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Bottom-up quantification of inter-basin water transfer vulnerability to climate change

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ABSTRACT

Inter-basin water transfer (IBWT) projects offer us a long-term means to minimize the mismatch between water demand and water availability. Climate change may impose significant vulnerability to IBWT projects through perturbations in water availability. However, previous studies of climate change's impacts on IBWT's vulnerability are mainly based on a top-down framework, i.e. forecasting the climate change via a wide range of GCMs, which may underestimate the uncertainty of climate change. In order to address this problem, a bottom-up vulnerability assessment framework is developed to evaluate the vulnerability of IBWT. In this framework, an IBWT vulnerability indicator is proposed based on three dimensions of vulnerability including exposure, sensitivity and adaptive capacity. The framework also highlights the deep uncertainty of climate change by adopting a probabilistic Budyko model, which can estimate the water availability over a broad range of climate futures. The South-to-North Water Transfer Project (SNWTP) in China is adopted as a case study to illustrate the effectiveness of the proposed framework. It shows that the framework is a useful tool for identifying the detrimental climate condition scope for the IBWT's vulnerability, and is valuable to guide long-term water resources management and planning for policymakers.

1. Introduction

With its large capacity to convey water from one river basin (the donor basin) to another (the recipient basin), inter-basin water transfer (IBWT) projects have been promoted for many years to alleviate the problem of the heterogeneous distribution of water resources (Zhang et al., 2015). The key of IBWT's long-term reliable operation lies in whether the transferred water can effectively reduce the scale of mismatch between regional water demand and water availability in each basin involved in IBWT. The mismatch is closely related to climate change. Under climate change, the water availability in each river basin and the possible transferred water from the donor to the recipient basin may be significantly changed (Bates et al., 2008; Pittock et al., 2009). Consequently, climate change has become a key determinant of IBWT project's vulnerability (Zhang et al., 2012).

Vulnerabilities concentrate directly on a system which has weakness that susceptible to climate change which can alter its trajectory to reach its objectives (Vidal and Marle, 2012). A clear understanding of the vulnerability of IBWT is necessary, since the transferred water is typically related to the water availability for human consumption, irrigation, power generation, and industrial uses. Furthermore, systematically identifying vulnerabilities of IBWT can help governments optimize their expenditures and engineering designs for these projects, and also can facilitate water resource managers in the face of climate change.

Current vulnerability analysis frameworks can be classified in two main categories: top-down framework and bottom-up framework (Nazemi and Wheater, 2014; Moody and Brown, 2012). The top-down framework belongs to a scenario-led approach. The basic principle of this approach is to simulate future performance of a system over a set of emission scenarios. Most previous studies of the potential impacts of climate change on IBWT have used these scenario-led approaches (Xi et al., 2010; Gurung and Bharati, 2012; Maknoon et al., 2012). These top-down methods project future conditions from downscaled ocean-atmosphere general circulation models (GCMs) and simulate system responses using hydrological models. However, because of large irreducible uncertainties and poor capacity for representing climatic variability, these methods limit analytical and decision making abilities with respect to water resource management (Brown and Wilby, 2012).

To highlight the deep uncertainty about climate change as well as to avoid uncertainties initiated from downscaling GCMs, decision scaling or robust decision-making approaches to identifying climate change

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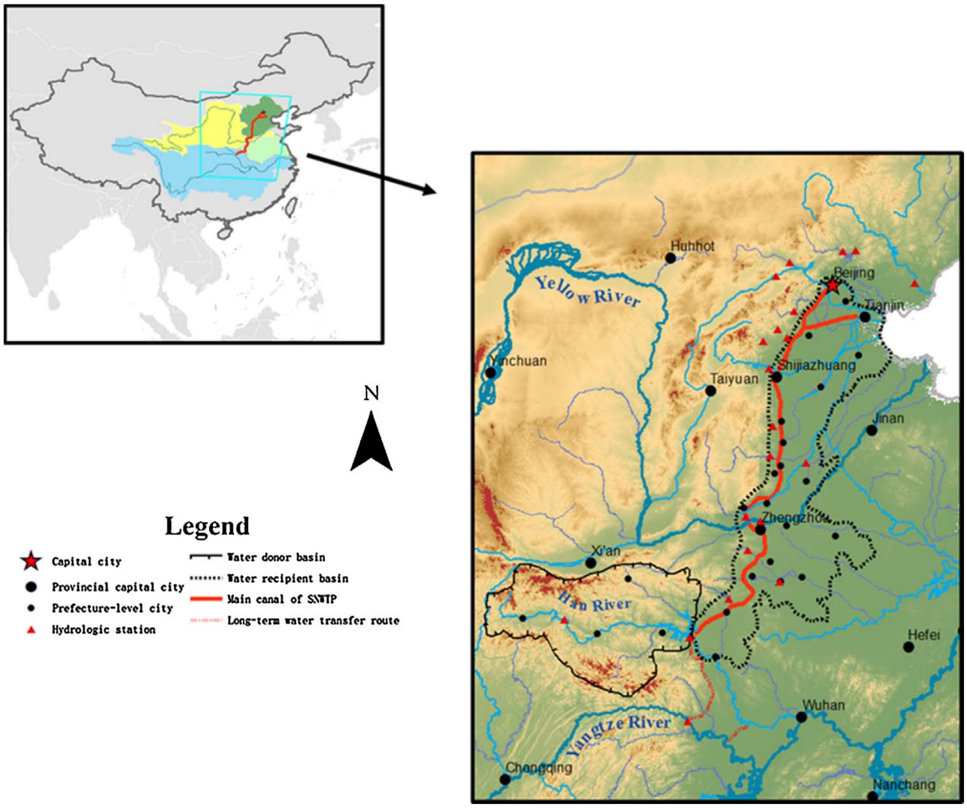

Fig. 1. Location of the Central Route of the SNWTP.

adaptations have been proposed and applied with a bottom-up framework (Brown and Wilby, 2012). Instead of directly assessing system responses to projected climate change, these approaches focus on systematically identifying the greatest vulnerabilities across all future possibilities and considering which suite of climate change adaptations will perform reasonably well across this range. Weaver et al. (2013) also affirmed the value of such frameworks because they are well suited to large-scale integration with climate modeling and have the potential to provide a quantitative, transparent tool to facilitate critical decision-making and may facilitate communication of modeling outcomes to the public and other stakeholders. The general process of bottom-up vulnerability quantification can be divided into five steps: defining system performance criteria, building a system model, conducting vulnerability analysis, evaluating options to inform decision(s), and identifying a preferred decision. Poff et al. (2015) summarized out these steps and applied them to a hypothetical case study of the Iowa River, USA. Most recent bottom-up vulnerability case studies have focused on river basins or water supply systems and have proven these approaches feasible for decision making when projections of the future are highly uncertain (Nazemi et al., 2013; Ghile et al., 2014; Singh et al., 2014).

Despite lots of efforts to examine the climate change induced vulnerabilities in various kinds of water resource systems, only a few studies have been performed on the vulnerability of the IBWT. For example, Gurung and Bharati (2012) quantified the downstream effects of diverting water from the donor basins of the Melamchi Water Supply Project in Nepal under current as well as future climate scenarios. Maknoon et al. (2012) used Dez to Qomrood Inter-Basin Water Transmission Project in Iran as a case study and evaluated the efficiency of different protocols under the effect of climate change. Shrestha et al. (2015) analyzed the impact of climate change on the water diversion plan for the Melamchi Water Supply Project (MWSP) in Nepal. However, the existing studies were all based on the top-down framework mentioned above, i.e. forecasting the climate change via a wide range of GCMs. They cannot avoid the inherent weaknesses of scenario-led approaches.

The bottom-up framework can partly resolve these problems. However, to date there are no studies on IBWT's vulnerability quantification based on the bottom-up framework. Furthermore, no studies have put forward system performance criteria or selected a water system model which is really suitable for the IBWT. Due to the significant difference in scale and complexity between the ordinary water supply systems and IBWT, the bottom-up vulnerability assessment framework established for the ordinary water supply systems is not suitable for the IBWT.

In this paper, we provide a framework of vulnerability quantification of an inter-basin water diversion system. Beginning with identifying hazards which bring the key vulnerability of future climate to IBWT, a performance indicator is then developed to quantitatively measure vulnerability. Next, a water system model is chosen to predict annual water availability under the identified hazards, and we further combine the indicator and the model as a whole to involve greater complexity for the water transfer system and accurately reflect vulnerability for the bottom-up decision making. In order to show the practicality and feasibility of the framework, this study provide a demonstration of bottom-up quantification of future vulnerability for the Central Route of the South-to-North Water Transfer Project (SNWTP). Quantifying vulnerability of IBWT will help people to reexamine the performance of this kind of project under climate change, and provides a reference for water resource managers to face future climate effects wisely.

2. Central Route of the South-to-North Water Transfer Project

2.1. Description of the project

The SNWTP in China is the largest and the most strategic water transfer project ever undertaken. The SNWTP diverts water from the water rich south-central China to the arid North China plain through a large canal (Fig. 1). The total length of the canal is approximately