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Drought hazard assessment in the context of climate change for South Korea

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ABSTRACT

Drought has had large impacts on economies, societies and the environment, and could become even more disruptive given the context of climate change characterized by increasing temperature and more variable and extreme precipitation. Changes in the frequency, duration, and severity of droughts will have enormous impacts on the hydrological cycle, water management and agricultural production. Therefore, one major concern arising from climate change is its potential effects on water resources. Although South Korea has been experiencing serious drought and water scarcity issues in recent years, preparedness for potential changes in the frequency, severity and duration of drought disasters due to climate change effects has received only limited attention. It is important to detect changes in temporal trends of drought at the regional scale. This information will aid understanding the impacts of climate change and its subsequent effects on hydrology and agriculture. In this paper, we have addressed the question of how climate change might influence the impact of drought hazard by estimating the potential changes in temporal trends of drought in South Korea. We have assessed the temporal trends of future drought with drought indices (Standardized Precipitation Index [SPI], Standardized Precipitation Evapotranspiration Index [SPEI], and Self-Calibrating Palmer Drought Severity Index [SC-PDSI]) using past observed data (1981–2010) from 54 meteorological stations maintained by the Korea Meteorological Administration (KMA) and projected climate change scenarios (2011–2100) as depicted by the Representative Concentration Pathways models (RCPs). The drought hazard assessment was quantitatively evaluated by analyzing drought frequency, duration, severity and magnitude using the run theory method based on different timescales of the drought indices. The results demonstrated a significant increase of potential drought impacts in the future. Additionally, significant increases in the drought magnitude and severity were found at different time scales for each drought indicator. The results indicated that the temporal pattern of potential drought progression and recession across South Korea can be used for the development of proactive drought risk management and mitigation strategies.

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1. Introduction

Climate change is one of the most significant issues facing the world because it is predicted to alter climate patterns and increase the frequency of extreme weather events (Palmer and Raisanen, 2002; Hayes et al., 2004; Intergovernmental Panel on Climate Change (IPCC), 2012). In recent years, the frequency of droughts that are due to global warming-related climate change has increased and is accompanied by a rise in the severity of these phenomena (Dai et al., 2004; Sheffield et al., 2012; Intergovernmental Panel on Climate Change (IPCC), 2013). Drought is expected to become more frequent and severe, with increasing water demand due to population growth, limited and uncertain water supplies in the context of climate change characterized by increasing temperatures, and more extreme precipitation regimes (Smith and Katz, 2013; Trenberth et al., 2014). For these reasons, it is important to establish appropriate expectations of future drought impacts caused by severe droughts due to climate change. Therefore, studies that attempt to anticipate droughts on a long-term scale by analyzing the effects of climate change on drought characteristics are necessary to reduce vulnerability and establish appropriate and innovative strategies for drought mitigation and preparedness

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(Wilhite et al., 2014). Mitigation in the context of natural hazards refers to actions taken in advance of the occurrence of the hazard to reduce or avoid the impacts associated with the event.

One important characteristic of drought that distinguishes it from other natural hazards is the lack of a universal definition; drought must be defined according to the characteristics of each climatic regime and specific impact sector (Wilhite et al., 2007). Another complicating factor in characterizing drought impacts is that they vary on both spatial and temporal scales, especially from a hydrologic or disaster prevention perspective (Wilhite, 1997). Thus, drought assessment methods and various kinds of drought indices have been used in an attempt to predict and monitor droughts using indicators based on hydrologic and meteorological data (Keyantash and Dracup, 2002; Svoboda et al., 2002; Shahid and Behrawan, 2008; Knutson and Haigh, 2013; Labedzki and Bak, 2014; Otkin et al., 2015). The Standardized Precipitation Index (SPI), Palmer Drought Severity Index (PDSI), and Standardized Precipitation Evapotranspiration Index (SPEI) have been defined as the representative indices for drought analysis. These drought indices can provide the spatial and temporal characteristics of drought management tools for decision makers in government and for public stakeholders.

Effective drought management depends on the ability to anticipate future drought conditions and provide drought countermeasures through risk-based drought management (Wilhite et al., 2000; Botterill and Hayes, 2012; World Meteorological Organization (WMO) and Global Water Partnership (GWP), 2014; Svoboda et al., 2015). The general method used to forecast long-term drought is to analyze projected hydrologic and meteorological data through a global climate model (GCM), in which various climate scenarios can be applied. Extensive research efforts based on global climate models depicting future climate scenarios show significant changes in occurrence and duration of severe drought (Dai, 2013; Bak and Labedzki, 2014; Dubrovsky et al., 2014; Touma et al., 2015). Many studies of drought assessment have focused on drought frequency analysis, drought monitoring and short-term forecasting of drought using various types of hydrologic variables and drought indices. Less research has been conducted on quantifying changes in the possible future occurrence of drought as a result of climate change. This quantitative assessment of drought risk to establish effective drought mitigation measures relies on drought indices, which consider the characteristics of drought severity, frequency, impacted area, and duration. Thus, drought risk evaluation should include occurrence frequency and spatial extent of drought, drought magnitude, and drought severity (Nam et al., 2012b; Spinoni et al., 2014). It is important to conduct research on predicting the effect of climate change on potential drought vulnerability and to quantify the temporal/spatial pattern of droughts in order to systematically prepare for drought-related disasters.

South Korea is one of the countries classified as water deficient by the United Nations, and, in recent years, has experienced serious droughts and water scarcity problems (Kim et al., 2014). Historical weather records confirm that South Korea has recently experienced large-scale drought at the national level (Min et al., 2003; Kim et al., 2011). In addition, the climate of South Korea experienced a gradual warming throughout the 20th century (Im et al., 2011). The change of the mean climate state could lead to a change of climate extremes due to a shift in the temperature and precipitation distribution (Sohn et al., 2013). Anthropogenic climate change is projected to accelerate in the future, and South Korea will be vulnerable to changes in various types of extreme climate events. In fact, changes in climate extremes have been documented over South Korea (Nam et al., 2015a). Although some empirical studies have performed the vulnerability analysis to assess the effect of climate change on water resources (Kim et al., 2009; Lee and Kim, 2013; Nam et al., 2015b), the indicators used in the previous works may not adequately reflect the impacts of drought, especially at the local level, and may not be relevant across multiple regions and sectors. Faced with these challenges, water resources decision makers in South Korea need explicit information to help develop preparedness plans and establish policies that are aimed at reducing the impacts of drought under a changing climate (Nam and Choi, 2014). Research on the temporal and spatial characteristics of drought is necessary to evaluate the potential impacts of drought and to carry out rational management of water resources.

A number of concerns are associated with climate change and changes in the temporal trends of drought impacts in South Korea. In this study, we focus on changes in the temporal trends in the different regions within South Korea, using the regional responses to modeled climate change. The objectives of this study include (1) analyzing and quantifying changes of the temporal trends of the SPI, SPEI, and SC-PDSI drought indices, and (2) detecting and quantifying future potential drought duration, magnitude, and severity. The multiple drought indices and multiple timescales (e.g., 1, 3, 6, 9, 12 and 24 months) were compared with past drought events to identify the effects of climate change on the drought impacts. Various drought indices were used to estimate current and future changes in both frequency and duration for each drought classification (e.g., moderate and severe drought classes). The change in the temporal pattern of the potential drought hazard is presented in an attempt to identify the most vulnerable period and to help in determining ways to reduce drought vulnerability in specific sectors. The final results are expected to provide useful information for drought risk decision makers and for the wide range of stakeholders interested in the occurrence and consequences of recurrent droughts.

2. Materials and methods

2.1. Study area

The Korean Peninsula is located between China and the Japanese Islands in East Asia (35° 50′ N, 127° 00′ W). Korea's climate is predominantly influenced by the Asian monsoon, with an annual mean temperature of 12.3 °C and a range of average temperatures from 6.6 °C (winter) to 16.6 °C (summer). Climatologically, the annual maximum precipitation is recorded during the summer rainy season, from late June through July. Except in the dry regions (characterized by topographical effects and generally having less 1000 mm of precipitation), many parts of South Korea receive 1200 mm to 1400 mm of precipitation, which is about 30% more than the worldwide average of 973 mm (Korea Meteorological Administration (KMA), 2010; Jung et al., 2011). Climate variability in South Korea may have complex spatial and temporal variation because of the varying climatic and topographic characteristics arising from a complicated mountainous terrain. Fig. 1 shows the land cover map and the spatial distribution of the weather stations across South Korea. These data were classified on a Landsat satellite image (2009) obtained from the Ministry of Environment. This land cover map (Fig. 1) shows two major land cover types (i.e., urban or built-up land and agricultural land) and major agricultural areas of South Korea. The total cultivated paddy rice area in South Korea was 924 10^3 ha, accounting for around 53.2% of the total farm land area (Nguyen et al., 2012). According to FAO, South Korea provides 0.8% of the global rice production about 5632 10^3 MT to the Korean economy (FAO STAT, http://faostat.fao.org, 2013). Approximately 70% of the total paddy fields lie in the western and southern lowlands, with the rest in the valleys between mountains. A mountain range runs along the east coast and rivers flow both west and south. The midwest and southwest regions are agricultural areas. Agricultural water withdrawal constitutes approximately 47% of the total water use in South Korea and is mostly utilized for paddy irrigation.