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Drought Analysis and Impact of Climate Change Effect on Drought

DROUGHT ANALYSIS AND IMPACT OF CLIMATE CHANGE EFFECT ON DROUGHT

Jae Won, Kwak[1], Hee Sung, Noh[2], Na Rae, Kang[3], Hung Soo, Kim[4]

ABSTRACT

Recently, in Korea, occurrences of floods and droughts have been increased due to Drought is a normal and recurrent phenomenon. But, recurring prolonged droughts have caused consequences and diverse impacts on human system. Therefore, understanding drought characteristics is indispensable element in well-prepared drought management. This study used the observed runoff to apply and evaluate hydrological droughts in different levels, and induced drought events to analyze drought frequency in a conventional way. Analysis of the relationship between drought variables such as drought duration and drought severity was performed and drought frequency analysis using the Clayton copula theory was performed. Then the results from the frequency analysis by the conventional single variable and the copula theory were compared. Also, joint probability was used to analyze the return period of droughts and the severity-duration-frequency (SDF) curve was constructed.

1. INTRODUCTION

Droughts are natural disasters that profoundly affect society and the ecosystem. Wilhite (2000) pointed out that of all natural disasters, drought causes the greatest damage. In general, a drought is caused by rainfall shortages that affect water resources in both urban and rural areas. Especially, in recent years, drought damage caused by the direct influence of climate change is on the increase, making it necessary to study drought characteristics to lessen their impact

This study intends to simulate future runoff phenomenon and drought occurrences using the A1B climate change scenario, CNCM3 GCM (Salas-Mélia et al, 2005), and KMA RCM(Im et al., 2008) models, targeting the upstream of Namhan River basin, which is the upper region of the Han River in Korea. The study will estimate joint probability distributions for drought severity and durations using the copula method, and will suggest future drought events in 'frequency-based droughts amounts' by preparing a 'drought severity-duration-frequency curve' (or SDF curve).

2. METHOLOGY

2.1 Drought Identification using streamflow Series

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Yevjevich (1967) proposed the theory for identifying drought parameters and investigating their statistical properties: (a) duration, (b) severity, and (c) intensity. The most basic element for deriving these parameters is the truncation or threshold level, which may be a constant or a function of time. A run is defined as a portion of time series of drought variable Xt, in which all values are either below or above the selected truncation level of Xo. The run is called either negative run or positiverespectively. Figure 1 represents a plot of a drought variable denoted by Xt which is intersected at many places by the truncation level X0, which can be a deterministic variable, a stochastic variable, or a combination thereof. Various statistical parameters concerning drought duration, magnitude and intensity at different truncation levels are much useful for drought characterization.

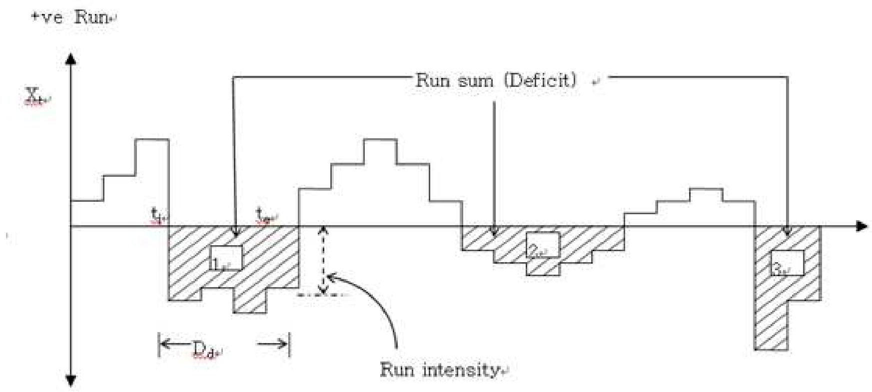

Figure 1 Drought characteristics using the run theory

2.2 Future Runoff Simulation that Considers Climate Change

Using the method of Kwak et al. (2012) that estimates the joint probability distribution of drought using runoff, this study intends to analyze hydrological drought events which may be caused by future climate change. For the application of this method, simulated future runoff data is essential. However, runoff is estimated from rainfall based on the physical elements of the basin, and future observational data does not exist. Therefore, this study will simulate future runoff of the upstream part of the Namhan River basin, which was analyzed by Kwak et al. (2012), using climate change scenarios, climate models, and rainfall-runoff models, and then will analyze the hydrological drought models.

According to Kyoung et al (2012), monthly rainfall series were generated using the CNCM3 and KMA RCM climate models and the A1B scenario. As the generated climate data are forward looking monthly data, spatio-temporal downscaling was performed to the Daegwallyeong and Jecheon observatories in the upstream of Namhan River basin using the Nearest Neighbor-Genetic Algorithm (NN-GA) and Simple kriging with local mean (SKLM) methods suggested by Kim(2011).

Long-term runoff simulations were carried out using the climate data of 2 observatories located inside of the upstream of Namhan River basin and the TANK model. For the calibration and verification of the model parameters which are required, daily data for 8 years from 2000 to 2007 were used because the impact of climate change can only be properly evaluated with data from after 2000, when rainfall frequency and intensity appeared to have actually changed, in accordance with the purpose of this study, i.e. the assessment and simulation of the impact of climate changes, even though existing observation data from 1967 still exists. Accordingly, data from after 2000 was used as input data for the construction of actual models. For the calibration of the models, daily rainfall-runoff data from 2000 to 2005 were used, and for verification of the models, daily rainfall-runoff data from 2006 to 2007 were used. As the result of model calibrations, the simulated value appeared to simulate the observation value well, but still showed problems with reflecting peak discharge, which is often a problem in long-term runoff simulations. However, low flows are considered more important comparatively than peak discharges for drought assessments; thus, this study used the relevant simulation results as they were.

3. BIVARIATE ANALYSIS OF DROUGHT

The copula function was first suggested by Sklar in 1959 as a method of understanding complex dependence structure between various random variables. It is used to measure the relationship between more than 2 random variables like the correlation coefficient. However, as the correlation coefficient is effective in oval-type distribution, it is considered proper to understand dependence structure by copula rather than by correlation coefficient for the variables which show the tendency of the same directivity. Recently, the Archimedean copula, the Clayton copula, the Gumbel copula, and the Frank copula are much used, and this study will adopt Clayton copula which can be widely applied with its simplicity and availability. In particular, Clayton copula is considered appropriate in drought simulations because it is known to well reflect tail structure of droughts.

Bivariate return period which considered both of drought duration and severity can be largely divided into the probability of exceeding both of drought duration and severity (D>d and S>s), or the probability of exceeding either one of drought duration and severity (D>d or S>s). For each condition, the copula-based return period can be defined as follows;

$$Return\ Period_{D>d \text{ and } S>s} = \frac{E(L)}{P(D>d \text{ and } S>s)} = \frac{E(L)}{1-F_D(d)-F_S(s)+C(F_{D(d)},F_S(s))}$$

$$Return\ Period_{D>d \text{ or } S>s} = \frac{E(L)}{P(D>d \text{ or } S>s)} = \frac{E(L)}{1-C(F_{D(d)},F_S(s))} \quad (1)$$

As described earlier, the drought duration and severity according to the return period can be approximated into an IDF curve, which is commonly used in frequency analysis. In order to achieve this, a similar method for inducement of an IDF curve is needed. Approximation is to be done in the form of the drought duration – severity, according to the return period's frequency. By placing duration on the x-axis, and severity on the y-axis, an SDF curve can be drawn, which can be utilized to calculate the probability drought amount.

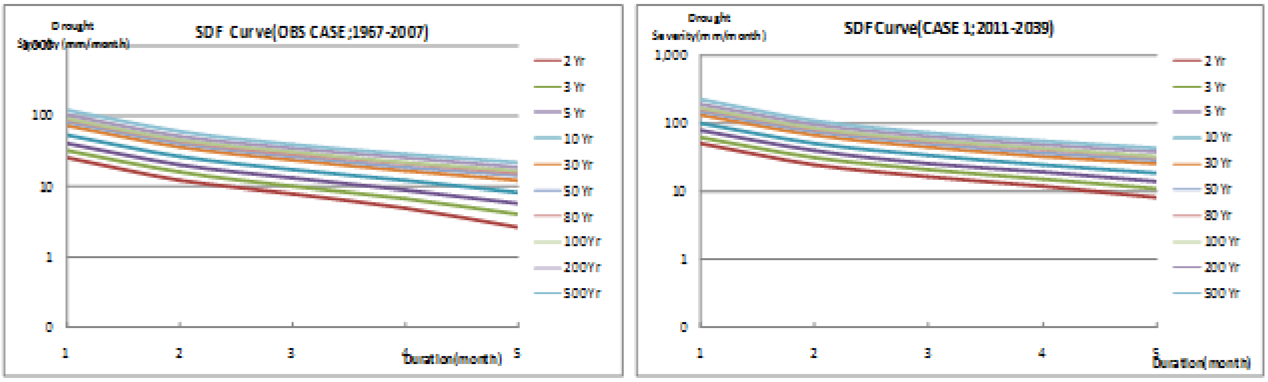

Figure 2 Drought SDF curve of OBS CASE (1967 to 2007) and CASE 1 (2011 to 2039)

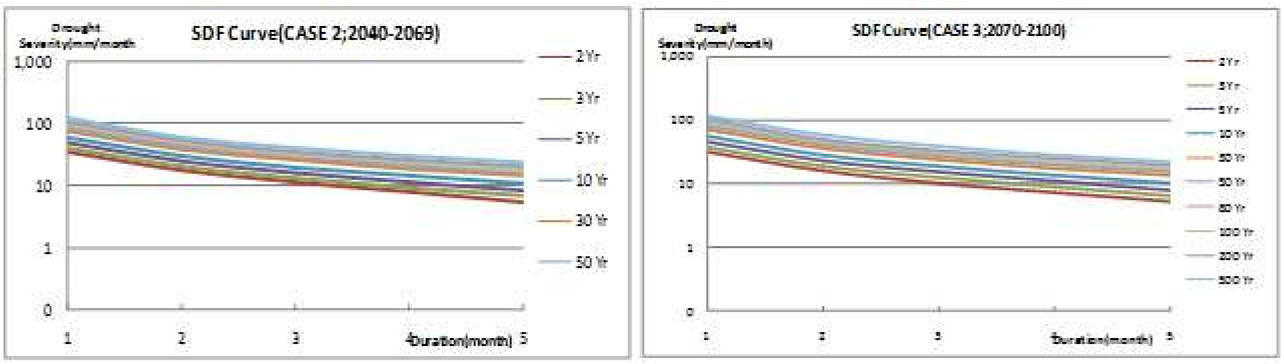

Figure 3 Drought SDF curve of CASE 2 (2040 to 2069) and CASE 3 (2070 to 2100)

The difference between the SDF curve and the IDF curve is that, generally the probability rainfall amount estimated by an IDF curve uses Areal Reduction Factor (ARF) to approximate areal rainfall. Whereas the SDF curve is based on runoff, therefore the basin area is implicit in the drought area. So, the SAD (Drought Severity-Area-Duration) curve, commonly used in drought analysis, should be understood as containing the concept of area within. By utilizing the SDF curve from the above, it's possible to calculate the probability drought amount, and it could be used as an important preliminary data to deal with future droughts. For example, if there were to be a plan to deal with droughts lasting 3 months within 30 year return period by the upper reaches of South-Han River, measures need be taken corresponding to the approximately runoff depth of 51mm.

4. CONCLUSION

Drought is one of important elements in the perspective of water resource plan and management. Trying to understand the drought is also considered as an important step in solving drought-related problems occurring in the perspective of water resources. In this study conducted the analysis of drought characteristics through observed streamflow data and continuous theory for study areas of Namhan-river upper stream. In addition, analysis of drought characteristics was conducted to droughts by establishing drought probability through Copula theory. As the SDF curve from copula theory, it's possible to calculate the probability drought amount, and it could be used as an important preliminary data to deal with future droughts.

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