

Exploring the impacts of climate change on water resources— regional impacts at a regional scale: Bangladesh

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Abstract Bangladesh is located at the confluence of three major river basins: the Ganges, Brahmaputra and Meghna (GBM) basins. The GWAVA (Global Water AVailability Assessment) model, a global-scale gridded approach to hydrological modelling, has been applied to all GBM basins to investigate the impacts of climate change on water resources at a regional scale. The entire model set-up is composed of a coarse-scale GBM-wide model at 0.5 degrees resolution and a fine-scale model at 0.1 degrees representing Bangladesh. A suite of climate scenarios have been collated from regional climate data using the Hadley Centre's HadRM2 and that generated by the Indian Institute of Tropical Meteorology using the Hadley Centre's PRECIS. Scenarios for water demands have been developed for the present and future based on socio-economic data from various publicly available sources and local water management plans. The comparison of water demands with supply using spatial-temporal distributed water availability indices enables areas of future scarcity to be identified.

Key words water resources modelling; climate change; impacts study; grid-based models; water demand; water scarcity; regional climate models

INTRODUCTION

Bangladesh is one of the world's most densely populated countries and has a high incidence of poverty. The fact that the country already suffers greatly from flooding and drought, and lacks financial resources, means that Bangladesh has been identified as being highly vulnerable to the effects of climate change. With roughly 80% of the landmass made up of fertile alluvial lowland and the major employer being agriculture, current climate change predictions of wetter wet seasons and possible drier dry seasons, depending on the global climate model used (IPCC, 1998), can only exacerbate an already critical water resources situation. Despite this predicament, climate change has not been considered so far in the National Water Management Plan of Bangladesh. In this paper, a model is presented that is aimed at providing a tool that is both accessible and relevant at a regional scale, which highlights the impacts of climate change on water resources in Bangladesh.

HYDROLOGICAL SITUATION

Bangladesh is located at the confluence of three major river basins: the Ganges, Brahmaputra and Meghna (GBM) basins. In order to understand the future impacts on water resources in Bangladesh, it is necessary to investigate these trans-boundary rivers (only 5% of the Ganges catchment and 7% of the Brahmaputra catchment lie in Bangladesh). The GBM basins are hydrologically complex, ranging from the glaciers of the Himalayas to the deltaic flood-prone Bangladesh. Not only are the river flows glacial but are subject to annual monsoonal rains where more than 80% of the annual rainfall is received during the wet season.

METHODOLOGY

The Global Water AVailability Assessment (GWAVA) model, a global-scale gridded approach to hydrological modelling, has been applied to the basins to investigate the impacts of climate change on water resources in the region. The model was developed to provide a consistent and realistic examination of water resources problems as described in Meigh *et al.* (1999).

Surface flows are estimated using the probability distributed model of Moore (1985), linking climate to runoff and, in the major river basins, the runoff estimates for individual grid cells are accumulated to give estimates for the total flows at all points of interest. GWAVA has been adapted to local conditions in the GBM region in order to stimulate local interest in the impacts of climate change. A new module, specifically developed for the Himalayas, has been included to provide a more sophisticated approach to the modelling of glacial hydrology.

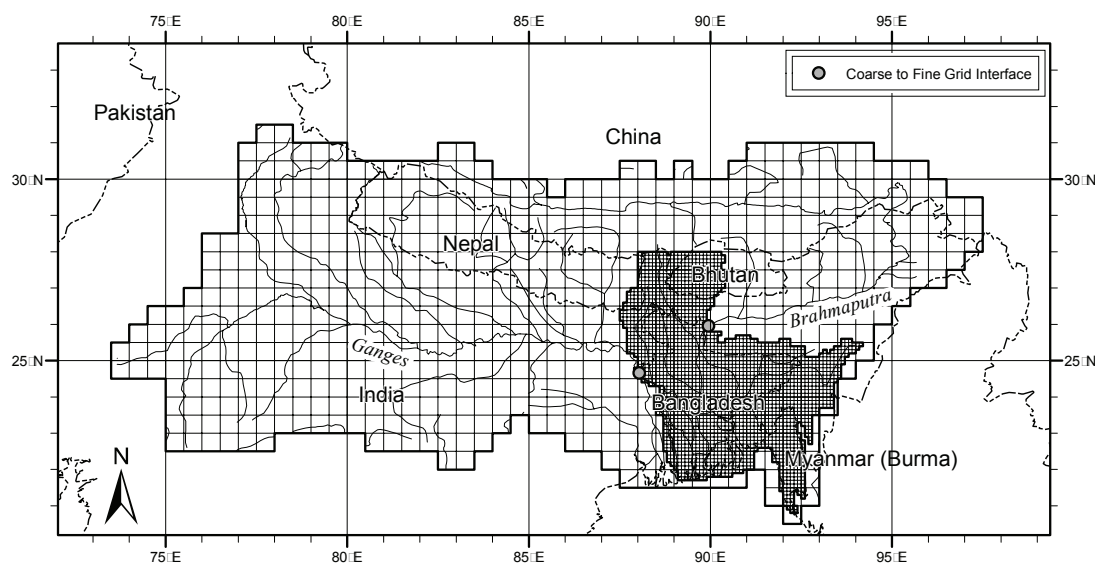


Fig. 1 Map of Ganges-Brahmaputra-Meghna River Basins showing discretization of coarse and fine-scale grids.

The model has been refined such that it is composed of a coarse-scale GBM-wide model at 0.5 degrees resolution and a fine-scale model at 0.1 degrees representing Bangladesh (Fig. 1). The “downscaling” of the model to the fine-scale grid has been necessary not only for scientific interest, but to provide results at a scale that is relevant to water resource managers in Bangladesh (the 0.1 degrees resolution is a balance between the resolution of available data sources and the size of administrative areas).

A finer-scale grid resolves more hydrologically important features, including the complex network of irrigation schemes that exist in Bangladesh. Moreover, the country is low-lying and with its capital city, Dhaka, 225 km from the coast and at about 8 m above the mean sea level, differences in elevation are very small. Therefore the application of digital elevation models to provide automatically-generated drainage networks is very difficult. Using local maps and expertise, a new drainage map of Bangladesh has been produced at the 0.1 degree scale.

As Bangladesh is at the downstream end of all the river basins, the model allows a simple non-dynamic transfer of flow from the coarse grid to the fine grid at two strategically-placed points close to the Bangladesh border, and to flow gauges which are used for calibration purposes. In addition to the explicit modelling of dam operations, lakes, wetlands and water transfers, the water-sharing agreement between India and Bangladesh, which controls river flows into Bangladesh at the Farakka Barrage, have been included in this case study.

CLIMATE SCENARIOS

The advent of regional climate models has made it possible to provide more details of climate characteristics at a scale relevant to nation states. A suite of climate scenarios have been collated from regional climate models (RCM) to drive the hydrological component of GWAVA. These

Table 1 Mean changes in generated daily climate for the whole GBM region relative to the observed climate data set, Mitchell *et al.* (2003). HadRM2 refers to the data generated using RCM results for a perturbed climate where CO₂ doubles during the next century by Hassel & Jones (1999) and PRECISA2 refers to data generated using PRECIS for the SRES scenario A2 with sulphur by IITM (2005).

Season	Climate Variable	2020s		2050s	
		HadRM2	PRECISA2	HadRM2	PRECISA2
Dry	Precipitation (%)	+26	-2	+58	-4
	Temperature (°C)	+0.4	+0.3	+0.7	+0.5
	Potential evaporation (%)	+22	+33	+46	+58
Wet	Precipitation (%)	0	+13	+8	+28
	Temperature (°C)	+0.6	-0.2	+1.0	-0.1
	Potential evaporation (%)	35	21	71	39

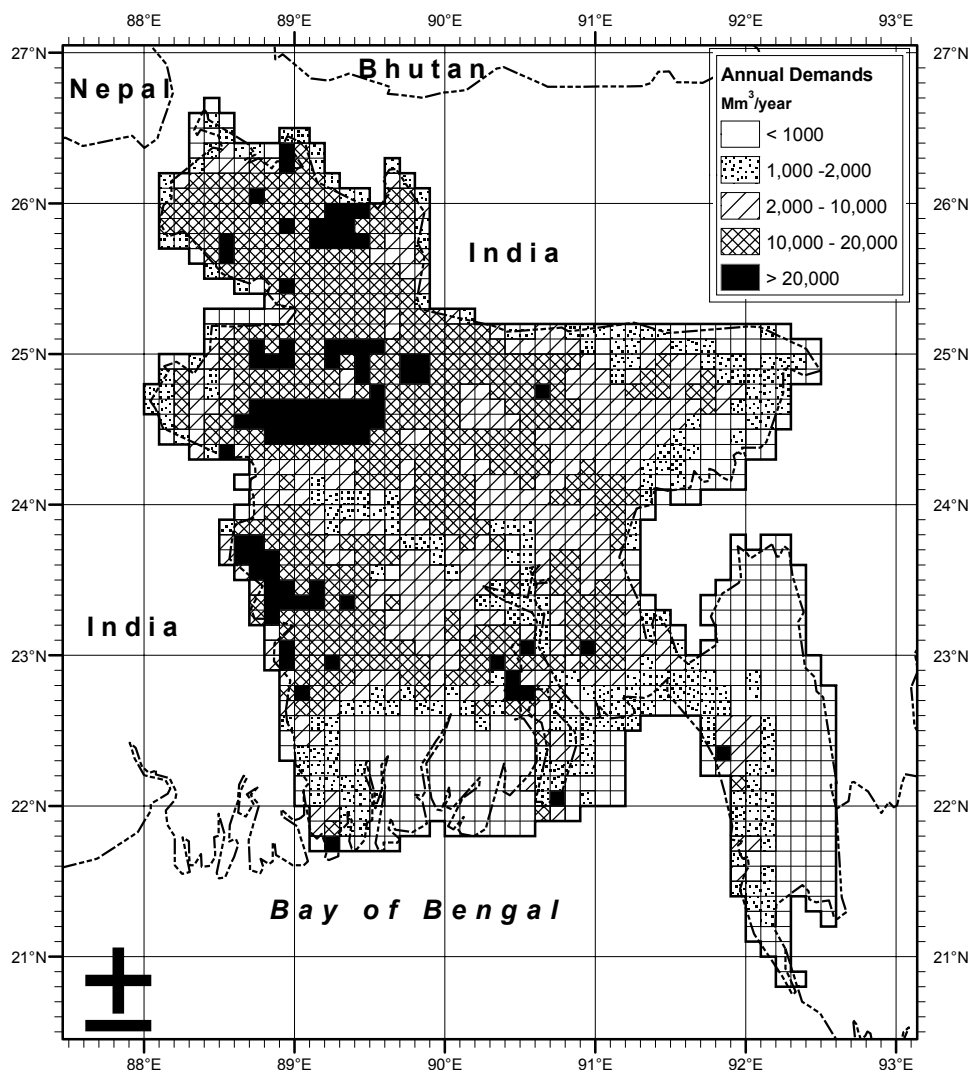


Fig. 2 Baseline annual water demand for Bangladesh based on locally-obtained water use statistics.

have included new data generated using PRECIS at the Indian Institute of Tropical Meteorology (IITM, 2005) and HadRM2 by Hassel & Jones (1999) (at a grid resolution of approximately 50×50 km), as well as results of global climate models.

RCM data was provided for baseline (1961–1990) and future horizons (2070–2100 for PRECIS and 2041–2060 for HadRM2). The time horizons available present a problem, as water managers prefer to plan on timescales of a maximum of 25 to 50 years. Moreover, with the inclusion of the more sophisticated glacier model, initial conditions of the glaciers at the start of the future horizon are required. Previous applications of GWAVA where the baseline and future horizons are treated as independent runs are therefore not possible. In order to drive the model for the 2020s and 2050s, climate variables had to be generated during the interim period between the end of the baseline and the start of the future horizon.

Average changes in monthly precipitation, temperature and potential evaporation between the future climate and the baseline (or control climate for HadRM2) were calculated from the daily RCM data. An annual incremental increase in the monthly values of each of the three climate variables was then applied to the baseline climate data set used to calibrate the model. Summary statistics of the driving climate variables for future horizons are presented in Table 1.

WATER DEMANDS DATA

Scenarios for water demands have been developed for baseline and future horizons corresponding to the climate scenarios. Data requirements for their calculation include human and livestock population, domestic, industrial and irrigation water use. Detailed data on water use in countries

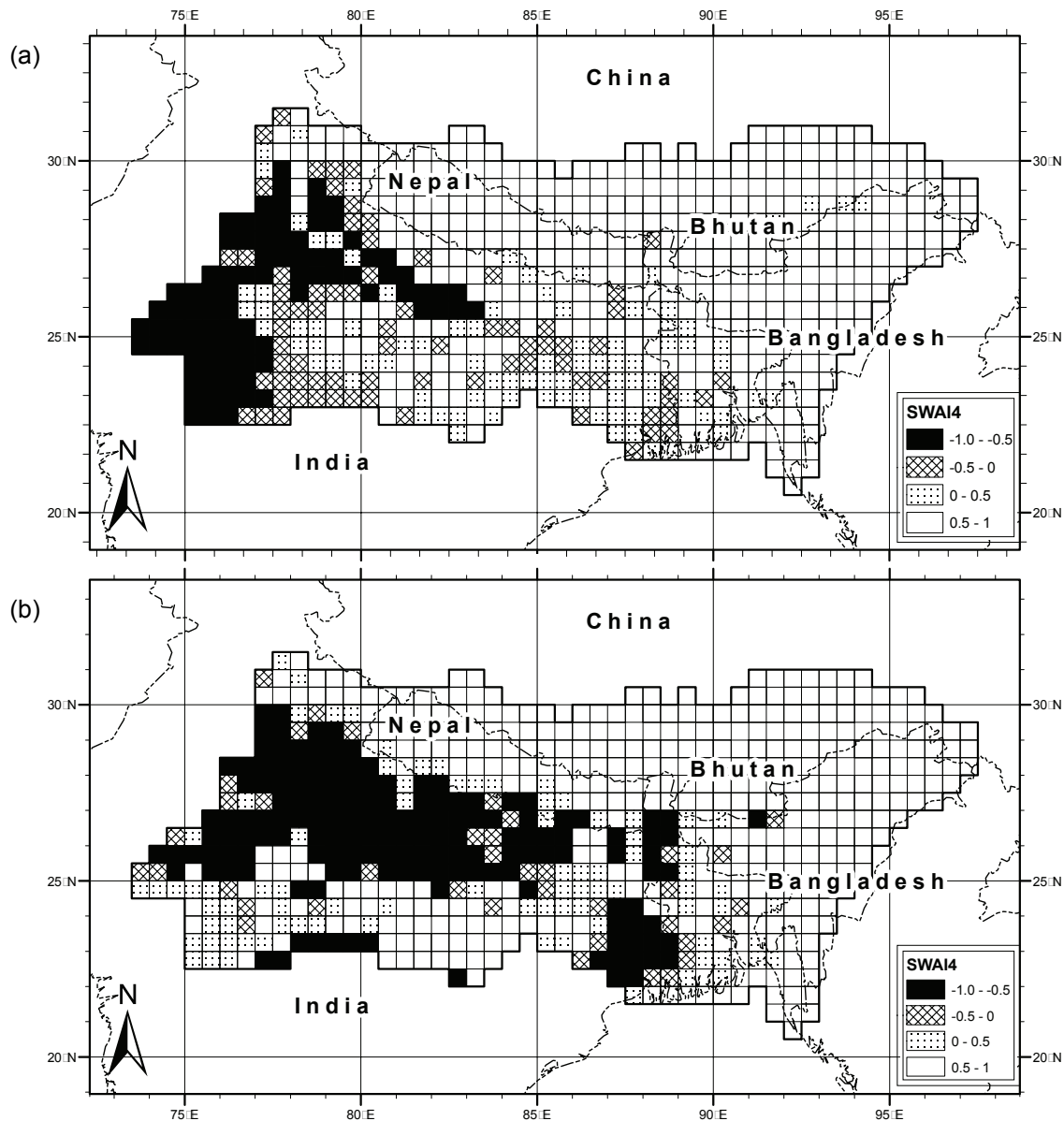


Fig. 3 Annual surface water availability index number 4 (SWAI4) for the whole of the Ganges-Brahmaputra Basin region during: (a) the baseline period 1961–1990, and (b) the 2020s.

upstream of Bangladesh are not available. Hence, for areas outside of Bangladesh, socio-economic data from various publicly available sources were used. Methods to resolve the various formats and resolutions of data were developed similar to that used by Gaffin *et al.* (2004), with an emphasis on providing a set of data that can be represented spatially. For Bangladesh, it was important to use locally sourced data and develop scenarios relevant to local water managers (see Fig. 2). Therefore, for the development of future water demands, the National Water Management Plan for Bangladesh was used.

RESULTS AND DISCUSSION

The socio-economic scenarios were combined with the climate scenarios to provide an ensemble of future scenarios, giving an indication as to the possible impacts of climate change on water resources in Bangladesh. The main outputs of the work are a set of spatial-temporal distributed water availability indices, comparing water demands with supply, enabling areas of future scarcity to be identified. An example of one of these indices is presented in Fig. 3 for the whole of the GBM region. The index presented is the surface water availability index type 4 (SWAI4), which is a ratio comparing the minimum of the 90% reliable monthly runoff during the whole run minus the

water demand for that month, and the overall 90% reliable monthly runoff plus the water demand for that month. Regions of water excess have a positive value and regions of water deficit a negative value. For further details of the different indices see Meigh *et al.* (1999).

Figure 3 shows that despite the large increases in annual precipitation predicted by the RCMs, the dry season is becoming drier for the more recent PRECIS run (see Table 1). With the increases in water demand due mainly to population increases, there is a general increase in the water deficit, especially along the Ganges in India (Fig. 3). The results suggest future changes could have major implications for trans-boundary water management.

The large variation in magnitude of the climate change data from different climate models suggest that ensembles of runs are required to provide a better indication as to the likelihood of the modelled future water availability results. GWAVA provides a useful tool to assess and highlight climate change impacts on water resources and will provide a more reliable picture of future water availability as more climate change data becomes available.

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