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Research paper

The effects of climate change on the water resources of the Geumho River Basin, Republic of Korea

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Abstract

Assessments of the variation and vulnerability of water resources due to climate change are essential for future planning in agriculture. In this study, the impacts and uncertainty associated with climate change on water resources in the Geumho River Basin were measured based on the relative change in the mean annual runoff and the aridity index. Statistically adjusted and downscaled multi-ensemble General Circulation Model (GCM) predicted rainfall and temperature data for three representative concentration pathways (RCPs) (RCP2.6, 4.5 and 8.5) were applied to two lumped parameter conceptual rainfall runoff models. The results revealed considerable uncertainty in the projected temperature, rainfall, potential evapotranspiration (PET), runoff and aridity index (AI). Additionally, temperature and rainfall were predicted to increase significantly in the future. The PET was projected to increase by a mean (range) of 9% (7–12%), 18% (9–30%) and 25% (8–49%), while the mean annual runoff was projected to change by a mean (range) of 1% (−33 to 40%), −9% (−47 to 27%) and −4% (−44 to 35%), in the 2030s, 2060s and 2090s, respectively. The AI was projected to decrease in the future, particularly for the RCP8.5. Overall, the results of this study indicate that climate change will most likely lead to lower water resource levels than are currently present in the Geumho River Basin.

Keywords: Climate change; Water resources; Korea; Runoff; Aridity index

1. Introduction

Numerous assessments of the relative effects of climate change and population growth on future global and regional water resources have been conducted (Arnell, 2004). There is a consensus that recent changes in atmospheric temperature and rainfall (frequency, intensity and distribution) that have affected the occurrence and magnitude of natural disasters (flood, drought, etc.) are closely related to climate change (Kang et al., 2007). Systematic treatment of uncertainties and pragmatic application of risk-analysis techniques in both climate change scenarios and impact response are required for effective mitigation and adoption methods (Jones et al., 2006). Climate change is expected to increase water resource stress in some parts of the world in which rainfall and runoff decrease, including the Mediterranean, parts of Europe and America (Döll, 2002). Despite the annual mean rainfall being projected to increase in all Korean basins, the annual mean runoff has been projected to decrease in many basins by the end of this century (Bae et al., 2008). Assessments of the variation and vulnerability of runoff due to climate change are essential for future planning because changes in climatic processes affect both the water resources availability and demand for water by agriculture (Elmahdi et al., 2005).

Chen et al. (2012) evaluated and compared the uncertainty in runoff simulated from different impact assessment steps in the Hanjiang River basin and confirmed that multiple General Circulation Models (GCMs) improve the reliability of the results of a study. The ensemble modelling approach for hydrological climate change impact assessment has been widely adopted (Kling et al., 2012; Bae et al., 2008; Chen et al., 2012). Decisions about climate scenarios and the number of

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GCMs to apply to a hydrological model typically involve a trade-off between representing a broad range of plausible climate change uncertainties and the realistic representation of climate variability within each scenario (Jones et al., 2006). Modelling rainfall runoff relationships can be complicated and time-consuming because simulation models typically require extensive input data and user expertise for various stakeholder levels (Muthukrishnan et al., 2006). A review by He et al. (2011) revealed that numerous studies have shown the usefulness of limited data in regionalization for continuous stream flow simulation. The hydrological response of a catchment is a holistic function that integrates structural and hydro-climatic features into one signature (He et al., 2011). Quantitative assessment of the impact of climate change on water resources is challenged by statistical, model and fundamental uncertainty (Peterson et al., 1997).

We predict that (1) the water resources levels will be significantly altered by climate change and (2) the associated uncertainty will be largely due to GCMs rather than rainfall runoff models in the future (Xu et al., 2012). Therefore, this study was conducted to assess the uncertainty of the surface runoff simulated from 5 GCMs predictions using two rainfall runoff models in the Geumho River Basin, Korea.

2. Materials and methods

2.1. Study area

The Geumho River is 118.4 km long and has a catchment area of 2078 km^2 (Fig. 1). The Geumho River Basin occupies about 10% of the Nakdong River Basin. The river originates from Mt. Gato (EL720m), flows through the southeastern part of the Korean peninsula, and then joins the middle part of the main stream of the Nakdong River. The base population of the basin was 1,991,718 in 2009. The basin supports an economy based on agriculture (high quality apples and oriental melons) and manufacturing (textiles, metals and machinery). Land use in the basin can be classified into water bodies (2%), irrigated crops (20%), forests (58%), grasslands (10%) and urban areas (10%) (Chung and Nkomozepi, 2012).

Fig. 1. Map of the Geumho river basin.

The Geumho River Basin is subject to a humid subtropical climate, and two-thirds of the annual rainfall occurs in the summer months (May to September). The average annual rainfall and temperature in the basin from 1970 to 2000 was 1021 mm and 12.3 °C, respectively. The hydrology of the Geumho River is strongly influenced by summer rain, and approximately 60% of the average annual discharge occurs during summer. The average annual discharge at the confluence with the Nakdong River is almost 20 $m^3 s^{-1}$ (based on 1970–2000 data).

2.2. Climate and runoff data

Historical climate data (rainfall and temperature) for the river basin were extracted from the Korean Meteorological Administration (www.kma.go.kr). Records of flow at the Geumho river confluence into the Nakdong River were extracted from the Korean Water Information System (water.nier.go.kr/). GCMs with sufficient historical and future datasets of the representative concentration pathways (RCPs) family were selected. The selected number allows sufficient assessment of uncertainty without exacerbating the computational demands of the study. The GCM ensemble herein includes 5 out of the 60 GCMs in the World Climate Research Programme's (WCRP's) Coupled Model Intercomparison Project phase5 (CMIP5) dataset, BCC-CSM1.1, CanCM4, ACCESS1.0, IPSL-CM5A-LR and MIROC5 developed by the Beijing Climate Center, Canadian Centre for Climate Modelling and Analysis, Commonwealth Scientific and Industrial Research Organisation (Australia), Institut Pierre-Simon Laplace (France) and the Atmosphere and Ocean Research Institute (Japan), respectively.

2.3. Statistical adjustment and downscaling method

Weather generators replicate the statistical attributes of local climate variables, but not the observed sequences of events (Wilby et al., 2004). In this study, the Long Ashton Research Station stochastic Weather Generator (LARS-WG) was used because it has been validated worldwide and shown to perform well in the simulation of different weather statistics relevant to agriculture (Semenov and Barrow, 1997). Outputs from 5 GCMs for the 1971–2000 (baseline), 2021–2040 (2030s), 2051–2070 (2060s) and 2081–2100 (2090s) time periods were used to generate climate change scenarios. The period from 1970 to 2000 was adopted as the baseline because it is a standard reference for many impact studies (Zhang et al., 2011). The 2030s, 2060s and 2090s correspond to short-, mid- and long-term forecasts, respectively. The input observed weather was used to determine the parameters that specify the probability distributions of weather variables and their correlation coefficients used in the LARS-WG. Future climate change scenarios were generated stochastically by perturbing the baseline climate. The LARS-WG simulates rainfall occurrence using a two–state, first-order Markov chain: rainfall amounts on wet days using a gamma distribution and temperature and radiation components using first-order tri-