Bangladesh. J Coast Conserv 17(3):515–526. https://doi.org/10.1007/s11852-013-0251-6

Seneviratne SI, Nicholls N, Easterling D, Goodess CM, Kanae S, Kossin J et. al.,(2012) Changes in climate extremes and their impacts on the natural physical environment. In: Field CB, Barros V, Stocker TF, Qin D, Dokken DJ, Ebi KL et. al (eds) Managing the risks of extreme events and disasters to advance climate change adaptation. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change (IPCC). Cambridge University Press, Cambridge, pp. 109–230

Scoones I (1998) Sustainable rural livelihoods: A framework for analysis. IDS Work Paper 72, IDS, Brighton. https://opendocs.ids.ac.uk/opendocs/bitstream/handle/123456789/3390/Wp72.pdf?sequence=1. Accessed 25 January 2015

Shahid S (2010a) Rainfall variability and the trends of wet and dry periods in Bangladesh. Int J Climatol 30(15):2299–2313. https://doi.org/10.1002/joc.2053

Shahid S (2010b) Probable impacts of climate change on public health in Bangladesh. Asia-Pac J Public Health 22(3):310–319. https://doi.org/10.1177/1010539509335499

Shahid S (2011a) Impact of climate change on irrigation water demand of dry season Boro rice in northwest Bangladesh. Clim Chang 105(3–4):433–453. https://doi.org/10.1007/s10584-010-9895-5

Shahid S (2011b) Trends in extreme rainfall events of Bangladesh. Theor Appl Climatol 104:489–499. https://doi.org/10.1007/s00704-010-0363-y

Simelton E, Fraser EDG, Termansen M, Forster PM, Dougill AJ (2009) Typologies of crop-drought vulnerability: an empirical analysis of the socio-economic factors that influence the sensitivity and resilience to drought of three major food crops in China (1961-2001). Environ Sci Policy 12:438–452. https://doi.org/10.1016/j.envsci.2008.11.005.

Smit B, Wandel J (2006) Adaptation, adaptive capacity and vulnerability. Glob Environ Chang 16(3):282–292. https://doi.org/10.1016/j.gloenvcha.2006.03.008

Sohel SI, Akhter S, Ullah H, Haque E, Rana P (2017) Predicting impacts of climate change on forest tree species of Bangladesh: evidence from threatened Dysoxylum binectariferum (Roxb.) Hook.f. ex Bedd. (Meliaceae). IForest 10:154–160. https://doi.org/10.3832/ifor1608-009

Sullivan CA (2011) Quantifying water vulnerability: a multi-dimensional approach. Stoch Environ Res Risk Assess 25:627. https://doi.org/10.1007/s00477-010-0426-8

Sultana F (2010) Living in hazardous waterscapes: gendered vulnerabilities and experiences of floods and disasters. Environ Hazards 9(1):43–53. https://doi.org/10.3763/ehaz.2010.SI02

Taasoobshirazi G, Wang S (2016) The Performance of the SRMR, RMSEA, CFI, AND TLI: an examination of sample size, path size, and degrees of freedom. J Appl Quant Methods 11(3):31–39 http://www.jaqm.ro/issues/volume-11,issue-3/pdfs/2_GI_SH_.pdf. Accessed 18 May 2017

Temby O, Sandall J, Cooksey R, Hickey GM (2017) Examining the role of trust and informal communication on mutual learning in government: the case of climate change adaptation in New York. Organ Environ 30(1):71–97. https://doi.org/10.1177/1086026616633254

Thurlow J, Dorosh P, Yu W (2012) A stochastic simulation approach to estimating the economic impacts of climate change in Bangladesh. Rev Dev Econ 16(3):412–428. https://doi.org/10.1111/j.1467-9361.2012.00671.x

Tinsley HE, Tinsley DJ (1987) Uses of factor analysis in counseling psychology research. J Couns Psychol 34(4):414–424. https://doi.org/10.1037/0022-0167.34.4.414

Tompkins EL, Adger WN, Boyd E, Nicholson-Cole S, Weatherhead K, Arnell N (2010) Observed adaptation to climate change: UK evidence of transition to a well-adapting society. Glob Environ Chang 20(4):627–635. https://doi.org/10.1016/j.gloenvcha.2010.05.001

Turner BL, Kasperson RE, Matson PA, McCarthy JJ, Corell RW, Christensen L, Eckley N, Kasperson JX, Luers A, Martello ML, Polsky C, Pulsipher A, Schiller A (2003) A framework for vulnerability analysis in sustainability science. Proc Natl Acad Sci 100(14):8074–8079. https://doi.org/10.1073/pnas.1231335100

Urwin K, Jordan A (2008) Does public policy support or undermine climate change adaptation? Exploring policy interplay across different scales of governance. Glob Environ Chang 18(1):180–191. https://doi.org/10.1016/j.gloenvcha.2007.08.002

Wilbanks TJ, Kates RW (1999) Global change in local places: how scale matters. Clim Chang 43(3):601–628. https://doi.org/10.1023/A:1005418924748

Younus MAF (2015) Crop adaptation processes to extreme floods in Bangladesh: a case study. Environ Hazards 14(1):36–53. https://doi.org/10.1080/17477891.2014.986041

Younus MAF (2017) Adapting to climate change in the coastal regions of Bangladesh: proposal for the formation of community-based adaptation committees. Environ Hazards 16:21–49. https://doi.org/10.1080/17477891.2016.1211984

Younus MAF, Harvey N (2014) Economic consequences of failed autonomous adaptation to extreme floods: a case study from Bangladesh. Local Econ 29(1–2):22–37. https://doi.org/10.1177/0269094213515175