

An uncertainty-based framework for agricultural water-land resources allocation and risk evaluation

Mo Li^a, Ping Guo^{a,*}, Vijay P. Singh^b, Gaiqiang Yang^{a,c}

^a Centre for Agricultural Water Research in China, China Agricultural University, Beijing 100083, China

^b Department of Biological and Agricultural Engineering & Zachry Department of Civil Engineering, Texas A & M University, College Station, TX 77843-2117, USA

^c Institute of Environmental Science, Taiyuan University of Science and Technology, Taiyuan, Shanxi 030024, China

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ABSTRACT

Agricultural land and water resources are simultaneously declining due to population growth and economic expansion, which emphasizes the need for optimal allocation of these resources to balance socioeconomic development and water conservation. This study develops a framework for allocation of agricultural land-water resources and risk evaluation under uncertainty. The framework is capable of fully reflecting multiple uncertainties expressed as intervals and probability distributions, considering the connections of agricultural water and land resources. The developed framework will be helpful for managers in gaining insights into the tradeoffs between system benefits and constraint-violation risks, permitting an in-depth analysis of risks of agricultural irrigation water shortage under various violating probabilities. The framework is applied for optimization of agricultural water and land resources in the middle reaches of Heihe River basin. A series of water and land allocation results under different flow levels and violating probabilities were obtained and analyzed in detail through optimally allocating limited water and land resources to different irrigation areas and crops. Comparison with actual conditions shows that both the “net benefit per unit water” and “net benefit per unit land” increase which will demonstrate the feasibility and applicability of the developed framework. In addition, probability distributions of water allocation under various flow levels are generated to help decision makers learn detailed water distribution information and thus help make comprehensive irrigation schemes in the planning horizon under uncertainty. Results of evaluation of agricultural irrigation water shortage risks indicate that the water shortage risks in the middle reaches of Heihe River basin are in the category of acceptable risk level or brink risk level. The developed framework can be valuable for providing a reliable decision aid for optimal water and land resources allocation, and can ensure that the management policies and plans are made with reasonable consideration of both system benefits and risks.

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1. Introduction

In recent decades, the conflict-laden issues of water allocation among competing users have been of great concern for many countries due to shrinking water availability and deteriorating water quality that interfere with socioeconomic development and people's daily lives (Wang and Huang, 2014; Li et al., 2015). These issues restrict the development of agricultural sector in which irrigation water consumption is responsible for approximately 70% of total water consumption (Pereira et al., 2015), because water resources

originally used for agricultural irrigation have to be diverted to industrial and ecological activities on the basis of guaranteeing domestic water to reduce the loss of industrial output and promote environmental protection (Bao and Fang, 2007; Dong et al., 2014). This diversion will correspondingly reduce agricultural benefit and thus affect the distribution of crop cultivation. Therefore, optimal allocation of available agricultural irrigation water and land-use resources is desirable and beneficial for agricultural development.

Optimal allocation of agricultural irrigation water and land-use resources can be determined using optimization models (Stray et al., 2012). Recently, many real-life case studies about agricultural irrigation water and land-use resources management using various programming techniques in optimization modelling have been reported (Sethi et al., 2006; Letcher et al., 2007; Cheng et al., 2009; Fasakhodi et al., 2010; Alabdulkader et al., 2012; Sabouni

* Corresponding author at: Centre for Agricultural Water Research in China, China Agricultural University, Tsinghua Street No.17, Beijing 100083, China.
E-mail address: guop@cau.edu.cn (P. Guo).

and Mardani, 2013; Guo et al., 2014; Das et al., 2015; Singh, 2015). However, many studies focused on optimizing agricultural irrigation water and land-use resources separately, and did not especially consider how agricultural irrigation water resources of higher scales restrict agricultural land-use distribution of lower scales.

Optimal allocation of agricultural irrigation water and land-use resources in real field conditions is more challenging, because various uncertainties exist in the interactions among many system components. Examples include the temporal and spatial variation of water availability and water demand due to various random parameters, e.g. rainfall, evapotranspiration, and other climate conditions in irrigation areas, and errors in estimating crop yield, irrigation quota and economic related parameters, etc. (Li et al., 2014; Singh, 2015). Therefore, introduction of uncertainty into traditional optimization methods is an effective way to reflect the complexity and reality of an agricultural water-land resources allocation system.

In recent years, a number of studies on agricultural irrigation resources or agricultural land-use resources allocation involving uncertainties have been reported (Cai et al., 2004; Regulwar and Gurav, 2011; Dai and Li, 2013; Dong et al., 2014; Li and Guo, 2015). Among them, inexact two-stage stochastic programming (ITSP) has proved to be an effective technique for dealing with uncertain coefficients with known probability distributions and independent uncertain coefficients (Maqsood and Huang, 2003; Guo et al., 2009). In ITSP, random parameters (e.g., runoff and precipitation), that obey certain probability distribution functions (PDFs), are expressed by interval numbers, of which the degree of uncertainty is determined by a certain confidence interval or a probable error range in order to overcome the difficulty of requiring PDFs (Chen et al., 2014). However, such simplified method will

result in loss of information to some extent without knowing the distribution of allocated results. Furthermore, ITSP is based on the assumption that the decision maker is risk neutral and can hardly reflect the reliability of satisfying (or risk of violating) system constraints under uncertainty. As a result, ITSP may become infeasible when the decision maker is risk-taking under high-variability conditions (Chen et al., 2013). The chance constrained programming (CCP) technique, which requires that the constraints are satisfied in a proportion of cases under given probability levels, is capable of addressing the above difficulty (He et al., 2008). Therefore, a potential approach is to integrate ITSP with CCP in a comprehensive framework of agricultural irrigation water and land-use resources allocation by fully considering the randomness and risk violations of water availability for agricultural systems.

Uncertainties exist in agricultural systems and risk originates from the uncertainty (Iglesias et al., 2007). Agricultural irrigation water shortage is unavoidable because of the randomness of precipitation and runoff, especially in arid regions. When agricultural irrigation water shortage is on a small scale, the main consequence may simply be the loss of system benefits. However, if the degree of water shortage increases, the extent of the damage may change from the loss of benefits to system impairment (Li et al., 2015). Therefore, it is of paramount importance to reflect agricultural system impairment by evaluating the agricultural irrigation water shortage risk caused by the limitation of water availability to provide the guidance in both engineering and management. Nevertheless, limited cases have been reported on agricultural irrigation water shortage risk evaluation based on optimization models under uncertainty.

Therefore, the aim of this study is to develop an uncertainty-based framework for agricultural water-land resources allocation

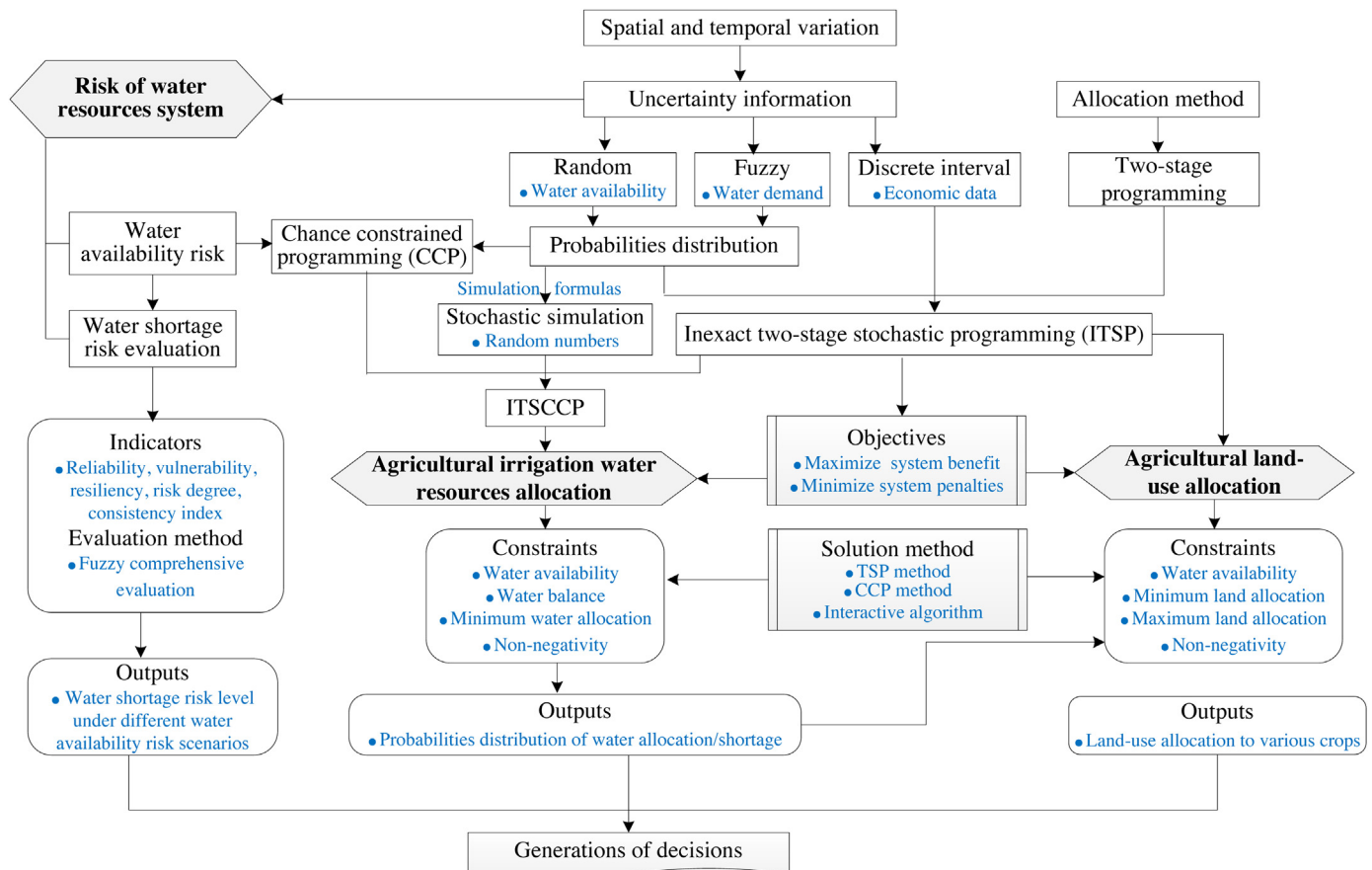


Fig. 1. Framework of agricultural water-land resources allocation and risk evaluation under uncertainty.

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