Bivariate copula function model for vegetation drought vulnerability mapping

Jeongeun Won[1] & Sangdan Kim[2,*]

[1]*Division of Earth Environmental System Science (Major of Environmental Engineering), Pukyong National University, Busan 48513, South Korea*

[2]*Department of Environmental Engineering, Pukyong National University, Busan 48513, South Korea*

**Corresponding author email: skim@pknu.ac.kr*

Highlights

- Vegetation vulnerability was investigated based on the bivariate copula function model.
- Seasonal vegetation vulnerability mapping under different drought conditions was performed.
- Areas vulnerable to meteorological drought were spatially identified.

Introduction

Drought is one of the most devastating natural disasters and has serious environmental and ecological impacts in the affected areas. Since vegetation is closely related to various hydrometeorological variables, the condition of vegetation during drought is greatly affected by water shortage(Du et al., 2019). Accordingly, studies to estimate the effects of drought on ecosystems such as vegetation are being actively conducted(Ding et al., 2020; Jiang et al., 2020). However, since the feedback between vegetation and climate during drought is very complex, it is necessary to construct a joint probability distribution that can describe and investigate the interrelationship between them(Jha et al., 2019). In other words, it is required to identify the interaction between vegetation and climate from a viewpoint based on joint probability. The purpose of this study is to construct a bivariate copula function model, investigate the vegetation response to different drought stresses, and create a vegetation vulnerability map.

Methodology

Drought Indices

Vegetation Health Index(VHI; Kogan, 1997) was used to estimate vegetation-related drought. VHI is a widely used vegetation drought index, which consists of a linear combination of Vegetation Condition Index (VCI) and Thermal Condition Index (TCI). VCI is estimated using Normailzed Difference Vegetation Index (NDVI) and TCI is based on Land Surface Temperature (LST). NDVI and LST were used MODIS MOD13C2 and MOD11C3 products, which are currently widely used.

Meteorological drought indices were used to define droughts affecting vegetation. In fact, drought is caused by various meteorological variables such as dry weather patterns and lack of precipitation, so this study tried to apply the drought condition from two aspects. To this end, the Standardized Precipitation Index(SPI; Mckee et al., 1993), which identifies drought by the water supply side(i.e., precipitation) from the atmosphere, and the Evaporative Demand Drought Index(EDDI, Hobbins et al., 2016), which identifies drought by the atmospheric moisture demand side(i.e., potential evapotranspiration) were used. The Climate Hazards Infrared Precipitation with Stations (CHIRPS) dataset was used as precipitation data for calculating SPI, and MODIS MOD16A2 product was used as PET data for estimating EDDI.

Bivariate copula function model

To quantify the response of vegetation from a probabilistic point of view, a bivariate copula function model was constructed based on the copula theory. Copula is a powerful approach that combines various random variables, and the probabilistic framework through copula can effectively investigate the response of vegetation to hydrometeorological stress. The bivariate copula function model constructs a bivariate joint probability distribution between SPI and VHI or EDDI and VHI. That is, the response of vegetation in terms of atmospheric moisture supply or atmospheric moisture demand can be investigated. From the constructed bivariate joint probability distribution between drought index and VHI, the conditional distribution of VHI under a meteorological drought scenario can be obtained. The drought scenario was defined as when the SPI (or EDDI) was below the threshold indicating a moderate drought. And the case of $u_{VHI} \leq 0.3$, vegetation was considered to be in an ecological drought state.

Results and discussion

A vegetation vulnerability map was prepared by spatially expressing the possibility of vegetation drought under a drought scenario for the South Korea. Vulnerability maps allow determination of areas where vegetation is sensitive to atmospheric moisture supply or moisture demand. Figure 1 is the result of spatially expressing the probability of vegetation-related drought (probability of $u_{VHI} \leq 0.3$) in the precipitation scenario(i.e., SPI scenario). Figure 2 shows the probability of vegetation drought in a PET scenario (i.e., an EDDI scenario). These figures show that the spatial patterns of vegetation vulnerability for each drought condition are expressed very differently. In addition, since the interaction between climate and vegetation differs by season, spatial distributions were prepared in various ways for each season.

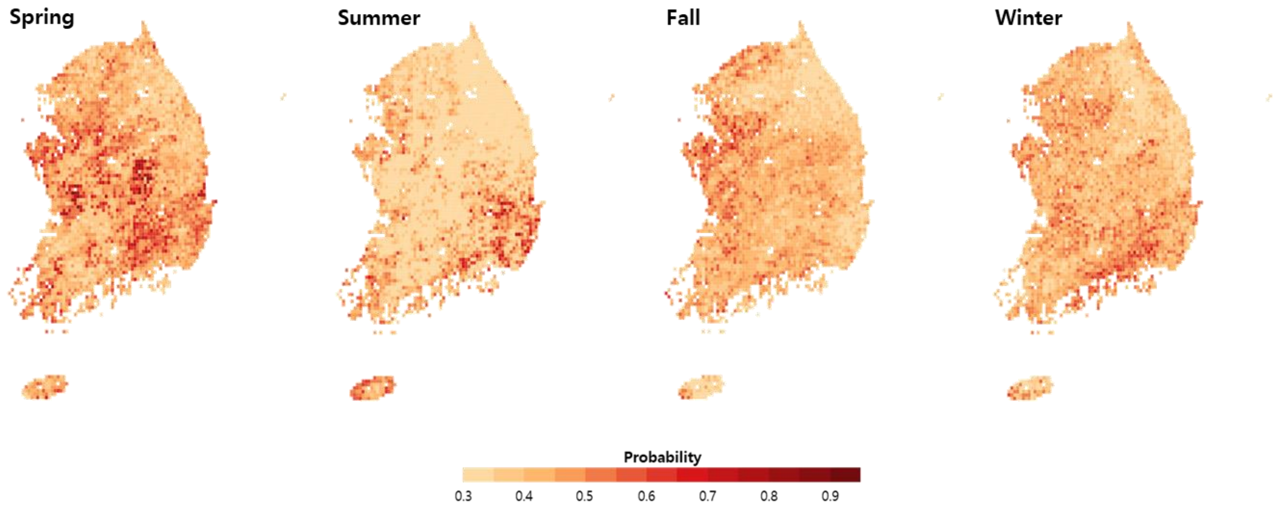

Figure 1. Vegetation drought vulnerability map for the particular VHI threshold ($u_{VHI} \leq 0.3$) under SPI scenarios.

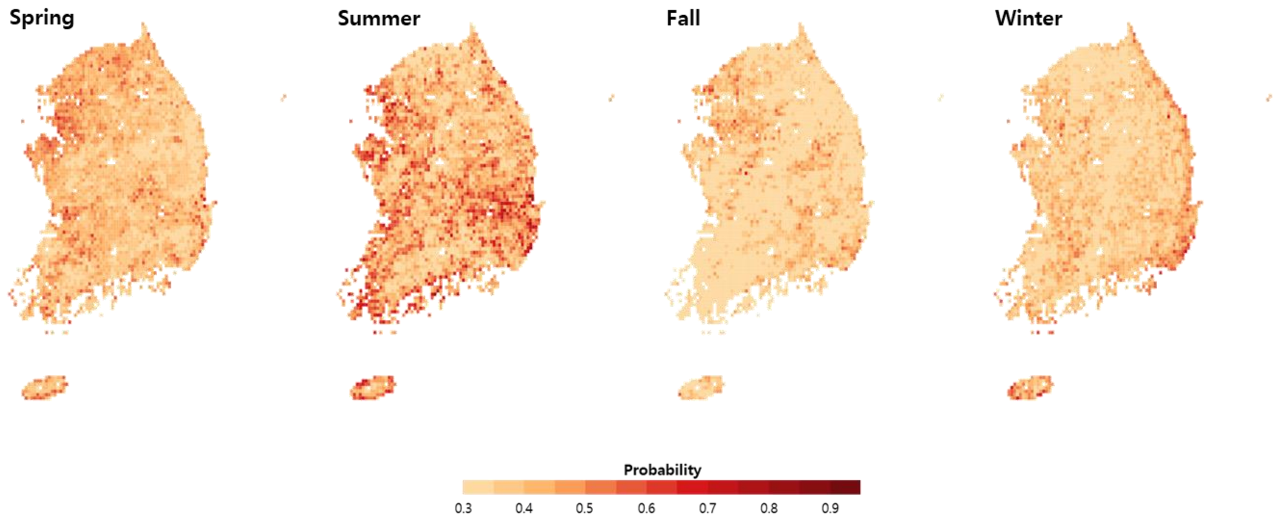

Figure 2. Vegetation drought vulnerability map for the particular VHI threshold ($u_{VHI} \leq 0.3$) under EDDI scenarios.

Conclusions and future work

In this study, we tried to understand the ecosystem response to climate variability by applying the bivariate copula function model that combines vegetation and drought information. Here, it was possible to quantitatively examine the vulnerability of vegetation under various drought conditions, and it was confirmed that it is very important to separately identify the drought situation in terms of atmospheric moisture supply and moisture demand. However, since extreme climate events can occur simultaneously, a multivariate analysis for the overlapping meteorological drought will be necessary in the future. In addition, although a specific threshold was used for vegetation drought in this study, it is necessary to obtain new information by applying various drought thresholds.

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