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Climate change adaptation: policy, practice and adaptation gaps in the agriculture sector in Bangladesh, India and Nepal

Shobha Shrestha, Prem Sagar Chapagain, Yili Zhang, Linshan Liu, Jianzhong Yan, Suresh Chand Rai, Md. Nurul Islam and Basanta Paudel

(Author affiliations can be found at the end of the article)

Abstract

Purpose – Various national and international policy instruments have been formulated to minimize vulnerability to climate risk at all scales, from the global to the local. However, gaps in adaptation and the adaptation process pose major impediments to the current climate change response in South Asia. This paper aims to examine climate change adaptation (CCA) policy implementation practices in Nepal, Bangladesh and India at the local level and identify adaptation gaps in the agriculture sector.

Design/methodology/approach – The study uses primary and secondary data and triangulation methods following a qualitative approach. A household survey, focus group discussion, key informant interview, policy documents and extensive literature review were conducted to examine policy and adaptation gaps.

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Findings – The study found that, despite the provision limited access to finance, knowledge various financial instruments for CCA, smallholder farmers in India have very limited access. In contrast, farmers in Bangladesh have higher access to institutions, but their willingness to participate is low and the government's delivery mechanism is poor. In Nepal, farmers face barriers to physical access and have limited financial instruments. Lack of sectoral integration, alignment on CCA targets and financing at the local level are major gaps on the policy front. Lack of understanding and awareness of CCA in a local sociocultural context among implementation authorities and weak institutional mechanisms are gaps at the institutional front. Reactive adaptation, such as increased use of chemical fertilizers and changing crop varieties without proper understanding, is a common adaptive action (inclining toward maladaptation) among farmers.

Originality/value – This paper recommends that understanding the adaptation response during policy updates and the implementation process offers insights into future anticipation and responses for successful CCA policy implementation.

Keywords Adaptation gap, Agriculture sector, Climate finance, Policy landscape, Smallholders, Risk-sharing

Paper type Research paper

1. Introduction

Climate change (CC) and variability impact agriculture, though the intensity of these impacts varies at different spatial scales. The extent of the impact is generally uncertain, although major impacts are predicted in higher altitudes and coastal areas (Adams *et al.*, 1998; Holleman *et al.*, 2020; UNEP, 2021). Climate risk involves possible adverse effects of CC on human and socio-ecological systems or the measures taken to address it (Reisinger *et al.*, 2020). An increasing trend of climate risk is reported with an increased number of events (IPCC, 2023a), making agriculture a highly vulnerable sector and smallholders the most vulnerable group.

Agriculture is the mainstay in South Asian countries, where the contribution of agriculture to GDP is 11% in Bangladesh (MoF Bangladesh, 2023), 15% in India (GoI, 2023) and 24% in Nepal (GoN, 2021a, 2021b). Rainfed agriculture accounts for 65% of agricultural livelihoods in Nepal and 56% in India, heavily relying on the monsoon (Kattel, 2022; Rani and Maheshwari, 2021). This status quo makes smallholder farmers highly vulnerable to CC risks, potentially exceeding their coping capacity with the predicted severity of future CC without effective adaptation measures (Aryal *et al.*, 2020; Devendra, 2012; IPCC, 2022). The impact of CC on the rainfed agriculture sector has been particularly intense (Habib-ur-Rahman *et al.*, 2022; Wang *et al.*, 2017). The major impacts and losses in the agriculture sector are linked to water availability and crop production, with the largest adverse impact on small-scale and low-income food farmers in developing countries (IPCC, 2023b). With the anticipated increase in climate extremes by 2050, current effective adaptation practices may become less effective, potentially reaching adaptation limits (Ming *et al.*, 2021). Evidence shows that climate-related risks and vulnerability to agriculture and food security intensify with a 1.5°C global warming scenario (Shaw *et al.*, 2022). Studies conducted in Bangladesh, India and Nepal reveal increasing impact and growing climate risk in agriculture (Daron *et al.*, 2022; Kumar *et al.*, 2020; Manjula *et al.*, 2022; Rijal *et al.*, 2022).

The vulnerability of smallholders to climate shocks and risks is primarily because of a lack of enabling policies, limited adaptive capacity and inadequate investment, all of which contribute to high vulnerability and low resilience in the local food system and livelihoods. Climate change adaptation (CCA) is defined as the "process of adjustment to actual or expected climate and its effects to moderate harm or exploit benefits" (IPCC, 2022, p. 2898). Embedded within climate policy, CCA is considered an intervention and actions tailored to

local settings in response to CC impacts at various scales (Burton *et al.*, 2006). Adaptation actions can take various forms, including changes in processes, practices, structures, or a combination of those.

The Paris Agreement mandates adaptation planning and implementation through tools such as National Adaptation Plans (NAP), vulnerability and risk assessments, monitoring and evaluation (M&E) and economic diversification for climate risk management. Though progress in preparing NAPs and related policy instruments has been optimistic, gaps in the adaptation process remain a significant impediment to the current CC response at both global and national levels, with issues related to capacity, financial support and coherence in adaptation efforts (UNEP, 2023). Furthermore, risks associated with responses to CC, such as uncertainties in CC policy implementation and climate-related investments, technology adoption or system transitions, are less featured than those related to CC impacts (Reisinger *et al.*, 2020). With the current pace of adaptation responses and varying effectiveness, the adaptation gap will likely increase, pushing toward soft and hard limits as well as maladaptation (IPCC, 2023a). Smallholders in South Asia's highly vulnerable mountain, coastal and tropical regions are already experiencing soft limits because of limited adaptive capacity and systemic constraints such as financial, governance and policy issues (IPCC, 2022).

Limited research has been conducted on adaptation policy discussions in South Asian countries (Vij *et al.*, 2018), and only a few research papers are available on how CCA plans shape on-the-ground adaptation (Ulibarri *et al.*, 2022). A substantial knowledge gap exists regarding CCA policy, planning and implementation, particularly in the adaptation knowledge gap (Arteaga *et al.*, 2023; IPCC, 2023b; Malik and Ford, 2024). Against this backdrop, this study focuses on a comparative analysis of:

- the CCA policy landscape;
- implementation practices at the local level; and
- gaps in the agriculture sector and policy implications in Nepal, Bangladesh and India.

2. Conceptual frame

Various approaches have been suggested and practiced to frame CCA policy planning and implementation, ranging from the physical system (ecosystem/nature) to human system (vulnerability and risk) based approaches (IPCC, 2022; Murieta *et al.*, 2021; Samaddar *et al.*, 2015). Adaptation policy framing is based on the duration, such as incremental, systematic and transformational (Hadarits *et al.*, 2017; Mitter *et al.*, 2018), and is characterized in terms of hazard-based, vulnerability-based, adaptive capacity and policy-based approaches (Mimura *et al.*, 2014). Spatial planning (geographic scale and agroecological zones) is also emphasized (Zong *et al.*, 2022).

Adaptation as a response to CC is a continuous process with a reciprocal relationship: change leads to a response and the response leads to further change (Campeanu and Fazey, 2014), and ranges from structural (physical/tangible) to non-structural (policy to socio-behavioral); compensatory, curative and preventive; or proactive and reactive. CCA can be actor-based (autonomous), system-based (planned adaptation), or maladaptation (unintentional adverse adaptation) (Schipper, 2022). Agricultural diversification, farm and crop management, risk management and livelihood diversification are documented key agriculture-based adaptation measures (Sarker *et al.*, 2023). Barriers and limitations to adaptation actions are associated with policy, governance, resources, information and

psycho-social aspects (Berkhout and Dow, 2023; GCA and WRI, 2019). Barriers (hindrances to planning, implementing and practicing CCA) may evolve into limitations (soft: socially determined with adaptation options, or hard: without adaptation options) or maladaptation (adverse adaptation process, malpractices) once they reach the tipping point (policy failure to meet objectives) (IPCC, 2022). Significant barriers to CCA policy implementation reflected in the literature include socio-political barriers, inadequate institutional structures/governance, inequity in power and resources, economic dependence, lack of/limited risk-sharing mechanisms (climate security) and lack of/limited access to finance, knowledge, awareness, technology and information (Biswas and Rahman, 2023; GoI, 2020; IPCC, 2022; MoEFCC, 2022). All types of barriers and limitations to CCA contribute to adaptation gaps: the difference between existing adaptation needs and efforts indicated in plans and policies, implementation practices at the ground level and adaptation potentials (IPCC, 2022; UNEP, 2023). This study is framed around the CCA concepts, approaches and measures as discussed by Berkhout and Dow (2023) and Schipper (2022).

3. Methods and materials

3.1 Study area

Bangladesh, India and Nepal lie in the Ganga-Brahmaputra Basin and have a monsoon climate. The region comprises irrigated and rainfed agriculture as well as semi-mechanized and traditional farming systems, and around 90% of farmers practice intensive subsistence agriculture (World Bank, 2021a, 2021b, 2021c). The general climate is warm and wet summers and relatively dry winters with variable temperatures. More than 80% of the rainfall occurs during the monsoon season (June to September). The sample study sites in these countries comprise sub-district-level administrative units (Figure 1).

The study area in Nepal spans three ecological regions of the Gandaki River basin, comprising 15 villages from five municipal units. These units have diverse topographies (ranging from 170 m to 2700 m) and cool to warm climates. The increasing frequency of extreme precipitation is a major climate risk in the country, followed by land degradation and soil erosion (GoN, 2021a, 2021b). The field study site in India is located in the Central-North plain region, comprising 21 villages in four Taluks (sub-district units) of the Barabanki district, Uttar Pradesh. It is highly vulnerable (VI 0.622) to mitigate risk, with a high proportion of rainfed agriculture, yield variability, a high percentage of marginal and smallholders and a low percentage of crop insurance coverage (GoI, 2020). Field study sites in Bangladesh include 11 villages in four Unions (sub-district units) of the Manikganj district, near the confluence of the Padma and Jamuna rivers. The district lies in floodplains/erosion-prone Char areas, which face prominent climate stresses such as river flooding and bank erosion, rainfall variability and extreme heat waves. It is one of the hotspot areas concerning river systems and estuaries (MoEFCC, 2022).

3.2 Data and method

This study is based on primary and secondary data and follows a qualitative approach. Country-specific CCA policies, NAPs, Nationally Determined Contributions (NDCs) and policy review documents are major documentary sources. Qualitative document analysis was carried out following Morgan's (2022) method. Primary data sources included focus group discussions (FGDs), farm household questionnaire surveys, key informant interviews (KIIs), consultations with local authorities, communities and individuals. Study results were derived by triangulating data and information collected from secondary and primary sources.

The farm household questionnaire, FGD and KII checklist covered demographic characteristics; human, natural, social and physical assets and resources situation; information, knowledge and communication level; diversity and flexibility; experienced

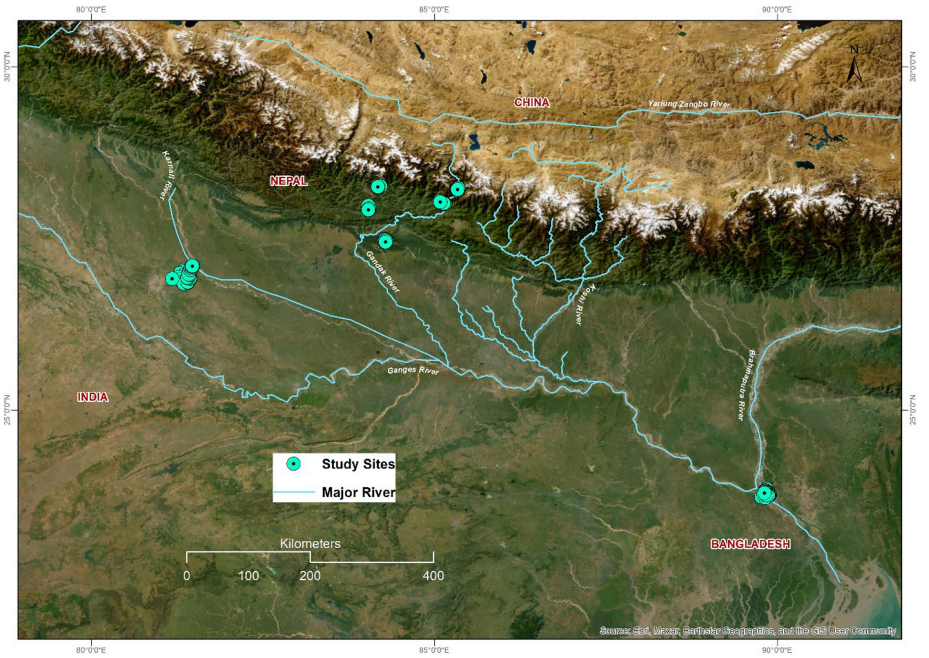

Figure 1. Location of study sites
Source(s): Esri, Maxar, Earthstar Geographics and the GIS User Community, 2025

climate variability and impact; exposure and sensitivity; and policy, institution and governance aspects. A total of 633 farm households (211 in each country) were surveyed using purposive random sampling in 47 villages. A total of nine mixed-group FGDs (three in each country), 18 KIIs (six in each country) and consultations with 15 local authorities (four in Bangladesh and India and five in Nepal) were conducted. The KIIs included elderly farmers, local leaders, user group members (female), agricultural input agents and local extension officers. The analysis of policy implementation, adaptive action and gaps at the field level is based on the components and variables detailed in Table 1.

4. Results

4.1 CCA policy landscape and pathways

The preparation and endorsement of CCA policy documents in the three countries adhered to the global CCA timeline. The CCA policy pathway of study countries follows a climate-resilient development approach, involving strategies and actions to improve livelihoods and social and economic well-being through accountable environmental management. Consequently, initial CCA policies in Bangladesh, India and Nepal were developed around the period 2008–2011 (Figure 2). Major characteristics of CCA policy instruments of the three countries are presented in the supplementary material (Table 1; see supplementary Table 1 for details).

The agricultural sector was not explicitly specified in earlier CC policy and NAP documents of Bangladesh and Nepal. India was the first to launch CC policies at sub-national

Table 1. Analysis of components and variables

Components	Variables
Climate characteristics and CC experience	Education level Experience Impact
Access/information	Weather info, agriculture market info, agriculture input info, access to financial institutions
Knowledge: policy, programs and interventions	Climate-adaptive seed varieties, CC and agriculture-related policy and legislation; local-level CC and agriculture-related policy implementation; local-level CC and agriculture-related interventions/ projects
Impact and adaptive action (past 10 years)	Technology and innovations, new crop varieties and breeds, new tools, new agriculture inputs, diversity and flexibility, changing sowing and harvesting time Switching to multiple cropping, changing fishing location and changing occupation Risk sharing: insurance, subsidy
Barriers/constraints	Physical, social and policy

Source(s): GoI (2020); MoEFCC (2022); MoFE (2021); Singh *et al.* (2020) and Stock *et al.* (2021)

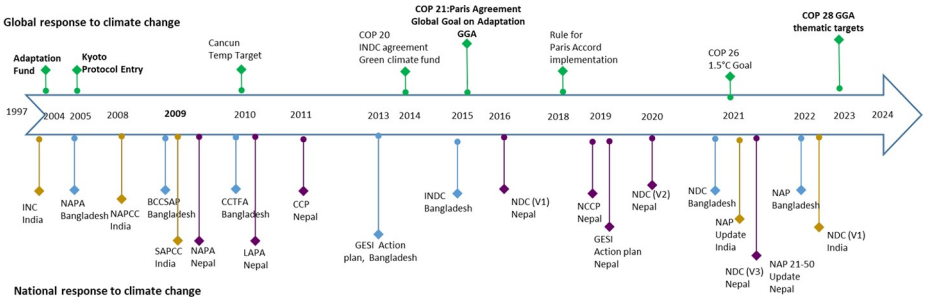

Figure 2. Evolution of the CCA policy development process
Source(s): GIZ (2019), GoI (2020), GoN (2021a) and MoEFCC (2022)

levels (2009), which were technology-focused and aimed at reducing poverty. Nepal was the first to develop a local adaptation plan of action in 2010, focusing on climate justice and livelihood improvement through an adaptation approach. Bangladesh focused on disaster risk management. These earlier policy documents lacked concrete institutional, legal and financial aspects.

A significant difference is found in the policy priorities and CCA institutional mechanisms of the study countries. Although the key focus is climate-resilient agriculture, Bangladesh (with medium priority) and India prioritize water efficiency in agriculture, whereas Nepal emphasizes reducing vulnerability and capacity building. Nepal's governance structure exhibits a stronghold of local authorities on CCA policy and related instrument development, endorsement and implementation, which is not evident in India and Bangladesh. Adaptation efforts in India are directed toward agricultural technology development and innovation, integrating technological and traditional practices while maintaining social structures. This priority on technology signifies a gradual shift from incremental to transformative adaptation. Bangladesh and Nepal

have explicitly stated transformative adaptation by focusing on climate-smart agriculture (CSA), climate services and weather information systems.

4.2 CCA practices

Planned CCA practice at the local level is limited, though it is explicitly outlined in NAPs in all three countries. Knowledge and awareness of CCA policy implementation are very low in Bangladesh, where more than 72% of farmers are unaware of local-level adaptation programs and interventions (Figure 3(a)). Awareness is highest among Indian farmers, with higher education level (with a ratio of secondary (2.47) and graduate (2.46) level farm HH in comparison to Bangladesh and Nepal). Access to weather information is reported to be highest in contrast to market access, agricultural input and financial institutions (Figure 3(b)). Farmers in Bangladesh reported relatively higher access to information and financial institutions. Nepal has lower access to markets and inputs, while Indian farmers reported low access to financial institutions.

In terms of technology use and innovation, India falls behind Nepal and Bangladesh (Figure 3(c)). Regarding awareness of crop insurance programs, 52% of farmers in India have crop insurance. In contrast, only 8% of farmers in Nepal and 3% in Bangladesh are aware of crop insurance programs, but none of them have crop insurance (Figure 3(d)). Eight percent of farmers in Nepal and India, and none in Bangladesh, are aware of livestock insurance. Farmers with health and life insurance are the highest in Nepal. Access to weather information is universal among sample farm households in all three countries. CCA policy components score (Figure 4) shows that India is ahead in five components: human and institutional capacity (with higher educational levels and appointment of human resources), mainstreaming (integrating digital tools and technology), implementation and mechanisms

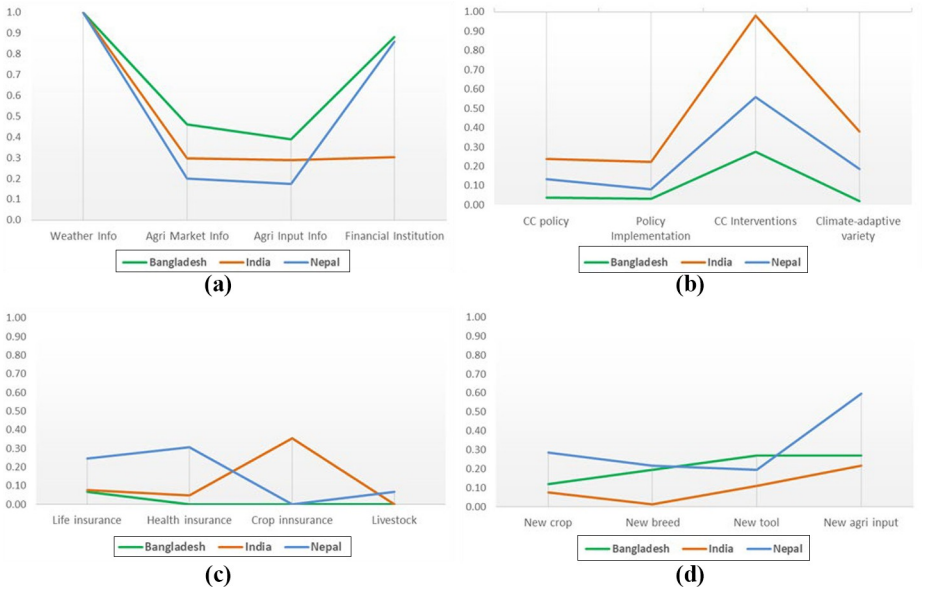

Figure 3. CCA access, knowledge and practice. (a) Knowledge and awareness; (b) access to information and institutions; (c) technology and innovation use; and (d) risk sharing

Source(s): Field survey 2022–2023

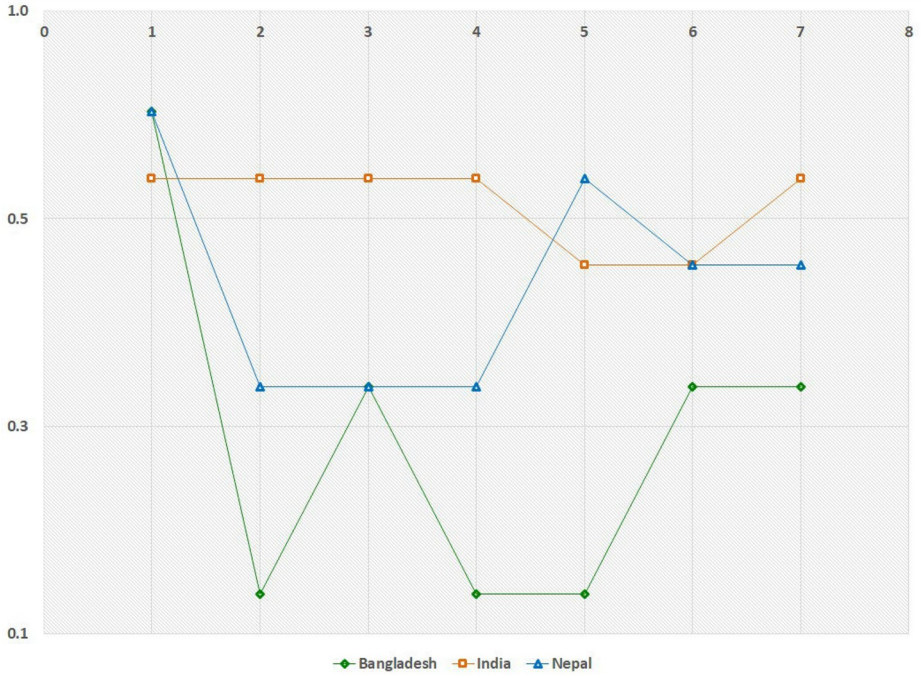

Figure 4. CCA policy component score

Note(s): 1: policy instruments; 2: human and institutional capacity; 3: mainstreaming; 4: implementation and mechanism; 5: participation and inclusion; 6: monitoring and evaluation; 7: planning/intervention at the local level

Source(s): Field survey 2022–2023 and UNEP (2022)

(with clearly defined roles and responsibilities) and interventions at a local level (with numerous farmer-centered welfare projects). However, it falls behind Nepal regarding participation and inclusion (particularly gender-responsive capacity development and interventions, community/collective agriculture and resource management). Both Nepal and Bangladesh have higher scores in terms of policy instruments (development and updates of policy, legal and regulatory frameworks).

The development and updates of policy instruments in both countries are largely driven by external funding. Bangladesh scored the lowest on human and institutional capacity (low understanding and awareness of CCA among local authorities), implementation mechanisms (limited functioning of institutions, no specific roles and responsibilities) and participation and inclusion (limited community/social organizations in collective agriculture and limited gender-based decision-making). Moreover, Nepal shows fluctuations with high scores on some components and lower on others. This exhibits context specificity and differential relationships of various instruments to CCA concerning CC experience, impact and response.

4.3 Climate change adaptation efforts and good practices

As intended by the NAP of the three countries, solar energy use for micro and small irrigation purposes (solar water pumps) is a good example of CCA adaptation and mitigation

co-benefits. Corresponding to the IPCC (2022) callout on future climate impact on water availability, water-efficient agriculture is a high priority in all three countries.

India has good provisions for financial instruments such as agricultural subsidies, cash incentives and insurance (a financial inclusion indicator of CCA). Input support policy is well practiced, under which selected crops are procured at a minimum support price by the central and state governments via local units. It includes input support for fertilizers, electricity, water/irrigation, seeds and machinery. More than two million solar pumps have been adopted as water-efficient technology (micro-irrigation schemes) (Hangzo and Samant, 2023; Mitra *et al.*, 2023) and agriculture subsidies in rainfed development areas (RAD). Similarly, loan debt waivers through the local government and smart technology support (e.g. UAVs, drones for pesticide/insecticide application and crop monitoring) to female farmers are good examples of gender-responsive adaptation. Additionally, incentives for direct seeding rice, a water-efficient technology, have been adopted by a large number of farmers in the study area. A total of 36% of farmers in the study area have adopted a crop insurance policy; under the input support scheme, 30.6% have introduced solar water pumps (as new technology adoption) and used government subsidies for major food crops.

Nepal: Financial and governance provisions for CCA exemplify institutional efforts in Nepal. Nepal is one of the first countries to adopt a budget code for CC-related program planning at the national and sub-national levels. Nepal also has a mandatory policy provision of allocating 80% of external funds to local-level CC interventions. It is found that approximately 30% of the federal government's total budget is tagged as climate-relevant, of which 5% is highly relevant and 25% is relevant. In the last seven years, the government has allocated an average of 22.5% of the development budget to climate-relevant actions (Singh *et al.*, 2020). Inclusive community participation is enabling CCA action in Nepal, where more than 60% of farmers are involved in community/social organizations and participate in collective actions. Gender-responsive regulations, such as 25%–50% tax exemptions (based on geographic location) on female land ownership registration and a 35% tax exemption for single women, are other enabling factors in CCA. Collective adaptive action, active participation in social/community organizations and a higher percentage of females in agricultural decision-making are other good examples found in the country (Figure 5(b)). At the local level, authorities in the study area allocate the highest percentage (39% of total climate financing) of the budget to the agricultural sector, particularly to agricultural

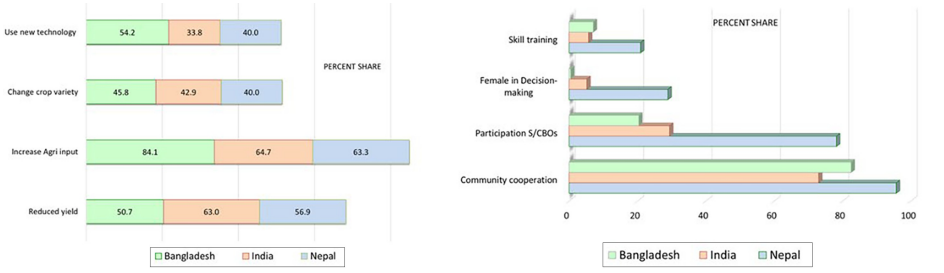

Figure 5. Adaptation measures: (a) measures adapted for reduced crop yield, and (b) participation, inclusion and capacity

Source(s): Field survey 2022–2023

mechanization, incentives, subsidy and small and micro irrigation programs, besides agricultural road construction for market access.

Bangladesh: Notable interventions in Bangladesh include internal drainage management, land reclamation for agriculture, agricultural drought and variability assessment. Access to financial institutions is very high (88.2%), including incentives for stress-tolerant varieties and no-cost agricultural inputs (quality seeds, fertilizers and insecticides) for marginal farmers. Another significant intervention is the use of indigenous knowledge and practices to improve agriculture and manage climate-induced challenges, such as floating agriculture, combining rice farming and fisheries (adopted by 68% of farmers). Other examples of reactive autonomous measures without government facilitation include raised beds and zero tillage, recharge ponds and early harvesting. Action research and field demonstrations on CSA at all governance levels are also notable CCA efforts. Regarding policy, the Bangladesh NAP highlights transboundary coordination and cooperation, joint projects on water resource management (WRM) and upstream–downstream linkages along major river basins. Of the total sampled HH, 21% have adopted stress-tolerant varieties, while 23% have used insecticides since the no-cost agricultural inputs program was launched.

5. Discussion

5.1 On barriers and adaptation gap

The emphasis of the CCA policy framework in all three countries is on building resilience in the agricultural sector; however, translating policies into action remains a major challenge. Adaptation efforts are fragmented, inadequate and unevenly distributed across sectors and regions, with less consideration of local context (UNEP, 2023). A review of 65 research studies on CCA in the agriculture sector revealed reduced crop yields and crop area, economic losses, increased labor and agriculture input costs as major negative impacts (Grigorieva *et al.*, 2023). Other studies highlight a lack of coordination among sectoral agencies, isolated CCA responsibilities, a lack of vertical integration among stakeholders and government authorities and the influence of external funding agencies (Aryal *et al.*, 2020; Stock *et al.*, 2021; Vij *et al.*, 2018). There is no standard monitoring framework at the sub-national and local levels (Ahmed and Fatema, 2023; GIZ, 2019; Singh *et al.*, 2020). Moreover, it is realized that alongside tools for monitoring the progress of CCA implementation, there is a need to identify and monitor gaps in adaptation responses to validate future adaptation interventions (Ford *et al.*, 2013; UNEP, 2023). The energy sector is not mentioned in the NAP, and the agriculture sector is absent in the NDC 2021 in Bangladesh policy documents, while there is no provision for a district-level CCA plan in India.

On the policy front, spatial planning frameworks such as vulnerability mapping at a micro level, identification of agroecological zones (AEZ), microclimatic regions and climate stress areas are emphasized for successful interventions (Vij *et al.*, 2018). However, such frameworks are identified only at the sub-national level in Bangladesh (AEZ and climate stress areas) and India (AEZ and climatic regions). In Nepal, neither climate-stress areas, microclimatic regions nor agroecological zones are defined, although the NAP has outlined CCA interventions such as crop diversification and crop varieties based on AEZ.

In Bangladesh, the highest percentage (51%) of the estimated budget is allocated for augmenting surface water for irrigation, but there is limited allocation for promoting market facilities for agricultural products (8.7%). Besides knowledge gaps and normative beliefs, as well as low interaction among stakeholders, have resulted in weak policy interactions in Bangladesh (Chowdhury *et al.*, 2022; Singh *et al.*, 2020; Uddin *et al.*, 2024). The major CCA gap in India is in institutional mechanisms regarding financial security. Despite the provision

of several CCA schemes under national and state authorities, access to finance is limited (reported at 30%) in comparison to Bangladesh and Nepal (over 80%). Of the total financial allocation, only 35% reaches the ground, and marginal farmers have very low access. Landholding size is an important criterion for receiving certain financial incentives in India (as stated in the CC sustainable agriculture program). However, such criteria, targeted to improve livelihood, have excluded poor, landless and marginal farmers.

The most common reactive adaptive action identified is the increased use of agricultural inputs, particularly fertilizer use, with more than an 80% increase (Figure 5(a)). Other adaptive actions include changing crop varieties and using new tools and technology. Participation and gender inclusion are low in Bangladesh and India, with few targeted interventions. Participation of females in agricultural decision-making is very low in Bangladesh (0.5%), and the number of farmers with skill development training is minimal in India (Figure 5(b)). In both countries, mainstreaming and gender responsiveness are not explicitly visible in CCA interventions at the ground level (Chowdhury *et al.*, 2022; Deshpande *et al.*, 2023). All these earlier findings align with the findings of this study.

5.2 On policy tools, planning and the implementation process

The change and variability in climate and resultant negative effects in the study countries are exemplified by previous studies (Aryal *et al.*, 2020; Chowdhury *et al.*, 2022; Hangzo and Samant, 2023; Sarker *et al.*, 2023; Uddin *et al.*, 2024). The negative effects of the changing climate are increasing the vulnerability of smallholders and disrupting CCA efforts locally. Poorly designed policy, planning and implementation processes can be barriers to overcoming negative CC effects, while efficient and appropriate policy instruments and effective implementation processes are enablers of CC vulnerability and risk reduction (Ulibarri *et al.*, 2022).

The social resilience to CC is associated with both objective (physical/tangible) and subjective (perception/interest/response/ability) components of CCA policy and planning. However, in most cases, technological solutions are emphasized for CCA in adjusting to climatic and biophysical conditions, but adaptation is a social process that goes beyond merely adjusting to a changing climate. The structural challenges to CCA planning and process are reflected in technological fixes without flexibility, a short-sighted understanding of adaptation, a separation between adaptation and development, the quantification of inherently qualitative contextual evidence using proxy measures to evaluate success and effectiveness and the marginalization of adaptation priorities over other planning priorities (Bertana *et al.*, 2022). Likewise, CCA policy assessment is largely confined to describing processes and accounting for outputs, with little focus on the initiatives (Murieta *et al.*, 2021). The association between policy tools, target groups and regions is well documented, highlighting their critical role in policy effectiveness and suggesting a mix of policy tools (Ulibarri *et al.*, 2022).

Capacity building can reduce vulnerability, information provision can enhance adaptive capacity and financial instruments can promote climate security and resilience. These strategies may yield co-benefits in specific contexts but could be counterproductive in others. This is evident in two cases from the study countries. First, crop insurance, which covered up to 80% of production value in Bangladesh for losses because of CC-induced disasters, was introduced in the 1980s. However, the program was terminated because of a lack of policy support and ambiguity in crop-loss estimation methods (Habiba and Shaw, 2013). Despite being indicated under NAP interventions and large-scale pilot programs by international agencies, crop insurance is non-existent for smallholders. Second, in Nepal, livestock insurance outnumbers crop insurance because of easier claim settlements, despite similar

provisions for both. Nepal's regulatory provision mandates a minimum of 5% of all other insurance to be crop-livestock and agricultural produce insurance, with a 75% subsidy on insurance premiums, validating efforts toward climate security. However, smallholders' access to subsidies and their effectiveness remain a challenge, despite the endorsement of the Subsidy Management Procedure-2019. The livestock insurance situation of Nepal mirrors that of Bangladesh. India has relatively higher crop insurance coverage (47%), but operational flaws and farmers' preference for agricultural relief and subsidies over insurance have led to partial coverage (Singh and Agrawal, 2020).

The allocation of climate finance for agriculture sector interventions is highest in Nepal and India and is substantial in Bangladesh. However, distinct climate screening and investment assessment guidelines need to be adopted. Regulatory and incentive approaches provide checks and balances, such as the "carrot" (voluntary grants for farmers) and "stick" (environmental conditionality) methods. A good example of such coherence and integration is the subsidies in India's RAD, integrated with the micro-irrigation scheme, which could be replicated in Bangladesh and Nepal.

Water shortage is predicted as a major future CC impact affecting crop production in India (IPCC, 2022). Indian agriculture is characterized by a large number of marginal and smallholders (86%) and decreasing average farm size (1.41 ha in 1996–1.08 ha in 2016). Uttar Pradesh, with 15% of the area under food crops, uses 17.4% of the total fertilizer, the highest among 36 states. However, only 5.3% of farmers hold agricultural insurance, and 7.8% hold agricultural loans (GoI, 2023). Despite the priority on solar energy missions, India still uses 8.8 million diesel pumps (Hangzo and Samant, 2023). Farmers are reluctant to use solar pumps because of uncertainty regarding technology, additional maintenance costs and belief and trust in traditional systems of money lending. This finding coincides with a present study as well as a study carried out in Nepal that highlighted challenges such as lack of price revision, poor after-sales services and unequal distribution of subsidies (Kafle *et al.*, 2022). In Bangladesh, though the dominance of the informal sector is decreasing, the problem of leakage, lengthy administrative procedures, urban bias and limited assistance is found (Alauddin and Biswas, 2014). Such a tendency of informal loans directs attention to policy considerations not only for distribution but also for orienting and educating farmers toward formal agriculture loan systems and technology adaptation, alongside capacity building. Linking information to decisions that lead to adaptive actions is a significant challenge, particularly in culturally deep-rooted traditional societies (Mimura *et al.*, 2014).

In India, despite large government investments in financial instruments, informal credit sources such as traditional moneylenders still constitute more than 30% of total agricultural loans. This can be attributed to the complex and lengthy processes and eligibility criteria required to receive government agriculture loans (Deshpande *et al.*, 2023). A study in South Asian countries shows that borrowing from informal money lenders is a common coping strategy in Bangladesh and India, while abandoning agriculture is common in Nepal (Aryal *et al.*, 2020). Diverting individual-centered subsidies to collective and agro-cooperatives is suggested to maximize benefits and optimize government investment (Gulati *et al.*, 2020). It is argued that long-term subsidies make farmers more dependent and weaken the repayment culture; hence, replacing subsidies with crop insurance is recommended as climate-secure adaptation (Singh and Agrawal, 2020).

The interdependence between the resource base (on which the farmer is dependent), the social-institutional setting (where the farmer makes decisions and acts as an individual or in a group) and the adaptive process determines the effectiveness of CCA implementation at the farm level in resource-dependent agricultural livelihoods. The CC and adaptation policy framework at the national level, particularly in developing countries in the Global South, is

largely guided and influenced by international agendas and bilateral/multilateral funding agencies. At sub-national and local levels, it is influenced by political interests, willingness and institutional knowledge and attitudes (Barnett, 2020). The measures of successful CCA hinge upon policies and programs implemented, processes embarked on, readiness to adapt and the impact of policy programs on reducing vulnerability (Ford *et al.*, 2013). The success of policy implementation and adaptation actions depends not only on awareness and capacity but also on readiness and willingness to take action from the farm-household level to national and local institutional levels. Studies show that differential policy understanding at the institutional front has resulted in different policy outputs and implementation practices at the local level (Shrestha *et al.*, 2024). Besides, successful policy implementation hinges on factors affecting the adaptive capacity of farmers, such as a lack of access to information, a lack of access to extension services, limited awareness and knowledge and limited financial options (Nguyen *et al.*, 2021).

6. Policy implications and conclusion

The Global Goal for Adaptation was defined without adaptation targets in the Paris Accord 2015 (COP 21: legally binding international treaty on climate change). However, it was only in 2021 (COP 28) that sectoral targets were set for measuring progress, but without financial targets. It is estimated that the financial requirement for future adaptation at a global level might be more than ten times the current flow (UNEP, 2023). In Bangladesh, by 2050, more than five times the current investment in CCA will be required, and the current rate of annual GDP loss of approximately 1.3% may rise to 2% by 2050 (MoEFCC, 2022; MoF Bangladesh, 2023). Nepal will have to bear the economic cost of a 2%–4% drop in GDP and US$2.4bn for adaptation by 2030 (MoFE, 2021). Similarly, India will face a 40% agriculture yield loss (GoI, 2021; IPCC, 2022; UNEP, 2023).

Sectoral integration and alignment on CCA targets and financing at the sub-national and local levels are major areas of concern in the study countries. Increasing mean annual minimum temperature and declining overall precipitation have impacted crop yield reduction, but overall crop production (particularly food crops such as rice and wheat) has increased over the years. The difference in vulnerability and sensitivity manifests in differential priority and focus in CCA policy and planning. Nepal has a high level of exposure (rainfall variability, fluctuation in winter cold days, complex topography, wild animals and soil erosion/loss), followed by Bangladesh (highest rainfall variability and rising temperature, floods and increasing drought). However, India has a higher sensitivity to CC (reduced crop yield, low level of income diversification and water insecurity). Adaptive capacity is highest in Nepal (social capital: community participation, NGOs and policy), followed by India (human, education, land and incentives) and lowest in Bangladesh (social barriers and policy practice). Agricultural infrastructure, such as mechanization and irrigation, is low in Nepal. Bangladesh's vulnerability is in terms of policy impact, particularly in subsidies and insurance. CC vulnerability and risk manifest at the local scale, and climate adaptation should be designed jointly with vulnerable communities targeting specific locations (Clarke and Murphy, 2023). Because many climate impacts are local, devolving planning and financial responsibility to those most affected, such as farmers, is critical.

This study exemplifies that, although various adaptive actions are practiced, the predominant one is increasing agricultural inputs, particularly chemical fertilizers, to boost production and crop yield despite farmers being aware of the negative consequences of overuse, such as reduced soil fertility, loss of micronutrients and water pollution (Habib-ur-Rahman *et al.*, 2022). Farmers primarily rely on vendors (private sector) or government

extension staff for agricultural inputs. Local farmers trust and follow their recommendations, making their role in CCA decisions crucial. In Bangladesh, farmers have direct access to and interaction with vendors at the community level, in contrast to extension personnel, who must cover a larger service area in all three study countries. A strategy to invest in the awareness and capacity of these vendors and extension staff on climate-smart tools, technology and inputs is thus a co-benefit, integrating local and indigenous knowledge and practices. They are familiar with local conditions and indigenous practices and could act as agents of change by promoting and supporting government CCA efforts.

The immediate CC impact will be on farmers dependent on rainfed agriculture, marginal farmers and smallholders. Techno-centric, infrastructural and managerial solutions dominate South Asian CCA, requiring large investments and longer periods to be effective at the ground level. An immediate need and effective adaptation action with smaller investments are capacity building and awareness of CCA for local-level authorities and community leaders. The effective implementation of adaptation plans, developed at the national level, often exceeds the human and resource capabilities of local governments, as well as their understanding of implementation mechanisms. A strategy of providing incentives to the community and participatory farming using government financial instruments, such as no-cost input in Bangladesh and solar pumps for irrigation in India, is hence suggested. The suggested strategy will transform the short-term reactive adaptation (sometimes maladaptation) into anticipatory (as spelled out in the government's CCA policies) and would be the effective and successful implementation of CCA at a grassroots level.

Access to climate services, such as weather information, finance and the market, is key to CCA's success in enhancing adaptive capacity. Despite government efforts, there are major adaptation gaps (though in different forms and ranges) in the study countries. The quality and reliability of services and accommodating institutional mechanisms foster the trustworthiness, acceptance and ownership of services. To improve access, coverage and quality, digital technology (e.g. internet-based mobile phone use) is very important, and the provision of e-marketing, as practiced in India and Bangladesh, is a practical intervention for the physically remote areas of Nepal. A major adaptation constraint in the case of Nepal is poor transportation and a missing market for agricultural inputs and products. Adaptation strategies such as input support policy and farm-gate purchase of agricultural products under minimum support prices implemented by India are suggested for Nepal.

A study carried out in Nepal (Joshi *et al.*, 2022) revealed that access to information and finance (e.g. agricultural loans) significantly increases the possibility of embracing adaptive actions, particularly among women farmers (7.6 times higher) compared to male farmers. Gender roles in CCA in the agriculture sector are determinants of effective adaptation practices (Deshpande *et al.*, 2023; Paudyal *et al.*, 2019). GESI reflected in NAPs must be confirmed through improved institutional implementation processes and mechanisms. More effort into social integration and inclusivity in Bangladesh and India is imperative because social structures and deep-rooted values and beliefs largely mediate responses to climatic stressors rather than biophysical changes. A participatory and inclusive approach adopted by Nepal sets an example for both countries.

Good practices of CCA are evident at the farm household and community levels from this study. Understanding the adaptation response to CC dynamics in a local sociocultural context before policy updates and during the implementation process offers insight into future anticipation and response for successful CCA policy implementation. Although there are several common barriers to CCA implementation and practices in Bangladesh, India and Nepal, the sociocultural diversity and variable climatic effects across the topography mean that CC impacts are specific and inherently uncertain. The study concludes that it is

fundamental to acknowledge good practices of autonomous adaptations where government efforts on CCA awareness, information and interventions have not penetrated or are not owned by promoting planned CCA adaptation. This will accelerate urgent adaptation needs, rectify maladaptation and narrow down the adaptation gaps.

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Author affiliations

Shobha Shrestha and Prem Sagar Chapagain, Central Department of Geography, Tribhuvan University, Kathmandu, Nepal

Yili Zhang and Linshan Liu, Institute of Geographic Sciences and Natural Resources Research (IGSNRR), Chinese Academy of Sciences (CAS), Beijing, China

Jianzhong Yan, College of Resources and Environment, Southwest University, Chongqing, China

Suresh Chand Rai, Department of Geography, Delhi School of Economics, University of Delhi, New Delhi, India

Md. Nurul Islam, Department of Geography and Environment, Jahangirnagar University, Dhaka, Bangladesh, and

Basanta Paudel, Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, Beijing, China

Supplementary material
The supplementary material for this article can be found online.

Corresponding author
Shobha Shrestha can be contacted at: shobha.shrestha@cdg.tu.edu.np