Journal of Hydrology 564 (2018) 115–124

Contents lists available at ScienceDirect

Journal of Hydrology

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

Research papers

An interval parameter conditional value-at-risk two-stage stochastic programming model for sustainable regional water allocation under different representative concentration pathways scenarios

Qiang Fu[a,b,c], Linqi Li[a], Mo Li[a,b,*], Tianxiao Li[a,b], Dong Liu[a,b], Renjie Hou[a], Zhaoqiang Zhou[a]

[a] School of Water Conservancy and Civil Engineering, Northeast Agricultural University, Harbin, Heilongjiang 150030, China
[b] Key Laboratory of Effective Utilization of Agricultural Water Resources of Ministry of Agriculture, Northeast Agricultural University, Harbin, Heilongjiang 150030, China
[c] Heilongjiang Provincial Key Laboratory of Water Resources and Water Conservancy Engineering in Cold Region, Northeast Agricultural University, Harbin, Heilongjiang 150030, China

ARTICLE INFO

This manuscript was handled by G. Syme, Editor-in-Chief, with the assistance of Bellie Sivakumar, Associate Editor

Keywords:
Regional water resources allocation
Interval two-stage stochastic model
CVaR
RCP

ABSTRACT

The shortage of water resources and the increasing competition among water users have highlighted the importance of the water allocation problem. Water availability is crucial for water resource allocation and changes frequently, leading to the necessity to predict available water. This paper develops a framework aimed to plan regional water allocations under different representative concentration pathways (RCP) scenarios using an interval parameter conditional value-at-risk (CVaR) two-stage stochastic programming model. This framework combines prediction and optimization to reflect climate change, the uncertainty of water system and the coordination between water resources allocation and risk. The feasibility and practicality of the framework are demonstrated by its application in a real-world case study in the Lower Songhua River Basin in northeast China. Comparison between the results of the developed model and actual conditions show that 11.61×10^8 m^3 volume of water supply can be saved after optimization, indicating that the developed model tends to allocate water in a more efficient way. The ratio of surface water to groundwater is reduced from 2:1 to 1.62:1. The proposed model has practical relevance for saving water and alleviating groundwater overexploitation. The approach is applicable to most areas with severe water shortages and groundwater overexploitation, and decision makers can determine the appropriate options for water resources allocation based on risk preferences and actual conditions.

1. Introduction

With the development of society and the expansion of cities, the unsustainable planning and management of regional water resources have intensified the imbalance between water supply and demand, resulting in a serious waste of surface water and severe exploitation of groundwater (Asefa et al., 2014; Fu et al., 2018a). In addition, extreme weather conditions influence the uncertainty of the available water supplies and lead to economic risk for water management systems, thus creating a barrier to the allocation of water resources (Hu et al., 2016a,b). Therefore, water allocation based on reasonable and available water prediction is an intense global issue.

The available surface water is a critical factor for regional water resources planning. Runoff is the main source of surface water and is influenced by uncertain climatic factors such as temperature and precipitation (Najafi and Moradkhani 2015; Milly et al., 2008). To quantify these uncertainties, many studies have coupled the representative concentration pathways (RCP) scenarios that were proposed in the Intergovernmental Panel on Climate Change Fifth Assessment Report (IPCC AR5) (Intergovernmental Panel on Climate Change (IPCC) 2013) with multiple general circulation models (GCMs) to predict the future climate. GCMs are considered the best available tools for modelling the future climate (Wang et al., 2017a,b). The variable infiltration capacity (VIC) model can simulate the available runoff. Zhang et al. (2012) used the VIC model to explore the change trend of water resources in the Huaihe River Basin under global warming. These studies enable the accurate prediction of the available surface water.

Based on the prediction of available surface water corresponding to different climate change scenarios, regional water resources can be planned through optimization techniques. Li et al. (2015) developed the two-level linear fractional water management (TLFWM) model and the stochastic two-level linear fractional chance-constrained water management (STLFCWM) model to identify desired water resources management policies considering various uncertainties. Hu et al.

* Corresponding author at: School of Water Conservancy and Civil Engineering, Northeast Agricultural University, Harbin, Heilongjiang 150030, China.
E-mail address: limo0828@neau.edu.cn (M. Li).

https://doi.org/10.1016/j.jhydrol.2018.07.008
Received 8 April 2018; Received in revised form 1 June 2018; Accepted 4 July 2018
Available online 05 July 2018
0022-1694/

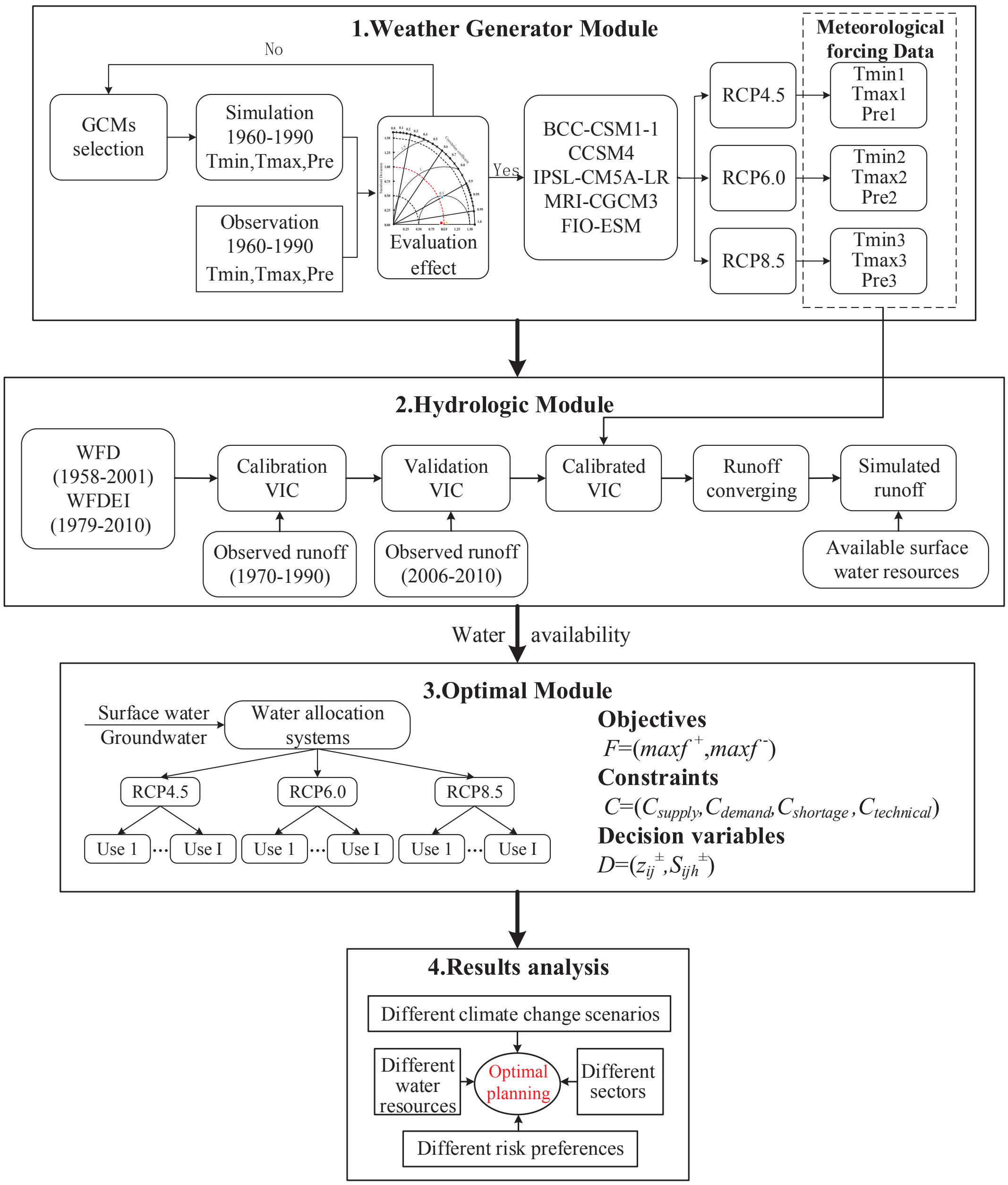

Fig. 1. Decision procedure of the developed framework for water resources planning.

(2016a) used the compromise programming (CP) method to trade off economic benefit efficiency and equity in the water allocation. Li et al. (2017) developed an intuitionistic fuzzy multi-objective non-linear programming (IFMONLP) model that solved multiple problems, including crop yield increases, blue water savings, and water supply cost reductions. However, there are many uncertainties, such as water availability variations, water price fluctuations, and allocation target changes, in regional water systems. Therefore, incorporating uncertainty programming methods into the optimization models for regional water allocation is necessary (Maqsood et al., 2005). The interval two-stage stochastic programming (ITSP) model is widely used in many uncertainty optimization models (Lin et al., 2009; Lu et al., 2009). The ITSP model can overcome the complexity and uncertainty of water resource systems by using interval parameters and probability distribution, such as unit product income, upstream water quantity and changes in ecological water demand in different sectors, these uncertainties can lead to multiple uncertainties and uncertain amplifications via their interaction (Fu et al., 2018b). In summary, to ensure the sustainable development of water resources and improve their utilization rate, the ITSP model can optimally plan the allocation of water resource systems.

Because water shortages are exacerbated by climate change, the allocation risks should be considered in water allocations to ensure the coordinated development of the regional economy and water resources (Shao et al., 2011). Wang et al., 2017a integrated conditional value-at-risk (CVaR) into factorial stochastic programming to solve the random uncertainties and interactions in water resource systems. Hu et al. (2016b) used CVaR to control the risk of economic efficiency loss corresponding to variations in water availability. CVaR, which is an improved value-at-risk (VaR) method, is an investment risk measurement method (Rockfellar 2000) and is effectively used in optimization models for regional water allocation because it is based on a simple calculation and it provides a better reflection of potential risks (Xu and Yu, 2014; Yamout et al., 2007). Further, using CVaR can ensure fair water allocations and balance the system benefits and expected losses. Accordingly, incorporating CVaR into the ITSP model is useful for