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Research paper

Assessment of drought hazard, vulnerability, and risk: A case study for administrative districts in South Korea

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Abstract

This article presents a methodology for assessing drought hazard, vulnerability, and risk, using hydro-meteorological and socio-economic data. Though drought is a common natural disaster in South Korea, very little attention has been so far paid to preparedness of drought disaster, especially to spatial assessment of drought risk. A data-based framework for drought hazard and vulnerability was proposed in this study using a drought risk concept presented by the National Drought Mitigation Centre, USA. To quantify drought risk, Drought Hazard Index (DHI) was proposed based on the occurrence probability of drought from precipitation-based index and Drought Vulnerability Index (DVI) was proposed to reflect 7 socio-economic consequences of drought. The framework presented herein emphasizes the combined role of hazard and vulnerability in assessing drought risk and utilizes hydro-meteorological and socio-economic data to map the drought risk for 229 administrative districts across South Korea. The overall results demonstrate the effectiveness of the framework for the understanding of potential risk of drought in South Korea.

Keywords: Drought; Hazard; Risk; Vulnerability

1. Introduction

Drought is a persistently recurrent phenomenon which is one of the most costly natural disasters in the world. Further, drought is expected to become more frequent and severe, with increasing water demand due to population growth, limited and uncertain water supplies due to climate change and variability (Fontaine and Steinemann, 2009). Extensive research works based on global climate models on future climate show significant changes in temperature and precipitation (Houghton et al., 2001) in East Asia. South Korea is one of the countries classified as water deficient by the United Nation, and, in recent years, has experienced serious droughts and water scarcity problems (Kyoung et al., 2011). In addition, South Korea is one of densely populated areas with high-degree economic growth and experienced the extensive land use changes due to rapid urban development. Faced with these challenges, decision makers in water resources of South Korea need explicit information to help making preparedness plans to reduce the impacts of drought.

Considerable research efforts have been put into the quantification of drought severity because drought is usually characterized by its duration, severity, and affected area. Various kinds of drought indices have been developed to express drought severity from different points of view, i.e., meteorological, hydrological, agricultural, and socio-economic perspective. For example, PDSI (Palmer Drought Severity Index) developed by Palmer (1965) and SPI (Standardized Precipitation Index) developed by Mckee et al. (1993) are the representative indices for drought analysis.

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At present, more than 50 drought indices are available in practice (Kim et al., 2011). Although the shortage of various hydro-climatologic variables, such as precipitation, streamflow, soil moisture, results in drought, a shortage of precipitation for a long duration is the predominantly causative factor of drought. The effective drought index (EDI) is increasingly used in hydro-meteorological drought research areas, since the EDI has strengths compared with other drought indices (Kim et al., 2011). For example, although the EDI is solely based on precipitation, it is calculated in a simply way and considered to be more appropriate for monitoring drought condition in a shorter time interval than other drought indices since it provides drought severity on a daily basis (Kim et al., 2011).

Drought has disastrous characteristics with vast damaged area even though it is very difficult to know when a drought event begins. Therefore, drought management has typically focused on analyzing the hazard and assessing the vulnerability. In order to reduce the damages from drought, vibrant and active studies on drought hazard and vulnerability have been progressed all around the world. For example, Goddard et al. (2003) introduced drought index and spatial data to realize the degree of exposure to drought risk which can support decision making for drought risk management. Wilhite (2000) suggested an effective counteraction plan against drought by proposing 10 stages of drought management. Fontaine and Steinemann (2009) presented a vulnerability assessment method that incorporates stakeholder data into integrated and quantitative assessments of vulnerability components.

Many studies performed recently have emphasized the importance of comprehensive assessment of the drought risk by combining the hazard and vulnerability (Knutson et al., 1998; Wu and Wilhite, 2004; Shahid and Behrawan, 2008; Verdon-Kidd and Kiem, 2010; Lin et al., 2011). In South Korea, the research works have been carried out to develop disaster risk maps to cope with various natural disasters such as flood, tsunami, and landslides. However, drought-related disaster risk map has not been entirely satisfactory. Motivated by Shahid and Behrawan (2008), in which drought risk assessment was performed for Bangladesh by incorporating hazard and vulnerability, this study develops a data-based framework for assessing regional drought risk in South Korea. Similar to Bangladesh, due to high spatial and temporal climatic variability, extreme weather events, high population density, and inequality of social and financial resources, drought hazard and vulnerability are highly dependent on local capacity to deal with drought.

Given the significant impacts of previous droughts and the need to prepare for future droughts, a framework for drought risk assessment is presented in this study to identify the most vulnerable regions and to help determining ways to reduce drought vulnerability. A foundation of the framework presented herein is the acquisition of data and information available for the administrative districts that are directly affected from droughts and are responsible for coping with droughts. We then apply the method to the assessment of drought risk for the 229 administrative districts across South Korea, as shown in Fig. 1.

2. Drought hazard, vulnerability, and risk

Similar to other natural hazard risks, drought risk depends on a combination of the physical nature of drought and the degree to which a population or activity is vulnerable to the effects of drought (Shahid and Behrawan, 2008). Therefore, in order to assess drought risk, it is essential to quantify the frequency, severity, and spatial extent of droughts as well as the infrastructural and socio-economic ability to cope with drought (Shahid and Behrawan, 2008). This quantitative assessment of drought risk is utilized to establish effective drought mitigation measures. For example, Knutson et al. (1998) proposed 6-stage procedure to mitigate potential drought disaster in which the 2nd and 3rd stage are focused on identifying the area with high drought risk.

In this study, to assess drought risk, we developed a conceptual model, as shown in Fig. 2, in which drought risk was defined as a product of hazard and vulnerability as suggested by NDMC (National Drought Mitigation Center, http://drought.unl.edu/). To implement this concept quantitatively, two composite indices such as Drought Hazard Index (DHI) and Drought Vulnerability Index (DVI) were developed to express drought hazard and vulnerability, respectively. Finally Drought Risk Index (DRI) was calculated as in Eq. (1) using the DHI and the DVI.

$$\mathrm{DRI} = \mathrm{DHI} \times \mathrm{DVI} \tag{1}$$

3. Effective drought index

To assess drought hazard, first of all, we incorporated the frequency and severity of drought and developed a conceptual index using the effective drought index (EDI). After investigating several effective precipitation (EP) models, Byun and Wilhite (1999) suggested the EDI as in Eq. (2) for the most appropriate EP model.

$$\mathrm{EP}_i = \sum_{n=1}^{i}\left[\frac{\sum_{m=1}^{n} P_m}{n}\right] \tag{2}$$

where i is the period over which precipitation is summed, and P_m is the precipitation m days ago. For example, when i is 3 then daily EP is $P_1 + \frac{P_1+P_2}{2} + \frac{P_1+P_2+P_3}{3}$. According to Kim et al. (2009), the EDI is calculated as follows: the first step is to compute the daily effective precipitation (EP), and then to calculate the mean EP (MEP) for each calendar day, i.e. from 1 to 365. The DEP is defined as the difference between the EP and MEP, i.e., DEP = EP-MEP. Finally, the EDI is calculated in Eq. (3).

$$\mathrm{EDI}_j = \frac{\mathrm{PRN}_j}{\mathrm{std}\left(\mathrm{PRN}_j\right)} \tag{3a}$$

$$\mathrm{PRN}_j = \frac{\mathrm{DEP}_j}{\sum_{n=1}^{j}\left(\frac{1}{n}\right)} \tag{3b}$$

where j denotes the time (day) and std(PRN) is the standard deviation of each day's PRN. More details on calculating the