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Peak drought severity time analysis of Cheongmicheon watershed using meteorological and hydrological drought index

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Abstract: This study analyzed the peak drought severity time of the Cheongmicheon watershed according to evaluation period based on 1) Past (period from 1985 to 2015) and 2) Future Climate Change scenarios (RCP 4.5 & 8.5 period from 2011 to 2100). In order to assess the peak drought severity of lag time and relationships between various drought indices, we used meteorological and hydrological drought index. Standardized Precipitation Index (SPI) was based on precipitation and Standardized Precipitation Evapotranspiration Index (SPEI) was based on precipitation and evapotranspiration, were applied as meteorological drought index. Stream Drought Index (SDI) based on Runoff data was applied as hydrological drought index. In the case of SDI, we used Soil and Water Assessment Tool (SWAT) model for simulation of daily runoff data and SWAT Calibration and Uncertainty Procedures (SWAT-CUP) for optimization of SWAT parameters. In order to analyze the relationship between meteorological and hydrological drought index, SDI was selected in the case of less than -1.5. We compared SPI, SPEI and SDI's peak drought severity time. As a result, in case of RCP 4.5, the differences of peak drought point between SDI and SPI and between SDI and SPEI were 0.8 months and 0.54 months. In case of RCP 8.5, the differences of peak drought point between SDI and SPI and between SDI and SPEI were 0.89 months and 0.99 months. As the duration was increased, the frequency of drought was decreased. This confirmed that SPEI gives a significant impact on SDI more than SPI.

Key words: Peak drought severity time, Meteorological drought index, hydrological drought index, SWAT

1. INTRODUCTION

Due to global warming, temperature is rising and precipitation is greatly changed, leading to an increase in evapotranspiration. As a result, areas of drought occurrence are widening, and drought severity and frequency are becoming serious. Various drought indices have been developed in order to minimize the damage of increasing drought areas and many studies are being conducted to quantify the severity of drought (Du Pisani et al., 1998; Sung and Chung, 2014). Generally, drought is classified as agricultural, meteorological, hydrological, and socioeconomic droughts (Wilhite and Glantz, 1985; Correia et al., 1991).

Among the drought indices used to evaluate drought, Standardized Precipitation Index (SPI; Mckee et al., 1993) is easy to be calculated and is most actively used because it can quantify the drought severity by the lack of precipitation. In recent years, Standardized Precipitation Evapotranspiration Index (SPEI; Vincente-Serrano et al., 2010) have been actively used to evaluate drought more physically by considering both precipitation and evapotranspiration (Lee et al., 2015). Furthermore, Nalbantis (2008) proposed a Streamflow Drought Index (SDI), a river water drought index, also proposed a method to distinguish severity and duration of drought with monthly flow.

Therefore, this study compares the difference between meteorological and hydrological drought indices at the time of peak drought severity, one of the characteristics of drought index. The study area is Chungmicheon watershed and the considered drought durations range from 60 to 270 days in units of 30 days, and the time of occurrence time of peak drought severity were analyzed using past and future scenarios. The past scenario is from 1985 to 2015 and the future scenario is analyzed from 2016 to 2100 using RCP 4.5/8.5. SPI and SPEI, which are meteorological drought indices, and SDI, a hydrological drought index were used as the drought index. The SWAT model was applied to the study watershed to simulate the runoff for calculating the hydrological drought index.

2. MATERIALS AND METHODS

2.1 Study watershed

The Cheongmichun watershed, which is the target area of this study, includes all or a part of Yeongju, Icheon, Anseong, and Yongin in Gyeonggi Province and Eumseong in Chungcheongbukdo. It is the first tributary of the south Han River. The total area of the watershed is 596.13 km^2. The weather data was obtained from the Icheon observatory. The precipitation from 1985 to 2015 was collected and used. The annual average precipitation for 31 years was 1,372.8 mm and the lowest annual average precipitation is 791.5 mm, which is 57.5% of the average annual precipitation in 2014.

2.2 Meteorological and hydrological drought indices

The drought index is an important factor in this study. SPI and SPEI which are meteorological drought indices, and SDI, which is hydrological drought index, were used in this study.

The meteorological drought index, SPI, is calculated as creation of a precipitation time series by time unit, Parameter estimation using Pearson Type-III (PT-III) distribution, Estimation of the cumulative distribution function and calculation of the drought index applied to the standard normal distribution. Finally, SPI is divided into seven stages.

SPEI is calculated by the difference between precipitation and potential evapotranspiration (PET). Thornthwaite method (Thornthwaite, 1948) was applied to obtain PET. SPEI's drought classification standard is the same to SPI.

SDI is calculated using cumulative stream flow volume from different time period. According to Nalbantis (2008), hydrologic droughts defined by SDI, were divided as extreme drought if the value is below -2, severe drought below -1.5, moderate drought below -1, mild drought below 0 and the others are not drought.

2.3 RCP scenarios

To project water quantity, we used the projected precipitations and temperatures of RCP4.5 and RCP8.5 to build SWAT program which has already been calibrated in Won et al. (2015). RCP8.5 assumes that the increase of greenhouse gas in the future will cause direct effect of 8.5 W/m^2 on the global climate system by 2100 and so is regarded as a scenario of extreme case which assumes that there will be no specific reduction policy, and the highest amount of greenhouse gases will be emitted, compared with RCP4.5.

2.4 SWAT formulation

The Soil and Water Assessment Tool (SWAT) model has been used to estimate the runoff of a watershed considering soil characteristics, land use and various climatic conditions. The SWAT model is a semi-distributed long-run runoff simulation model that can be simulated daily for each watershed. It is divided into four kinds of parent types: hydrological, nutrient, soil loss, and river tracing.

Among these, the hydrologic parent type calculates the water balance on a daily basis by the continuous equation. The composition of the water balance includes water loss, runoff, groundwater flow, evapotranspiration, surface, interception, and penetration. In this way, the runoff is calculated independently for each Hydrological Response Unit (HRU) and the runoff at the exit point of the watershed is calculated through the runoff trace.

For the observed flow in 2013, the simulated flow was optimized using the SUFI-2 algorithm. A

total of 19 parameters were used to optimize parameters related to flow simulations. Monthly and seasonal volatility is well reproduced, and the corresponding monthly flow rates are similar. In order to make a more quantitative comparison, the Nash-Sutcliffe Efficiency (NSE) and correlation coefficient were compared together. NSE was 0.88 and correlation coefficient was 0.90.

3. RESULTS

3.1 Comparison of peak drought time occurring in the past

This study assessed the timing of meteorological and hydrological drought at the peak of drought severity based on hydrological drought by each duration. For evaluation, drought was quantified, when the severity of SDI is less than -1.5. The differences of the peak occurrence time and duration of drought period are shown in Figure 1.

The 60–day duration drought confirmed that SDI had a total of 9 severe droughts. The average drought periods of each drought index were 3.22 months for SDI, 2.44 months for SPI, 2.22 months for SPEI. The difference between SDI, SPI and SPEI at the peak drought point is 1 month. The 90-day duration drought confirmed that, SDI had a total of 6 severe droughts. The drought periods of each drought index were 4.83 months for SDI, 3.83 months for SPI, 4 months for SPEI. The differences in SDI at the peak drought point are 0.68 month for SPI and 1 month for SPEI, respectively. Also 120-day duration of drought confirmed that SDI had a total of 5 severe droughts. The drought period of each drought index was 4.4 months for SDI, 4.2 months for SPI and SPEI. The differences between SDI, SPI and SPEI at the peak drought point is 0.8 month. The 150-day duration of drought confirmed that SDI had a total of 4 severe droughts. The drought period of each drought index was 4.5 months for SDI, 4.75 months for SPI, 5 months for SPEI. The difference between SDI, SPI and SPEI is 0.5 month. Droughts from 180-day to 270-day duration were observed, and SDI had 2 severe droughts. For 180-day duration, the drought periods were 7 months for SDI, 6.5 months for SPI and 7 months for SPEI. In 210-day duration, the drought periods were 8 months for SDI, 7 months for SPI and SPEI. In 240-day duration, the drought periods were 8.5 months for SDI, 7 months for SPI, and 8 months for SPEI and for 270-day duration, the drought periods were 7.5 months for SDI, 7 months for SPI, and 7.5 months for SPEI, respectively. According to the differences in the points of peak occurrences, the average difference of 180-day duration were 0.5 months to SPI and 1.5 months to SPEI. In addition, for the 210-day duration there is no difference. For the 240-day duration, the differences were 0.5 months to SPI and 1.5 months to SPEI. For the 270-day duration, the differences were -1 months to SPI and -2 months to SPEI. On average, SDI and SPI differ by 0.51 month and SDI and SPEI differs by 0.72 month.

3.2 Comparison of peak drought time occurring in the RCP scenarios

This study selected RCP4.5 and RCP8.5 scenarios among future climate change scenarios to predict future drought. According to the drought assessment using the RCP4.5 scenario, SDI had a total of 29 drought events for a 60-day duration. The mean period droughts in SPI, SPEI and SDI were 0.78, 0.78 and 1.17 months. The mean differences to the peak drought occurrence point to the SDI was 0.7 months for SPI and SPEI. SDI had a total of 30 drought events for a 90-day duration. The mean drought periods in SPI, SPEI and SDI was 1.37, 1.6 and 1.57 months. The mean differences of the peak drought occurrence point to SDI were 0.67 months for SPI and 0.7 months for SPEI. SDI had a total of 21 drought events for a 120-day duration. The mean period drought in SPI, SPEI and SDI was 1.85, 2.13 and 2.48 months. The mean differences to SDI were 1 month for SPI and 0.27 months for SPEI. SDI had a total of 19 drought events for a 150-day duration. The mean drought periods in SPI, SPEI and SDI were 2.33, 3.23 and 3.05 months. The mean difference were 0.83 months from SPI and 0.23 months from SPEI. SDI had a total of 17 drought events for a

180-day duration. The mean drought period in SPI, SPEI and SDI were 3.47, 3.83 and 3.53 months. The mean differences of the SDI were 1.07 months from SPI and 0.42 months from SPEI. SDI had a total of 18 drought events for a 210-day duration. The mean drought periods in SPI, SPEI and SDI were -3.94, 3.43 and 3.78 months. The mean differences of the SDI were 0.88 months for SPI and 0.86 months for SPEI. SDI had a total of 15 drought events for a 240-day duration. The mean drought periods in SPI, SPEI and SDI were 4, 4.33 and 4 months. The mean differences of the SDI were 1 month for SPI and 0.92 months for SPEI. SDI had a total of 13 drought events for a 270-day duration. The mean drought periods in SPI, SPEI and SDI were 4.33, 4 and 3.46 months. The mean difference of the SDI were 0.25 months for SPI and 0.18 months for SPEI. The results of the RCP 4.5 drought evaluation are shown in Figure 2.

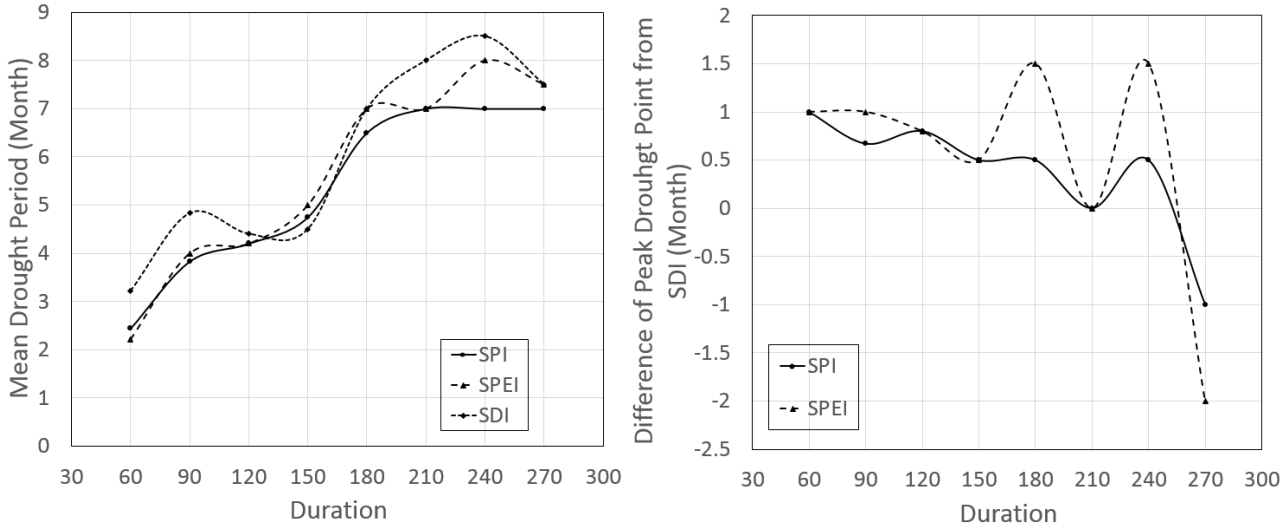

Figure 1. Results of mean drought period and difference peak occurred time in the past

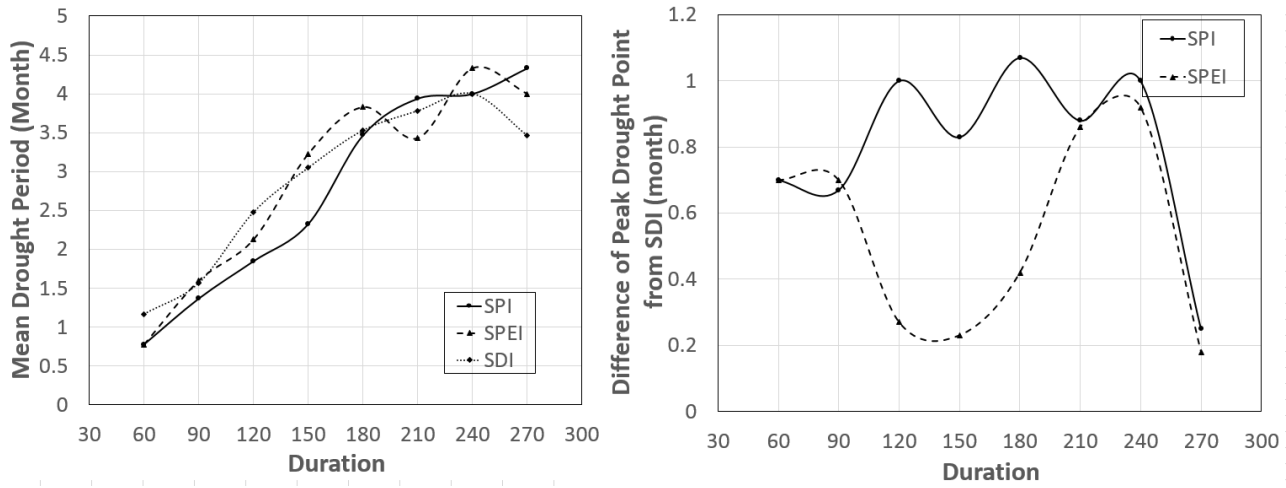

Figure 2. Results of mean drought period and difference peak occurred time in the RCP 4.5

According to the drought assessment using the RCP8.5 scenario, SDI had a total of 27 drought events for a 60-day duration. The mean drought periods in SPI, SPEI and SDI were 0.44, 0.56 and 1.33 months. The mean difference of the SDI were 1.56 months from SPI and 1.2 months from SPEI. SDI had a total of 25 drought events for a 90-day duration. The mean drought periods in SPI, SPEI and SDI were 1.61, 1.58 and 1.48 months. The mean difference of the SDI were 0.83 months for SPI and 0.89 months for SPEI. SDI had a total of 22 drought events for a 120-day duration. The mean drought period in SPI, SPEI and SDI were 1.71, 1.94 and 1.64 months. The mean difference of the SDI were 0.95 months for SPI and 0.94 months for SPEI. SDI had a total of 22 drought

events for a 150-day duration. The mean drought periods in SPI, SPEI and SDI were 2.00, 1.75 and 1.86 months. The mean difference of the SDI were 0.6 months for SPI and 0.94 months for SPEI. SDI had a total of 19 drought events for a 180-day duration. The mean drought periods in SPI, SPEI and SDI were 2.06, 2.85 and 2.37 months. The mean difference were 0.94 months for SPI and 0.92 months for SPEI. SDI had a total of 18 drought events for a 210-day duration. The mean drought periods in SPI, SPEI and SDI were 2.18, 2.85 and 2.89 months. The mean difference were 0.53 months for SPI and 0.85 months for SPEI. SDI had a total of 16 drought events for a 240-day duration. The mean drought period in SPI, SPEI and SDI were 2.71, 2.9 and 2.94 months. The mean differences of the SDI were 0.93 months for SPI and 1.1 months for SPEI. SDI had a total of 15 drought events for a 270-day duration. The mean drought periods in SPI, SPEI and SDI were 3.14, 4 and 3.13 months. The mean difference of the SDI were 0.79 months for SPI and 1.09 months for SPEI. The results of the RCP 4.5 drought evaluation are shown in Figure 3.

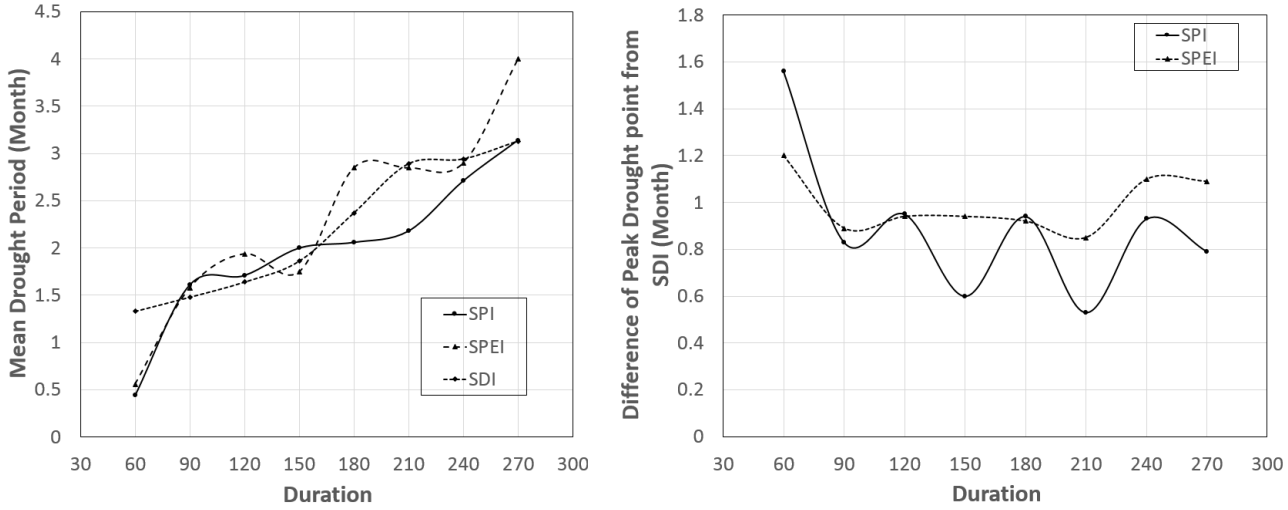

Figure 3. Results of mean drought period and difference peak occurred time in the RCP 8.5

4. CONCLUSION

This study analyzed past droughts (from 1985 to 2015) and future drought (from 2016 to 2100) using two meteorological drought indices and one hydrological drought index. In order to evaluate the future drought, the RCP scenarios were applied. Study area is the Chungmicheon watershed located in Korea.

At this time, the daily flow rate data used in SDI was calculated using SWAT model, and the weather data obtained from the Icheon Observatory. For effective comparison, only the drought severity of SDI was evaluated to be -1.5 or less. The past droughts from 1985 to 2015 were assessed by durations. Based on the SDI, the differences in peak drought occurrence point were 0.59 months for SPI and 0.72 months for SPEI, and Maximum difference was 2 months for both of SPI and SPEI.

As a result of evaluating the future drought from 2016 to 2100 using two RCP scenarios are follows. For RCP 4.5, mean period of drought by SPI, SPEI and SDI were 2.76, 2.92 and 2.88 months, respectively. The mean differences in peak drought occurrence point were 0.8 months for SPI and 0.54 months for SPEI, and mean maximum difference were 9 months for SPI and 7 months for SPEI. And in the case of RCP 8.5, mean periods of drought by SPI, SPEI and SDI were 1.98, 2.3 and 2.21 months. The mean difference in peak drought occurrence point was 0.89 months for SPI and 0.99 months for SPEI, and mean maximum difference was 5 months for both of SPI and SPEI.

It was confirmed that the meteorological drought affects the hydrological drought as the peak drought occurrence points were identified. However, in addition to the SPI, SPEI and SDI used in

this study, various drought indices are considered. Therefore, the follow-up study will apply this framework to various watershed appraisal using various drought indices, and will consider various watershed sizes.

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