Ecological Indicators 48 (2015) 120–131

Contents lists available at ScienceDirect

Ecological Indicators

journal homepage: www.elsevier.com/locate/ecolind

A dynamic assessment of water scarcity risk in the Lower Brahmaputra River Basin: An integrated approach

Animesh K. Gain*, Carlo Giupponi

Ca' Foscari University of Venice, Venice Centre for Climate Studies (VICCS), Department of Economics, Cannaregio 873, 30121 Venice, Italy

ARTICLE INFO

Article history:
Received 3 March 2014
Received in revised form 14 June 2014
Accepted 23 July 2014

Keywords:
Risk
Water scarcity
Climate change
Brahmaputra river basin
Integrated assessment

ABSTRACT

Many international river basins are likely to experience increasing water scarcity over the coming decades. This water scarcity is not rooted only in the limitation of resources, i.e. the shortage in the availability of freshwater relative to water demand, but also on social factors (e.g. flawed water planning and management approaches, institutional incapability to provide water services, unsustainable economic policies). Therefore, the assessment of water scarcity risks is not limited to the assessment of physical water supply and demand, but it requires also consideration of several socio-economic factors. In this study, we provide a comprehensive dynamic assessment of water scarcity risks for the Lower Brahmaputra river basin, a region where the hydrological impact of climate change is expected to be particularly strong and population pressure is high. The basin area of Brahmaputra River lies among four different countries: China, India, Bangladesh and Bhutan. For water scarcity assessment, we propose a novel integration of different approaches: (i) the assessment of water scarcity risk, considering complex social-ecological system; (ii) the analysis of dynamic behaviour of the system; (iii) exploration of participatory approach in which limited number of stakeholders identify the most relevant issues with reference to water scarcity risks and provide their preferences for the aggregation of risk assessment indicators. Results show that water scarcity risk is expected to slightly increase and to fluctuate remarkably as a function of the hazard signal. Social indicators show trends that can at least partially compensate the increasing trend of the drought index. The results of this study are intended to be used for contributing to planned adaptation of water resources systems, in Lower Brahmaputra River Basin.

1. Introduction

Physical water scarcity, by definition, is the shortage in the availability of freshwater relative to water demand. Scarcity occurs due to unfavourable trends of water supply or demand, which may have various origin, including climate variability and change, population dynamics, glacier melt, reservoir construction, and groundwater extraction (Immerzeel and Bierkens, 2012). Water availability changes substantially due to its inherent nature of high variability in time and space (Postel et al., 1996). Climate change is considered as one of the main driving forces, already affecting the temporal and spatial variability of water availability (Bates et al., 2008; IPCC, 2014; Kundzewicz et al., 2007; Stocker et al., 2013). In parallel, various factors including population growth, economic development, land use change, and environmental degradation affect the changes in water demand (Sophocleous, 2004). The increasing demand trends make the water resources more scarce, which in turn affect food security, access to safe drinking water, hygiene and public health, and well-being (Taylor, 2009).

Many of the international river basins are likely to experience increasing water scarcity over the coming decades (Beck and Bernauer, 2011). However, this water scarcity is not rooted only in the limitation of water resources in physical terms. In addition to the physical water scarcity, there are also social factors e.g., flawed water planning and management approaches, institutional incapability to provide water services, unsustainable economic policies, unequal power relationships, inequality and poverty that exacerbate scarcity, which are referred as social scarcity (UNDP, 2006). For characterizing the broad picture of water scarcity, both physical and social dimensions are thus equally important. The assessment of risks related to water scarcity is therefore not limited to physical water supply and demand only. It requires also consideration of several socio-economic factors including poverty, inequality, governance systems in place, policies.

Unfortunately, until recently, most water scarcity studies concentrate only on physical aspect, either demand driven water

* Corresponding author. Tel.: +39 041 234 9231; fax: +39 041 2349176.
E-mail address: animesh.gain@gmail.com (A.K. Gain).

http://dx.doi.org/10.1016/j.ecolind.2014.07.034
1470-160X/

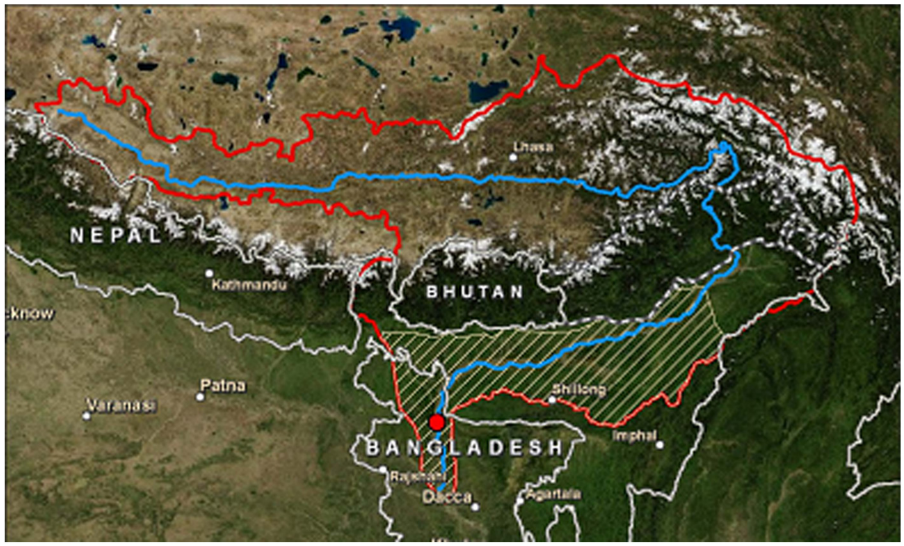

Fig. 1. Brahmaputra River Basin.

scarcity (water stress) or population driven scarcity (water shortage). The demand-driven scarcity is measured by calculating the ratio of estimated annual freshwater demand to availability, with a threshold set exceeding 0.4 (Vörösmarty et al., 2005). The supply-driven scarcity is instead measured by calculating per capita availability of renewable freshwater resources, with a threshold set at 1000 cubic metres per person per year (Falkenmark et al., 1989). Many of the previous studies (Arnell, 1999; Vörösmarty et al., 2000; Alcamo and Henrichs, 2002; Alcamo et al., 2003; Oki and Kanae, 2006; Islam et al., 2007; Kummu et al., 2010) used these concepts of water scarcity for their macro-scale assessment comparing water availability and water demand at a yearly time scale. Recently, a few macro-scale studies were carried out at a monthly scale on past records (e.g. van Beek et al., 2011; Wada et al., 2011; Hoekstra et al., 2012), but there are not many considering future projections. Very few studies (Beck and Bernauer, 2011; Gain and Wada, 2014) examine both the effects of climate change and the impacts of water demand on river basins, and provide geographically and seasonally detailed results for water distribution within the basin. These basin-scale assessments provide vital information since water management decisions are very often determined by the river basin management authorities.

The integrated assessment of water scarcity risk is currently an urgent need in water resources management (Biswas, 2005; WWAP, 2009; Varis et al., 2012). For assessing river basin-scale water scarcity risks, integration of both physical and social dimensions is required to go 'out of the water box'. To 'go out of the water box' is a response to the recent emphasis, which refers the extension of water resources discussion out of the conventional water sector centred discourse (Biswas, 2005; WWAP, 2009). Incorporating different important dimensions, such studies are rare. Recently, a few studies considered socio-economic and environmental issues when assessing water scarcity, but the studies were limited to the investigation of spatial variations of vulnerability among the basins or sub-basins in an static manner e.g., Babel and Wahid (2008); Pandey et al. (2009); Pandey et al. (2010); Pandey et al. (2011); Varis et al. (2012). In order to deal with future climatic as well as socio-economic changes, a dynamic simulation of future water scarcity is required through integrated consideration of both bio-physical and social dimensions.

In this study, we provide a comprehensive dynamic assessment of water scarcity risks for the Lower Brahmaputra river basin, a region where the hydrological impact of climate change is expected to be particularly strong and population pressure is high (Immerzeel et al., 2010; Gain et al., 2013a). The proposed approach incorporates several novel approaches. First, the assessment of water scarcity risk goes beyond the traditional assessment of water availability and demand and analyses the broader context of social-ecological system (SES), in which complex bio-physical and socio-economic factors are assessed, with their interactions in a resilient and sustained manner (Gunderson and Holling, 2002; Redman et al., 2004). The SES concept has been adopted to emphasize the integrated concept of humans in nature. Therefore, this study is an improvement of physical water scarcity assessment in the LBRB recently carried out by Gain and Wada (2014). For assessing the combined effect of different bio-physical and social variables, risk is conceptualized through a recently developed theoretical framework by Giupponi et al. (2013a) and Mojtahed et al. (2013). Second, we explore dynamic behaviour of the complex social-ecological system. Instead of focusing spatial variation of risk, we estimate water scarcity in LBRB towards the year 2025. Assessment of future behaviour of the system is required for climate change adaptation and water resources management. Third, we apply a participatory approach, in which only few stakeholders identify the most relevant issues with reference to water scarcity risks and provide their preferences for the aggregation of indicators within a non-additive aggregation operator similar to Giupponi et al. (2013b). The participatory approach is adopted here as a fundamental means for the involvement of stakeholder in the process of integrated water resources management (GWP, 2000; Gain et al., 2013b; Rouillard et al., 2014).

2. Study area

Brahmaputra River drains an area of around 530,000 km^2 and crosses four different countries: China (50.5% of total catchment area), India (33.6%), Bangladesh (8.1%) and Bhutan (7.8%). Immerzeel (2008) categorized the Brahmaputra basin into three different physiographic zones: Tibetan Plateau (TP), Himalayan belt (HB), and the floodplain (FP). The FP area with an elevation of less than 100 m above the sea level is defined as the Lower Brahmaputra River Basin (LBRB) and comprises about 27% of the entire basin. The sub-basin of the LBRB that is included in the geographical boundary of Bangladesh is considered as the spatial unit (Fig. 1).

Among river systems, the hydrological impact of climate change on the LBRB is expected to be particularly strong, because of several