Climate Change and Water Availability in the Ganges-Brahmaputra-Meghna Basin: Impact on Local Crop Production and Policy Directives

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Abstract

Climate change is a growing food security concern for countries in the Ganges-Brahmaputra-Meghna (GBM) basin; it is expected to have a direct impact on crop yield as a result of changes in temperature, precipitation, and carbon dioxide (CO_2) concentration. Research is needed to identify the scale and distribution of the potential impacts and possible adaptation strategies to support policy development. This paper presents the results of a hydrological simulation of the components of water balance in the GBM basin in the 2050s under different climate scenarios. The impact on the yield of major crops in two representative districts in Bangladesh and Nepal was assessed using the Decision Support System for Agro-technology Transfer (DSSAT) tool with projections for future seasonal water availability, temperature, and CO_2 concentration. The results indicate that the predominance of the monsoon season in water availability will increase by the 2050s, that there will be more frequent flood events of higher magnitude, and that groundwater recharge will increase. The change in surface water availability will be more pronounced during the pre-monsoon season in Nachole, Bangladesh and during the dry season in Rasuwa, Nepal. In Nachole, yield of monsoon season rice is projected to increase and of dry season rice to decrease; maize yield in Rasuwa, Nepal is projected to decrease. Three adaptation options were tested for reducing yield loss and addressing water stress issues. The results are discussed with a view to suggesting agricultural adaptation options and supporting formulation of water resources policy.

Introduction

Climate change is a growing food security concern for countries in the Ganges-Brahmaputra-Meghna (GBM) basin due to the high rate of population growth and dependence on rainfed and surface and groundwater irrigated agriculture. Today, 60% of the cropped area is rainfed, and the rural economy hinges critically on the success of the summer monsoon. Changes in temperature, precipitation, and carbon dioxide (CO_2) concentration are expected to directly impact crop yield (Karim et al. 1998; Ahmad et al. 2000). Moreover, indirect impacts will also be felt in terms of water availability, changing status of soil moisture, incidence of pests and disease, and changing frequency of events such as drought and flood. Research is needed to assess the scale and distribution of the potential impacts and identify possible adaptation strategies as a basis for developing appropriate policies.

During the past decades, several research studies have been undertaken to identify climate- and water-related threats to agriculture in the GBM basin. Aerts et al. (2000) used the grid-based lumped hydrological water balance model STREAM (Deursen and Kwadijk 1994) to simulate the spatial distribution of water availability in the GBM region and found that the contribution of snowmelt to annual river discharge was 2.3% in the Ganges and 2.6% in the Brahmaputra. Farquharson et al. (2007) and IWFM and CEGIS (2008) used the gridded hydrological model GWAVA (Meigh et al. 1999) to simulate overland flow and accumulation under climate change scenarios; the spatial pattern of water stress did not appear to change, indicating that the current water demand is already stressful in many parts of the basin. The river discharge in the Ganges showed an increase of 6–25% by the 2050s for different climate models, while that in the Brahmaputra did not follow any specific trend.

HDR (2006) notes that most of the people living in the basin will be affected by water stress and scarcity by the 2050s. In 2010, the World Bank (Yu et al. 2010) projected a generally increasing trend in flow in the basin by the 2050s during the monsoon months (May–September) using the MIKE BASIN modelling tool. The average flow increment in August–September was about 12, 10, and 7% in the Ganges, Brahmaputra, and Meghna rivers respectively.

The impact of climate change on water availability and crop yield has been assessed by various studies. Timsina and Humphreys (2006a,b), Karim et al. (1994) and Hussain (2006) used biophysical crop models (e.g., DSSAT) to simulate the impact of climate change on plant growth. However, these models used available climate data only and did not assess the impacts of surface and ground water availability. Recently, Yu et al. (2010) and Ruane et al. (2013) assessed climate change impacts on crop yield incorporating both climate and water resources parameters. The results show that by the 2050s, yield of the major monsoon season crop (aus and aman rice) would not be impacted by climate change, while yield of the major winter crop (e.g., boro rice) might be reduced by about 5%.

Contemporary literature pertaining to the impacts of changes in climate, water availability, and crop yield overwhelmingly points to detrimental consequences for food security in the GBM basin. This basin scale view, however, fails to take into account farmers' adaptation strategies, which are deeply influenced by the local climate and water availability situation as well as economic, cultural, political, historical, and institutional factors at multiple scales.

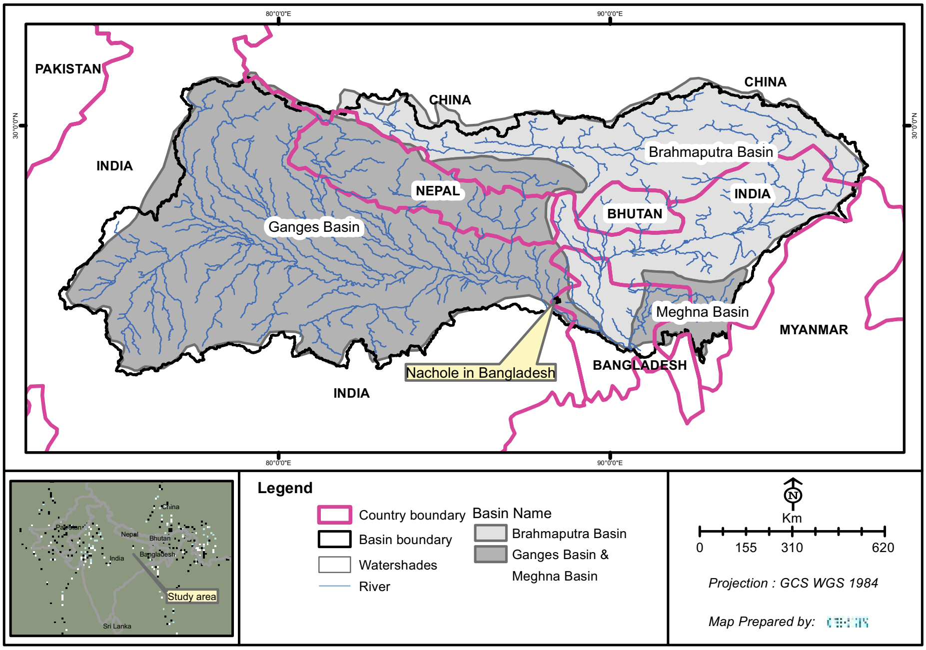
This paper presents the results of a hydrological simulation of climate change impacts on the components of water balance in the GBM basin, and uses this information to analyse the projected local seasonal surface and ground water availability in two districts, one in Bangladesh and one in Nepal. The yield of major crops under the changed climate and water situation is estimated, and a set of agricultural adaptation options for local farmers proposed. These outcomes should help in the identification of economically viable and locally acceptable adaptation options to ensure future food security.

Methods

Study area

The Ganges-Brahmaputra-Meghna (GBM) basin is composed of three sub-basins: the Ganges (China, Nepal, India, and Bangladesh), the Brahmaputra (China, Bhutan, India and Bangladesh), and the Meghna (India and Bangladesh) (Figure 31). The basin has a total area of more than 1.7 million km^2, distributed between India (64%), China (18%), Nepal (9%), Bangladesh (7%), and Bhutan (3%). Nepal is located entirely in the Ganges basin and Bhutan is located entirely in the Brahmaputra basin. The basin is home to 630 million people, the great majority of whom are poor. The population density is very high with 195,432, and 1,013 inhabitants/km^2 in the Nepal, India, and Bangladesh sections, respectively.

Figure 31: **GBM basins and case study districts (Nachole in Bangladesh and Rasuwa in Nepal)**



The basin is unique in terms of its diversity of climate. It is characterized by low precipitation to the northwest and high precipitation in the areas along the coast. The Meghna basin has the highest average annual precipitation of the three GBM basins; the highest average annual precipitation locally – greater than 5,000 mm/yr – is found in northeast Bangladesh. The average annual precipitation in the Ganges basin ranges from 500 mm to 3,000 mm, both extremes in the area within Nepal. The average annual precipitation in the Brahmaputra basin ranges from less than 500 mm in the section within China to 4,500 mm in India near the border with Bangladesh.

The case study district of Nachole is situated in the drought prone northwestern part of Bangladesh, while Rasuwa lies in north-central Nepal (Figure 31).

Agriculture – largely dependent on precipitation and surface water availability – is the primary income generating activity in both districts. The average annual precipitation during the base period (1981–2012) was 1,413 mm for Nachole and 2,808 mm for Rasuwa. Available annual surface water – based on simulated surface runoff of the area – was 525 mm for Nachole and 646 mm for Rasuwa, and groundwater recharge was 217 mm and 1,040 mm respectively. Rasuwa is considered highly vulnerable according to the vulnerability district mapping of Nepal (NAPA 2010) due to ecological and landslide-related threats.

Methods and data sets

The methods used in the study comprised a) collection of climate change scenario data based on biophysical and agricultural data and regional climate model(s); b) assessment of water balance at different temporal and spatial scales using a physically-based semi-distributed hydrological model (SWAT) (Arnold et al. 1998, Arnold et al. 2009a, 2009b); c) assessment of the impact of water resources availability on crop yields using the Decision Support System for Agro-technology Transfer (DSSAT) (Jones et al. 2003, Hoogenboom et al. 2010); and d) developing suitable adaptation options to address the water stress situation.

Climate change scenario data for the 2050s – ensemble average (50%) from 16 general circulation models (GCMs) – were obtained from the Climate Wizard tool (Girvetz et al. 2009) for the high (A2), medium (A1B) and low (B1) emission scenarios of the IPCC SRES scenario family (Nakicenovic et al. 2000). The datasets are 0.50 x 0.50 degree grids.

The SWAT model was calibrated and validated on a monthly scale using available observed discharge data from Nepal and Bangladesh. Before calibration, sensitivity analysis was performed using the Latin hypercube one-factor-at-a-time (LH-OAT) method (Van Griensven et al. 2002, 2005) to rank the simulation parameters of the model for each sub basin. The calibration and validation results were then evaluated against four performance measures – Nash-Sutcliffe efficiency (NSE), mean relative bias (PBIAS), ratio of the root-mean-square error to the standard deviation of measured data (RSR), and coefficient of determination (R2) (ASCE 1993; Moriasi et al. 2007). The calibrated and validated SWAT model was run for the baseline condition to simulate the temporal and spatial distribution of water in the case study districts. The model was then set up for the different climate change scenarios to simulate the climate change impact on water availability.

Basic meteorological, topographic, land use, and soil data were obtained from local and global sources. Topographic data were obtained from the Shuttle Radar Topography Mission (SRTM), USA (resolution 90 m, available from http://srtm.csi.cgiar.org); land use data for the GBM basin (spatial resolution 1 km) were obtained from the USGS database (United States Geological Survey – Global Land Cover 2000); and soil type data with soil properties for two depth layers (0–30 cm and 30–100 cm; spatial resolution 10 km) were obtained from the Food and Agriculture Organization database (FAO 1995). Weather data were obtained from NASA POWER (http://power.larc.nasa.gov). Daily weather data for 1981–2012 (precipitation and minimum and maximum temperature) were downloaded for the GBM basin (spatial resolution 0.5 degree grids). Monthly stream flow data for calibration and validation were obtained from the National Water Resources Database (NWRD) of Bangladesh and the Department of Hydrology and Meteorology (DHM) of Nepal.

DSSAT was used to simulate crop growth, development, and yield as a function of soil-plant-atmosphere dynamics. The data and information required for crop modelling and development and validation of adaptation options at the local level were obtained from agricultural organizations in Bangladesh and Nepal and global data sources.

Results and Discussion

Climate change and water balance

The Ganges-Brahmaputra-Meghna (GBM) basin covers an area of 1.7 million km^2 and is home to 630 million people. Changes in the climate and water availability will influence agricultural production and food security, ecology, biodiversity, river flows, floods, and droughts, water security, and human and animal health.

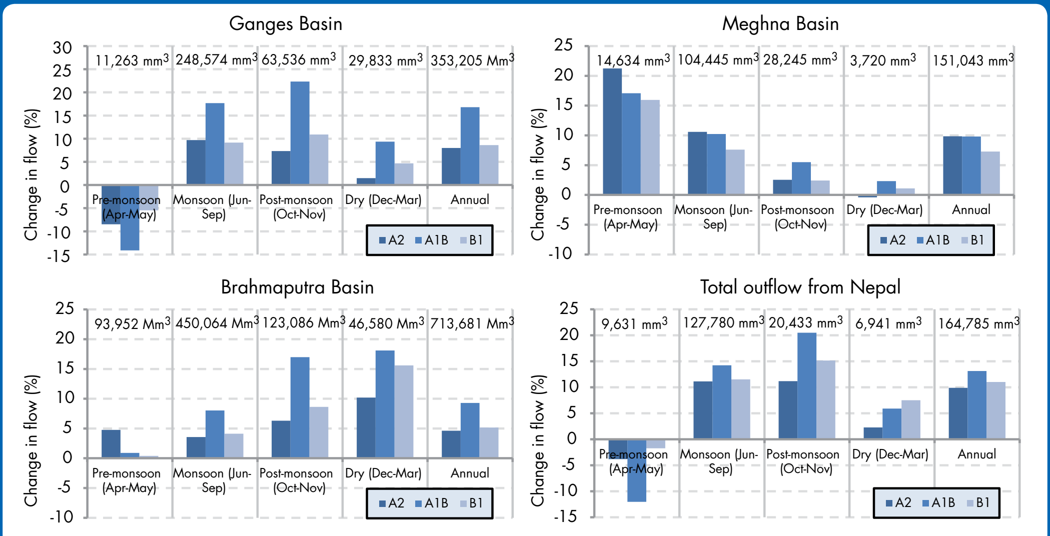
The annual water balance results indicated that the three GBM basins received 981 mm, 1,981 mm, and 3,816 mm average annual precipitation during the base period 1981–2012. The model results indicated that in the Ganges basin, 59% of the precipitation evaporates, 33% is converted to surface runoff, and 8% percolates into the soil. In contrast, the evaporative losses in the Brahmaputra and Meghna basins are comparatively low – 33% and 32% of total precipitation, respectively; while surface runoff is high – 60% and 64% of total precipitation, respectively. The contribution of snow melt in annual river flow was substantial in both the Ganges (10%) and the Brahmaputra (17%).

The water balance in the basins in the 2050s was simulated for the three different climate change scenarios – high (A2), medium (A1B), and low (B1). Figure 32 shows the results for overall streamflow under the three scenarios compared to the baseline period. The simulations show an overall increase in average annual precipitation and surface runoff, with more marked changes in seasonality. In the Ganges basin, dry season (Dec–Mar), monsoon (Jun–Sep) and post-monsoon (Oct–Nov) flow may increase by 2–9, 9–18, and 7–22% respectively, while pre-monsoon (April–May) flow may decrease by 5–15%. In the Brahmaputra basin, flow will increase in all seasons, with a marked increase in dry season flow (10–17%) due to temperature rise and accelerated snow melt. In the Meghna basin, there is a substantial increase in pre-monsoon and monsoon flows, and a minimal increase in post-monsoon and dry season flows.

One important feature of the modelled flows is the predominance of the monsoon season flow (Jun–Sep) in the total. The results indicate an increase of 10–17%, 4–8%, and 7–10% in monsoon flow in the GBM basin under the three scenarios A2 (high), A1B (medium), and B1 (low). This could lead to more frequent flood events of higher magnitude. Frequency analysis of flood events in the 2050s under climate change showed that 50-year flood events will become 20-year events in the Ganges basin under the A2 and B1 scenarios, and 10-year events under the A1B scenario. In the Brahmaputra and Meghna basins, 50-year events will become 35-year and 20-year events, respectively.

Groundwater is important for crop production in large parts of these basins in the dry season, thus the impact of climate change on groundwater recharge was analysed based on simulated

Figure 32: **Seasonal and annual changes in stream flow compared to baseline for different climate change scenarios (A2, A1B and B1) in the Ganges, Brahmaputra, and Meghna basins**



monthly percolation. In the Ganges basin, groundwater recharge in the 2050s will remain confined mainly to the monsoon period (Jun–Sep) and may increase compared to baseline. The Brahmaputra and Meghna basins also show an increase in groundwater recharge in the 2050s, with recharge starting in the pre-monsoon period and continuing well into the post-monsoon month of October.

Climate Change and Water Availability in the Case Study Districts

The impact of climate change on local water availability was analysed in the two case study districts – Nachole in Bangladesh and Rasuwa in Nepal. The results are shown in Table 24. They indicate that surface water availability will increase in both districts in all seasons except the dry season under all emission scenarios. The change in surface water availability will be more pronounced during the pre-monsoon season in Nachole and during the dry season in Rasuwa, in other words the climate change impact varies at local level. The results reflect the recent phenomena of dry season water scarcity in the mountain districts of Nepal and increase in floods in Bangladesh, both of which will be more marked by the 2050s with likely impacts on agriculture and rural livelihoods.

The amount of recharge is also expected to increase in both districts in the 2050s under all emission scenarios, and especially the A1B scenario (Table 25). Analysis of the temporal distribution of groundwater recharge shows that most occurs during the monsoon season (Jun–Sep).

Table 24: **Changes in surface water availability in Nachole and Rasuwa districts by the 2050s**

Area	Season	Available surface water in base period (mm)	Change in surface water availability (%)		
			A2	A1B	B1
Nachole, Bangladesh	Pre-monsoon (Apr–May)	18.5	+42.9	+44.3	+38.7
	Monsoon (Jun–Sep)	440.7	+4.9	+12.5	+11.5
	Post-monsoon (Oct–Nov)	59.7	+17.5	+28.1	+17.9
	Dry (Dec–Mar)	6.2	-9.6	-17.2	-3.3
	Annual	525.0	+7.5	+15.0	+13.0
Rasuwa, Nepal	Pre-monsoon (Apr–May)	33.6	+19.4	+7.4	+26.1
	Monsoon (Jun–Sep)	541.1	+16.3	+22.2	+10.8
	Post-monsoon (Oct–Nov)	11.3	+3.2	+36.4	+10.9
	Dry (Dec–Mar)	59.6	-43.6	-54.8	-35.9
	Annual	645.7	+10.7	+14.6	+7.3

Table 25: **Changes in groundwater recharge in Nachole and Rasuwa districts by the 2050s**

Area	Annual recharge in base period (mm)	Change in recharge (%)		
		A2	A1B	B1
Nachole, Bangladesh	217	+2.6	+7.9	+7.1
Rasuwa, Nepal	1,040	+3.0	+4.8	+2.7

Climate Change and Crop Yield in the Case Study Districts

The impact of climate change on the yield of major crops was analysed for the case study districts. The crop production model DSSAT was used to simulate the yield of crops in the base period (1981–2012) and under the three climate scenarios (A1B, A2, and B1). The crops analysed were monsoon rice (transplanted aman) and dry season rice (boro) in Nachole and maize in Rasuwa. Both aman rice and maize are grown under rainfed monsoon conditions, while boro rice depends on groundwater. The simulated base period crop yields were first compared with observed yields and found to be satisfactory. The simulated average yields of transplanted aman rice, boro rice, and maize in the base period were 3,830, 6,600, and 3,560 kg/ha, respectively. The impact of climate change and water availability on crop yield by the 2050s is shown in Table 26. The projected change in temperature and precipitation will have a negative impact on yields, while the change in CO_2 will have a positive impact.

Table 26: **Changes in crop yield by the 2050s in Nachole and Rasuwa districts due to changes in temperature, precipitation, and CO_2 concentration**

Area	Crop	Scenario	Average yield (kg/ha)[a]	% Change in yield		
				TP	C	TPC[b]
Nachole, Bangladesh	Monsoon rice (transplanted aman)	Base	3,827			
		A2	3,914	-1.4	+3.9	+2.3
		A1B	3,930	-1.5	+4.1	+2.7
		B1	3,936	-1.7	+3.3	+2.8
	Dry season rice (boro)	Base	6,595			
		A2	6,337	-5.5	+2.8	-3.9
		A1B	6,370	-5.9	+2.9	-3.4
		B1	6,293	-6.0	+1.2	-4.6
Rasuwa, Nepal	Maize	Base	3,789			
		A2	3,725	-2.4	+0.9	-1.7
		A1B	3,558	-6.3	+1.5	-6.1
		B1	3,678	-3.6	+0.5	-2.9

T = temperature; P =precipitation; C = CO_2 concentration

[a] yield with changes in T, P, and C

[b] effect of simultaneous changes in T, P, and C are not a simple sum or product of the individual impacts due to the non-linear biophysical interactions between the climate variables

The yield of monsoon rice in Nachole in Bangladesh is projected to increase by about 3% under all the emission scenarios (A2, A1B, B1) as the negative impact of changes in temperature and precipitation is offset by the increase from carbon fertilization. Similar results have been found in recent studies by others on the impacts of climate change on food security in Bangladesh (Yu et al. 2010; Ruane et al. 2013). In contrast the net impact on dry season rice (boro) yield will be negative, as the negative impact from changes in temperature and precipitation outweigh the positive impact of carbon fertilization. The results indicate that dry season rice cultivation may not be sustainable in Nachole as the demand for water is projected to exceed the expected recharge and water yield.

The yield of maize in Rasuwa, Nepal, is projected to decrease by 2–6% under the different climate change scenarios. CO_2 has only a small positive impact on yield because maize is a C4 plant and little affected by CO_2 increases (Goudriaan and Unsworth 1990; Adriana et al. 1998).

Adaptation Options for Sustainable Crop Production in Nachole, Bangladesh

Three adaptation options were tested in the model simulations to reduce yield loss and crop water requirement: (1) shifting the transplantation date, (2) sowing a short duration crop variety, and (3) crop diversification. These adaptation options were tested for the base period (1981–2012), and average, wet, and dry years (20, 50, and 80% probability of exceedance of precipitation) under the A2, A1B, and B1 climate change scenarios.

The analysis indicated that transplanting monsoon rice ten days earlier than at present (11 Jul) would be the most effective way to reduce the crop water requirement and yield loss in wet, average, and dry years under all the emission scenarios. The reduction in crop water requirement and yield loss can be maximized by using short duration (135 days) monsoon rice varieties (e.g., the BIRRI dhan49 and BR 11 varieties). Continuous weather forecast information should be provided to farmers to promote these measures so that they can adjust the transplantation date to reduce risk and sustain yields with less water. Moreover, farmers should be given training to help them understand the linkages between the weather and agricultural practices, and the benefits of agro-meteorological forecasting.

Transplanting dry season rice ten days earlier (11 Jan) also helps to reduce the crop water requirement, as does introduction of short duration (140 days) dry season rice varieties (e.g., BIRRI dhan28). However, the scenario for local water availability indicates that despite the slight increase in groundwater recharge in the 2050s under all emission scenarios, there will be an irrigation deficit for growing dry season rice. Thus, dry season rice cultivation should be replaced in phases by low water requiring cereal crops such as wheat and maize, oilseeds, pulses, and winter vegetables.

Conclusions and Policy Implications

There is no single viable generic solution for sustaining crop yield and ensuring food security in the GBM basin under climate change. The findings of this research point towards the need to adopt a context-specific mix of policy interventions and preferred routes for future water resources development at multiple spatial scales. These policy implications can be summarized as follows.

- **Work towards increasing water storage in the basins** – The predominance of the monsoon season is projected to increase by the 2050s due to climate change and there is likely to be an increase in the frequency of flood events of higher magnitude in all three GBM basins. Measures to increase upstream water storage will help to address this climate-induced challenge in the future. The lower evaporation loss in the Brahmaputra basin compared to the Ganges basin suggests the possibility of constructing multipurpose water storage reservoirs in the Brahmaputra basin. However, the approach and method of water storage should be rigorously researched to identify options that can be agreed by the co-riparian countries.
- **Promote water resources development and management in the basin** – Large changes in the seasonality of precipitation and water availability are expected by the 2050s. The results indicate an increase of 10–17%, 4–8%, and 7–10% in monsoon flow in the GBM basin for all three scenarios: A2 (high), A1B (medium), and B1(low). Climate change will have a greater impact on water seasonality in the Ganges basin than in the other two basins. The possible strengthening of the spatial and temporal dimensions of water availability in the future supports the argument for identifying opportunities for water-based cooperative development and management of the basins. The prospect of two or more co-riparian countries working in cooperative, project-based water development activities in the GBM basin has been endorsed by consecutive South Asian Association for Regional Cooperation (SAARC) summits.
- **Strengthen regional hydro-meteorological and agricultural information collection and sharing mechanisms** – The nested approach adopted by this research combining a regional water model with a local crop model has been able to assess the potential impact of changing agricultural practices on crop production. In order to change agricultural practices (e.g., changing the transplantation date to reduce water stress and maintain yields), there is a critical need to provide continuous hydro-meteorological forecast information to farmers based on regional and local assessments. Special emphasis should be directed to establishing governing principles for institution building including collection of regional hydro-meteorological and agricultural information and establishing monitoring networks.
- **Increase investment in agricultural research and extension** – This study has confirmed the disruptive and uncertain nature of the future climate and water situation for agricultural production in the GBM basin. The findings call for an improved agricultural extension services to help farmers adapt quickly in terms of cropping practices, crop diversification, and irrigation, and to strengthen farmers’ knowledge networks to help

broaden perspectives and awareness. For example, many farmers think that rainfed crops do not need irrigation. This may not hold true as the climate changes, and in the future previously rainfed crops may need supplementary irrigation. The government should also take the initiative to increase research and investment into the identification of new climate resilient short duration crop varieties.

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