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Irrigation vulnerability assessment on agricultural water supply risk for adaptive management of climate change in South Korea

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ABSTRACT

Climate change influences various environmental aspects, including those specifically related to agricultural water resources such as runoff, evapotranspiration, droughts and floods. Understanding the impact of climate change on reservoirs in relation to the passage of time is an important component of water resource management and the maintenance of a stable water supply. In different regions, changes in rainfall and hydrologic patterns due to climate change can increase the occurrences of reservoir water shortages and affect the future availability of agricultural water resources differently. It is a main concern for sustainable development in agricultural water resources management to evaluate the adaptive capability of a water supply under future climate conditions. Studies on climate change impacts and vulnerability assessments have been an essential process for preparing adaptive measures. This paper proposes a practical method to assess water supply vulnerability and sustainability in terms of climate change for the adaptive capability of agricultural reservoirs in South Korea based on a concept of probability theory and reliability analysis using time-dependent change analysis of water supply and demand. The objectives of this study were to investigate if there is evidence of climate change occurrences with respect to potential water supply capacity and irrigation water requirements; and to apply an irrigation vulnerability assessment model to assess the potential effects and predict the impacts of agricultural water demand and supply on reservoir operation to govern local water management decisions under climate variability and change. The irrigation vulnerability was estimated to evaluate the performance of water supplies in agricultural reservoirs; it is a recommended preparatory adaptive measure for developing a future water supply strategy in terms of using climate change scenarios reflecting different future conditions.

1. Introduction

Climate change influences various environmental aspects, including precipitation, evapotranspiration patterns and river discharge (Arnell et al., 2011; Zhang et al., 2011). Changes in precipitation patterns affect water availability and runoff directly, while changes in temperature, radiation and humidity have an effect on evapotranspiration (Buytaert et al., 2009). The hydrologic impact of climate change can increase occurrences of extreme hydrologic events, heavy rainfall, and droughts because of a considerable decrease in water availability caused by a deficit in precipitation during a significant period (Vrochidou et al., 2013). In particular, climate change has significant impacts on agricultural water resources such as availability of water supplies, agricultural water management, droughts and floods. The impacts of climate change on water resources, with respect to the various inherent uncertainties associated with water demand, regulatory requirements, consumer preferences and environmental standards, have been well described (Gober et al., 2010; Ncube et al., 2011; Georgakakos et al., 2012; Nkomozepi and Chung, 2012; Mehta et al., 2013; Trenberth et al., 2013). Due to increasing uncertainties related to potential climate change impacts, dynamic socio-economic conditions require an adaptive and flexible approach to water management (Paydar and Qureshi, 2012). Stakeholders need quantitative information concerning the inherent uncertainties of regional and management variability derived

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from climate change impact forecasts (Brekke et al., 2004; Wiley and Palmer, 2008; Ruane et al., 2013). It is important to consider the range of such impacts in the adoption of appropriate planning and mitigation measures of water resource systems due to climate change (Raje and Mujumdar, 2010); these impacts must be considered when making long-term planning and management decisions (Wilhite et al., 2000, 2014).

For agricultural water management, there are essential elements to be considered, including water supply in the agricultural reservoir and demand in the irrigation district. The predicted duration of a water supply could be impossible under the uncertainty of meteorological and hydrological phenomena. It is a main concern for sustainable development in agricultural water resources management to evaluate the adaptive capability of a water supply under future climate conditions. Understanding the impact of climate change on reservoirs in relation to the passage of time is an important component of water resource management and the maintenance of a stable water supply. A change in rainfall patterns, and the hydrological impact due to climate change thereof, can increase the occurrence probability of water shortages in agricultural reservoirs, affecting the future availability of agricultural water (Vano et al., 2010; Nam, 2013). The water supplied by reservoirs can be drastically affected by the climate variability of meteorological and hydrological phenomena, including the frequency, intensity and location of extreme events. Additionally, because of an increasing shortage of water resources, climate change will further threaten water availability and management (Koutroulis et al., 2013). The development of a sustainable agricultural water resource management system is necessary to evaluate the adaptive capability of a water supply under changes in environmental and climate conditions.

This study aimed to contribute an essential process for preparing adaptive management of agricultural resources under climate change and climate variability conditions, and to provide a method for the adaptation of agricultural resource management techniques under the conditions of a changing water supply and variable climate over time. The primary purpose of this study was to develop an assessment method for the irrigation vulnerability in agricultural reservoirs based on a concept of probabilistic reliability. The objectives were (1) to investigate if there is evidence of climate change occurrence at a local scale with respect to potential water supply capacity and irrigation water requirements, (2) apply an irrigation vulnerability assessment model using Representative Concentration Pathways (RCPs) climate change scenarios, and (3) predict the impacts of agricultural water demand and supply on reservoir operation under future climate change. The work presented in this paper deals with studying the potential impacts of future climate change on water supply and demand considering reservoir operation performance. We focused on how adaptive policy options can reduce irrigation vulnerability to climate change for efficient agricultural water resources planning and management.

2. Materials and methods

2.1. Materials

2.1.1. Description of agricultural reservoirs in South Korea

In South Korea, agricultural reservoirs are the main water sources of irrigated paddy field areas through irrigation facilities which have the purpose of securing reliable local water supplies while conserving the environment. Approximately 18,000 agricultural reservoirs in South Korea have been built in rice cultivation areas since 1900. According to the statistical yearbook of land and water development for agriculture in 2012 (KRC, 2012), there are a total of 17,531 agricultural reservoirs, of which 3356 (approximately 19%) are managed by the Korean Rural Community and

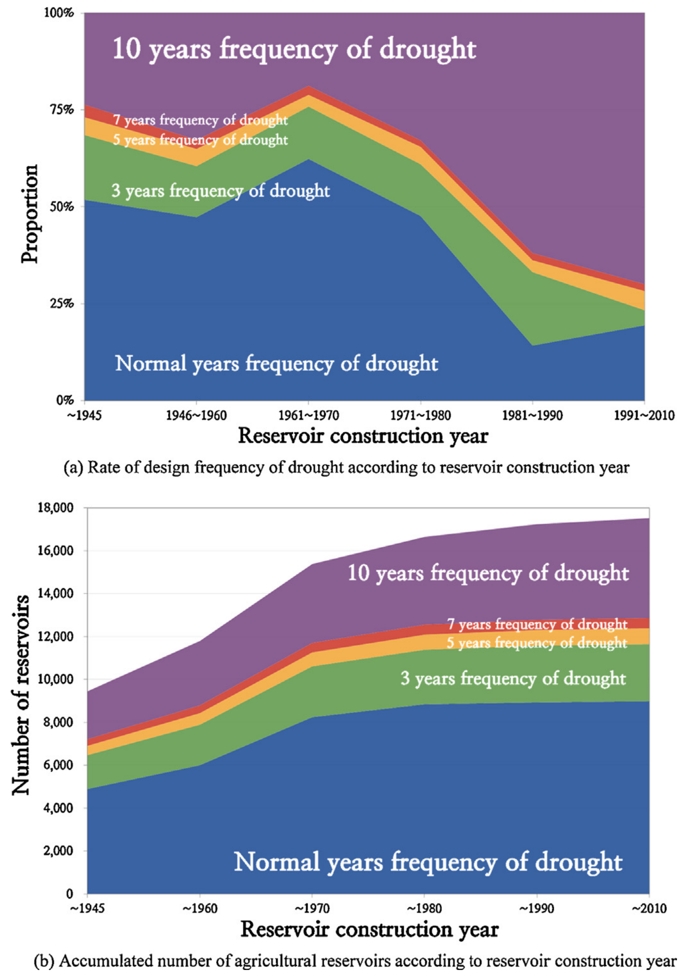

Fig. 1. Classification of agricultural reservoirs based on the relationship between design frequency of drought and reservoir construction year.

Agriculture Corporation (KRC) and 14,175 (approximately 81%) are managed by local governments. The design frequency of drought means one of the design criteria for water supply capability in reservoirs at the time of design and construction such as the degree of reservoir withstand drought phenomenon or capacity of drought resistance. In other words, it is the number of years a reservoir needs to be able to withstand a drought phenomenon; it is the standard drought resistance capacity for agricultural water resources, and is typically defined as the ability to withstand a 10-year drought. This indicator was defined to construct an irrigation system with enough capacity to meet the expected crop water requirements at the time of design and planning (Cuenca, 1989; MAF, 1998, 1999). According to KRC, the capacity of drought resistance expressed as year frequency such as normal-year, three-year, five-year, ten-year, etc. For example, the reservoir as the ten-year design frequency of drought can withstand drought condition of ten-year frequency. The design frequency of drought in the case of recently constructed reservoirs is a 10-year drought, as shown in Fig. 1(a), but approximately 22% of the agricultural reservoirs that are managed by the KRC, and approximately 86% of the agricultural reservoirs that are managed by local governments, do not satisfy the capacity requirements for a 10-year drought, as shown in Table 1 and Fig. 1(b). Sixty-two percent of the KRC reservoirs and 64% of the local government reservoirs have been in operation for more than 50 years; therefore, it is necessary to evaluate water supply malfunctions or inefficiencies, and the design frequency of drought is not appropriate to the current and future capacity of