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ORIGINAL ARTICLE

Analysis of Drought Characteristics in Gyeongbuk Based on the Duration of Standard Precipitation Index

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Abstract

Using the Standard Precipitation Index (SPI), this study analyzed the drought characteristics of ten weather stations in Gyeongbuk, South Korea, that precipitation data over a period of 30 years. For the number of months that had a SPI of -1.0 or less, the drought occurrence index was calculated and a maximum shortage months, resilience and vulnerability in each weather station were analyzed. According to the analysis, in terms of vulnerability, the weather stations with acute short-term drought were Andong, Bonghwa, Moongyeong, and Gumi. The weather stations with acute medium-term drought were Daegu and Uljin. Finally the weather stations with acute long-term drought were Pohang, Youngdeok, and Youngju. In terms of severe drought frequency, the stations with relatively high frequency of mid-term droughts were Andong, Bonghwa, Daegu, Uiseong, Uljin, and Youngju. Gumi station had high frequency of short-term droughts. Pohang station had severe short-term ad long-term droughts. Youngdeok had severe droughts during all the terms. Based on the analysis results, it is inferred that the size of the drought should be evaluated depending on how serious vulnerability, resilience, and drought index are. Through proper evaluation of drought, it is possible to take systematic measures for the duration of the drought.

Key words : SPI (Standard Precipitation Index), Drought, Resiliency, Vulnerability

1. Introduction

Over the years, globally, fluctuations have become larger owing to climate changes. Repeated and frequent occurrences of floods and droughts are a consequence of the climate changes. In particular, precipitation imbalances have become more severe as a result, the number of droughts, small or large, has been on the rise annually. According to a report on droughts by National Drought Information Analysis Center, the average rate of precipitation in the nation from 2014 to 2015 was 62% of its long-term average value. For example, in Nakdong River basin, droughts have occurred with 10-20 year frequency. In 2014, the precipitation rate in the central region was 50-61% of that during the normal years. Han River basin has faced droughts at 20-30 year frequency. The other regions have droughts of at 10-year frequency. In 2012, the precipitation in the central region and Jeollado was 32% of that during the normal years. In Gyeongbuk, the precipitation rate in May was 51% of that during the normal years. The average water reserves in the national reservoirs were 47% of their rated capacity, suggesting that severe droughts have occurred.

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From September-2008 to February-2009, the precipitation rate in the south region was 34% of that during the normal years, indicating that severe shortage of precipitation had occurred. From February. to June. 2001, the precipitation rate was 10~20% of the average rate, and therefore severe droughts had occurred across the nation. From June. 1994 to July. 1995, the average water reserves of agricultural watersheds in the nation were 56% of their related capacity, and among all the reservoirs in Youngname region, 5,838 reservoirs had less than 30% of water reserves. Therefore, the region experienced severe water shortage. In terms of national or local droughts, spring droughts occur at a frequency of 2-3 years, and a shortage of precipitation in the summer flooding season further leads to insufficient agricultural water, and hence, the vicious circle of drought continues(http://www.drought.go.kr/).

Apart froma floods, drought is one of the major natural disasters, imposing a huge burden on the natural as well as, socio-economic environment. An analytic study on droughts focused on the quantification of multiple characteristics, including the probability of drought occurrence, duration, average severity, and maximum depth(Kwak et al., 2013).

The Standard Precipitation Index (SPI) also called the meteorological drought index, is drought index for estimating the influence of sources of water supply in terms of a precipitation shortage per hour at a station(http://www.drought.go.kr/). As a general drought presentation indicator, the Palmer Drought Severity Index (PDSI) is calculated through a continual comparison of time and space, considering the deviation of two regions with different climates. A degree of drought severity is presented as a function of water shortage and period of water shortage. Modified Surface Water Supply Index(MSWSI) is a modified drought index of SWSI that considers the complex geographical features and the variety of water reserves(http://www.drought.go.kr/).

Among these drought indices, the Standard Precipitation Index(SPI) used in this study employes only the precipitation as an input variable for the analysis. As the other indices have disadvantages with data collection and analysis, the SPI is widely used. SPI can be applied differently with duration units. The short-term unit can be used for agricultural droughts, while the long-term unit can be used for water supply management. In addition, SPI can be used to estimate not only the current drought, but also the probability of precipitation necessary to tackle the drought(Chang et al., 2006). A number of studies for estimating the drought duration and severity have been carried out in thr recent past based on the SPI. For examle, a study on estimating the drought index the SARIMA (Seasonal ARIMA) model, which makes use of the drought time series calculated with SPI and SDI, was conducted for Chungju dam and Boryeong dam basins(Yoon et al., 2019). In another study, the drought duration and drought severity were analyzed based on SPI, and Copula theory was applied to research the joint probability distribution of drought variables and the suggest a drought return period(Kwak et al., 2013). In yet another study, the droughts of Cheongmi river basin were analyzed using the SPI as a meterological drought index, PDSI as an agrohydrological drought index, and SDI as a hydrological drought index(Won et al., 2016). In addition research was also conducted on the evaluation of government plans during a drought period and the establishment of drought stage criteria through the analysis of PDSI, SPI, and SWSI(Lee et al., 2003).

In this study, we analyzed droughts of the main wether stations in Gyeongbuk for 1 to 12 months of duration using the Standard Precipitation Index (SPI), and then examined the vulnerability, which represents the drought severity and resilience, which represents the duration of drought. In addition, we analyzed the frequency of droughts to find the characteristics of drought in each analysis station.

Table 1. Classification drought by SPI

Drought index	Wet condition
2.00 over	Extremely Wet
1.50~1.99	Very Wet
1.00~1.49	Moderately Wet
-0.99~0.99	Near Normal
-1.00~-1.49	Moderately Dry
-1.50~-1.99	Severely Dry
-2.00 below	Extremely Dry

2. Study method

The Standard Precipitation Index (SPI) is a the drought index developed by Mckee et al.(1993) basing on the premise that a drought begins from the reduction in an amount of precipitation resulting from a relative water shortage. In other words, the SPI was developed on the assumption that a reduction in the amount of precipitation influences the water supply sources, such as underground water, drifted snow, reservoir storage, soil water, and stream flow. In the SPI, the units of duration for the calculation of the amount of precipitation for a particular time is set at 3, 6, 9, or 12 months, and the precipitation shortage value is estimated in each time unit to calculate the influence of each water supply source on the drought.

Mckee et al.(1993) classified the droughts as shown in Table 1. to interpret the drought severity obtained from the SPI results.

To analyze the size and severity of drought, this study applied the methodology suggested by Charles et al.(1999) for reservoir reliability analysis to the process of returning a station from a drought to the normal state. This process is presented in formula (1). Resiliency is the indicator used to present how soon the water shortage state returns to the normal state in general water supply analysis. In other words, it is used as an indicator of how long the water shortage remains and then returns to the normal state in terms of water supply issue. To evaluate the temporal severity of drought whose SPI changes from (-) value to (+) value, this study applied the SPI.

Resiliency can be given by formula (1).

$$r = \frac{1}{E[T_p]} = \frac{\mathrm{Pr}ob\{X_t \in S \ \mathrm{and}\ X_{t+1} \in F\}}{\mathrm{Pr}ob\{X_t \in F\}} \tag{1}$$

where r represents the resiliency, T_F is the time duration of (-) SPI value, and $E[T_F]$ is the expectancy value of T_F which is the average time duration of (-) SPI value. $\mathrm{Pr}ob\{X_t \in S \ \mathrm{and}\ X_{t+1} \in F\}$ is the probability that a SPI value changes from X_t (+) to X_{t+1} (-). $\mathrm{Pr}ob\{X_t \in F\}$ is the probability of (-) SPI value at X_t. In short, the above formula is used to calculate the probability of returning a SPI value to (+) value.

Vulnerability is generally used to represent the magnitude of water shortage in terms of water supply. As the water supply causes the cycle of repetitions of between stable and shortage states, vulnerability can be used as an index to judge the magnitude of water supply stability and shortage. In this study, it was applied to judge how severe a drought has been in the repetition of drought and wet conditions in the estimated SPI value. It was estimated to present the average SPI size for a period of (-) SPI value.

3. Results of the analysis on standard precipitation index, resiliency and vulnerability

In this study, ten main weather stations of Gyeongbuk were used for the SPI analysis. Using the analysis results, the number of drought months with a drought index value of -1.0, was estimated and then an average SPI value was calculated. The count of turnover of changing drought to normal state was calculated to estimate the average number of drought months. Subsequently, the number of maximum shortage months was calculated as shown in Table 2.~Table 11. For the drought analysis at each weather station, the data collected over 30 years from 1989 to 2018 were used as shown in Table 2.

In Andong station, the lowest value was found at SPI3 which represented the severest drought. The average drought duration was the longest at SPI10. There were many droughts in 1994-1996, 2009, and 2015-2016 based on the duration.

In Bonghwa station, the lowest value was found at SPI3. The average drought duration was the longest or 5.60 months at SPI12. There were many droughts in 1993, 1995-1997, 2016, and 2018 based on the duration.

In Daegu station, the lowest value was found at SPI4. The average drought duration was the longest or 4.62 months at SPI11 and SPI12. There were many droughts in 1994-1997, 2009, and 2017 based on the duration.

In Gumi station, the lowest value was found at SPI2. The average drought duration was the longest or 6.50 months at SPI11. There were many droughts in 1995, 2002, 2009, 2010, 2016, and 2018 based on the duration.

In Moongyeong station, the lowest value was found at SPI1. The average drought duration was the longest or 104 months at SPI12. Droughts had occurred for a long period from 1989 to 1999.

In Pohang station, the lowest value was found at SPI2. The average drought duration was the longest or 4.55 months at SPI10. The vulnerability during the drought period was the highest at SPI9. There were many droughts in 1994-1997, 2000, 2009, and 2017-2018 based on the duration.

In Uiseong station, the lowest value was found at SPI3. The average drought duration was the longest or 5.22 months at SPI11. The vulnerability during the drought period was the highest at SPI11. There were many droughts in 1994-1997, 2001, 2014-2016, and 2018 based on the duration.

In Uljin station, the lowest value was found at SPI3. The average drought duration was the longest or 6.90 months at SPI12. The vulnerability during the drought period was the lowest at SPI8. There were many droughts in 1994-1997, 2009, 2011, and 2015-2016 based on the duration.

In Youngdeok station, the lowest value was found at SPI3. The average drought duration was the longest or 5.00 months at SPI12. The vulnerability during the drought period was the lowest at SPI10. There were many droughts in 1994-1997, 2009-2010, and 2015 based on the duration.

In Youngju station, the lowest value was found at SPI3. The average drought duration was the longest or 3.69 months at SPI12. The vulnerability during the drought period was the lowest at SPI10. There were many droughts in 1992-1993, 1996-1997, 2001-2002, and 2014-2015 based on the duration.

4. Analysis of drought characteristics in Gyeongbuk

To find the drought characteristics in Gyeongbuk, this study analyzed the SPI data of the same 360 months (;as mentioned previously, with the exception of Sangju station, in which case, the data were over a period of 204 months(17 years from 2002 to 2018). The drought frequency in each severity stage was analyzed as shown in Table 12-Table 21. Andong station had short-term severe droughts at SPI1 and mid and long-term severe droughts at SPI9. Bonghwa station had severe droughts at SPI9 and higher. In Daegu station, the frequency of extreme droughts increased at SPI4 and higher, therefore the region had many mid and long-term droughts. Gumi station and Moongyeong station had many short-term severe droughts at SPI1 and SPI2. Pohang station had long-term severe droughts at SPI8 and higher. Uiseong station had many severe droughts at SPI4 and higher, and

Table 2. SPI analysis result in Andong station

	SPI1	SPI2	SPI3	SPI4	SPI5	SPI6	SPI7	SPI8	SPI9	SPI10	SPI11	SPI12
Vulnerability	-1.64	-1.60	-1.56	-1.57	-1.54	-1.57	-1.50	-1.55	-1.61	-1.57	-1.55	-1.56
Resiliency	1.10	1.38	1.69	1.63	1.86	1.79	2.08	2.41	2.84	3.33	2.84	2.83
Maximum shortage months	2	4	5	4	6	6	7	8	9	9	9	9
Min SPI	-2.71	-2.75	-3.47	-2.69	-2.90	-2.90	-2.67	-2.68	-2.80	-2.77	-2.70	-2.75

Table 3. SPI analysis result in Bonghwa station

	SPI1	SPI2	SPI3	SPI4	SPI5	SPI6	SPI7	SPI8	SPI9	SPI10	SPI11	SPI12
Vulnerability	-1.63	-1.59	-1.58	-1.57	-1.58	-1.61	-1.61	-1.61	-1.61	-1.61	-1.61	-1.58
Resiliency	1.25	1.44	1.85	1.88	2.24	2.48	2.50	2.90	3.17	4.14	3.86	5.60
Maximum shortage months	3	6	8	9	11	10	10	10	11	12	12	12
Min SPI	-2.89	-2.90	-3.10	-3.80	-3.20	-3.60	-2.99	-2.99	-2.98	-2.97	-2.97	-2.92

Table 4. SPI analysis result in Daegu station

	SPI1	SPI2	SPI3	SPI4	SPI5	SPI6	SPI7	SPI8	SPI9	SPI10	SPI11	SPI12
Vulnerability	-1.53	-1.57	-1.56	-1.72	-1.61	-1.65	-1.56	-1.62	-1.62	-1.62	-1.62	-1.60
Resiliency	1.19	1.65	1.93	2.08	2.81	2.55	3.28	3.22	3.29	4.58	4.62	4.62
Maximum shortage months	3	6	5	6	8	8	9	9	10	14	13	22
Min SPI	-2.35	-2.60	-2.80	-2.96	-2.90	-2.90	-2.69	-2.84	-2.57	-2.66	-2.70	-2.58

Table 5. SPI analysis result in Uiseong station

	SPI1	SPI2	SPI3	SPI4	SPI5	SPI6	SPI7	SPI8	SPI9	SPI10	SPI11	SPI12
Vulnerability	-1.56	-1.58	-1.64	-1.58	-1.68	-1.75	-1.70	-1.64	-1.73	-1.72	-1.78	-1.69
Resiliency	1.22	1.65	1.90	2.31	2.52	2.53	2.65	2.89	4.45	4.45	5.22	3.92
Maximum shortage months	3	5	5	7	7	9	9	10	13	13	13	12
Min SPI	-2.62	-3.31	-3.46	-2.70	-2.80	-2.80	-2.70	-2.90	-2.70	-2.71	-2.90	-2.78

Table 6. SPI analysis result in Moongyeong station

	SPI1	SPI2	SPI3	SPI4	SPI5	SPI6	SPI7	SPI8	SPI9	SPI10	SPI11	SPI12
Vulnerability	-1.72	-1.59	-1.54	-1.49	-1.52	-1.53	-1.53	-1.55	-1.54	-1.53	-1.50	-1.51
Resiliency	2.14	4.00	3.42	4.60	8.82	13.86	24.50	25.00	34.00	33.67	52.00	104.00
Maximum shortage months	7	10	9	10	23	34	49	93	96	96	99	104
Min SPI	-3.90	-2.70	-2.80	-2.80	-2.50	-2.23	-2.30	-2.80	-2.30	-2.90	-2.40	-1.99

Table 7. SPI analysis result in Pohang station

	SPI1	SPI2	SPI3	SPI4	SPI5	SPI6	SPI7	SPI8	SPI9	SPI10	SPI11	SPI12
Vulnerability	-1.59	-1.61	-1.61	-1.61	-1.57	-1.55	-1.61	-1.65	-1.67	-1.63	-1.65	-1.60
Resiliency	1.17	1.46	1.69	2.00	2.63	3.00	3.50	3.43	3.46	4.45	4.55	4.50
Maximum shortage months	3	3	4	7	7	8	9	10	11	14	13	13
Min SPI	-2.90	-3.90	-3.24	-2.90	-2.46	-2.66	-2.80	-2.52	-2.80	-2.90	-2.90	-2.61

Table 8. SPI analysis result in Gumi station

	SPI1	SPI2	SPI3	SPI4	SPI5	SPI6	SPI7	SPI8	SPI9	SPI10	SPI11	SPI12
Vulnerability	-1.64	-1.54	-1.58	-1.58	-1.56	-1.58	-1.55	-1.53	-1.54	-1.50	-1.52	-1.53
Resiliency	1.11	1.62	2.19	2.73	2.95	3.16	3.94	3.30	3.61	5.23	6.50	6.00
Maximum shortage months	3	4	5	8	7	8	9	10	10	13	18	23
Min SPI	-2.80	-3.18	-2.77	-2.80	-2.60	-2.80	-2.30	-2.70	-2.80	-2.39	-2.70	-2.25

Table 9. SPI analysis result in Uljin station

	SPI1	SPI2	SPI3	SPI4	SPI5	SPI6	SPI7	SPI8	SPI9	SPI10	SPI11	SPI12
Vulnerability	-1.53	-1.60	-1.57	-1.52	-1.51	-1.57	-1.59	-1.63	-1.57	-1.53	-1.50	-1.52
Resiliency	1.22	1.55	1.83	3.05	2.71	2.90	3.39	3.31	3.44	4.71	4.19	6.90
Maximum shortage months	3	4	8	8	8	11	10	10	11	12	14	14
Min SPI	-2.90	-2.90	-3.20	-2.70	-2.20	-2.70	-2.70	-2.90	-2.50	-2.70	-2.80	-2.80

Table 10. SPI analysis result in Youngdeok station

	SPI1	SPI2	SPI3	SPI4	SPI5	SPI6	SPI7	SPI8	SPI9	SPI10	SPI11	SPI12
Vulnerability	-1.46	-1.55	-1.54	-1.52	-1.51	-1.52	-1.54	-1.58	-1.55	-1.65	-1.64	-1.61
Resiliency	1.23	1.71	2.00	2.18	2.71	3.10	3.53	2.95	3.35	3.92	3.53	5.00
Maximum shortage months	3	4	8	8	8	10	11	12	11	22	13	23
Min SPI	-2.60	-2.94	-3.34	-2.70	-2.43	-2.55	-2.50	-2.41	-2.40	-2.90	-2.90	-2.90

Table 11. SPI analysis result in Youngju station

	SPI1	SPI2	SPI3	SPI4	SPI5	SPI6	SPI7	SPI8	SPI9	SPI10	SPI11	SPI12
Vulnerability	-1.67	-1.63	-1.58	-1.53	-1.57	-1.60	-1.57	-1.61	-1.65	-1.70	-1.64	-1.64
Resiliency	1.26	1.40	1.80	2.07	2.38	1.93	2.52	2.48	2.94	3.33	3.40	3.69
Maximum shortage months	3	4	5	8	7	9	10	10	10	10	11	11
Min SPI	-2.64	-2.94	-3.30	-2.90	-2.80	-2.70	-2.51	-2.53	-2.90	-2.58	-2.80	-2.90

Table 12. Drought characteristic analysis result in Andong station

	SPI1	SPI2	SPI3	SPI4	SPI5	SPI6	SPI7	SPI8	SPI9	SPI10	SPI11	SPI12
Shortage months	45	47	49	49	52	52	50	53	54	50	54	51
Moderately dry months	21	27	29	28	27	27	30	26	27	26	27	28
Severely dry months	15	12	14	13	17	17	15	23	17	16	19	15
Extremely dry months	9	8	6	8	8	8	5	4	10	8	8	8

Table 13. Drought characteristic analysis result in Bonghwa station

	SPI1	SPI2	SPI3	SPI4	SPI5	SPI6	SPI7	SPI8	SPI9	SPI10	SPI11	SPI12
Shortage months	60	62	61	60	56	57	55	58	57	58	54	56
Moderately dry months	26	32	34	35	32	32	32	29	32	34	29	36
Severely dry months	25	21	22	19	17	16	15	20	15	14	15	9
Extremely dry months	9	9	5	6	7	9	8	9	10	10	10	11

Table 14. Drought characteristic analysis result in Daegu station

	SPI1	SPI2	SPI3	SPI4	SPI5	SPI6	SPI7	SPI8	SPI9	SPI10	SPI11	SPI12
Shortage months	63	61	58	52	59	56	59	58	56	55	60	60
Moderately dry months	28	32	33	19	27	27	31	29	24	26	31	30
Severely dry months	31	21	16	20	22	16	17	19	21	18	17	19
Extremely dry months	4	8	9	13	10	13	11	10	11	11	12	11

Table 15. Drought characteristic analysis result in Gumi station

	SPI1	SPI2	SPI3	SPI4	SPI5	SPI6	SPI7	SPI8	SPI9	SPI10	SPI11	SPI12
Shortage months	61	63	59	60	62	60	63	66	65	68	65	66
Moderately dry months	31	39	29	30	32	28	32	36	36	39	38	33
Severely dry months	20	16	24	23	25	25	26	26	24	25	23	27
Extremely dry months	10	8	6	7	5	7	5	4	5	4	4	6

Table 16. Drought characteristic analysis result in Moongyeong station

	SPI1	SPI2	SPI3	SPI4	SPI5	SPI6	SPI7	SPI8	SPI9	SPI10	SPI11	SPI12
Shortage months	60	76	82	92	97	97	98	100	102	101	104	104
Moderately dry months	21	38	47	53	46	42	42	41	41	40	47	44
Severely dry months	26	28	30	35	47	52	54	55	55	60	55	60
Extremely dry months	13	10	5	4	4	3	2	4	6	1	2	0

Table 17. Drought characteristic analysis result in Pohang station

	SPI1	SPI2	SPI3	SPI4	SPI5	SPI6	SPI7	SPI8	SPI9	SPI10	SPI11	SPI12
Shortage months	55	51	49	50	50	54	49	48	45	49	50	45
Moderately dry months	28	31	24	24	23	26	26	24	21	25	23	24
Severely dry months	18	12	18	21	21	22	15	13	14	15	16	10
Extremely dry months	9	8	7	5	6	6	8	11	10	9	11	11

Table 18. Drought characteristic analysis result in Uiseong station

	SPI1	SPI2	SPI3	SPI4	SPI5	SPI6	SPI7	SPI8	SPI9	SPI10	SPI11	SPI12
Shortage months	61	61	57	60	53	48	53	55	49	49	47	47
Moderately dry months	28	35	27	27	19	15	20	23	17	17	14	19
Severely dry months	29	17	22	23	24	20	22	21	19	19	21	16
Extremely dry months	4	9	8	10	10	13	11	11	13	13	12	12

Table 19. Drought characteristic analysis result in Uljin station

	SPI1	SPI2	SPI3	SPI4	SPI5	SPI6	SPI7	SPI8	SPI9	SPI10	SPI11	SPI12
Shortage months	61	65	64	64	65	61	61	53	62	66	67	69
Moderately dry months	36	32	36	33	31	31	29	25	29	36	41	44
Severely dry months	17	21	22	24	30	23	26	18	23	22	17	18
Extremely dry months	8	12	6	7	4	7	6	10	10	8	9	7

Table 20. Drought characteristic analysis result in Youngdeok station

	SPI1	SPI2	SPI3	SPI4	SPI5	SPI6	SPI7	SPI8	SPI9	SPI10	SPI11	SPI12
Shortage months	69	60	65	61	57	62	60	59	57	51	53	55
Moderately dry months	40	30	36	36	32	36	33	31	30	18	20	26
Severely dry months	24	24	20	18	20	20	21	21	20	27	26	20
Extremely dry months	5	6	8	7	5	6	6	7	7	6	7	9

Table 21. Drought characteristic analysis result in Youngju station

	SPI1	SPI2	SPI3	SPI4	SPI5	SPI6	SPI7	SPI8	SPI9	SPI10	SPI11	SPI12
Shortage months	54	56	63	62	57	56	58	57	53	50	51	48
Moderately dry months	22	32	35	35	30	24	27	25	28	14	23	22
Severely dry months	21	13	19	20	18	22	23	23	13	26	20	17
Extremely dry months	11	11	9	7	9	10	8	9	12	10	8	9

thus, it had mid and long-term severe droughts. Uljin station had severe droughts in the short and mid-term stages. Sangju, Youngdeok, and Youngju stations had no noticeable instances of severe droughts.

5. Conclusion

Drought characteristics of ten weather stations of Gyeongbuk province, with precipitation data available over the past 30 years, analyzed using the Standard Precipitation Index. Based on the analysis of 360-month SPI data, for the number of drought months with a drought index of －1.0 or less, the drought occurrence index, was calculated, and then the number of maximum shortage months, resilience, and vulnerability at each station were analyzed. As of vulnerability, the stations with severe short-term(1-4 months) droughts were Andong, Bonghwa, Moongyeong, and Gumi; the stations with severe midium(5-8 months) droughts were Daegu and Uljin: and the stations with severe long-term(9-12 months) droughts were Pohang, Youngdeok, and Youngju.

Based on SPI, the drought months were calculated and compared in the categories of moderately dry, severely dry, and extremely dry months. In terms of the frequency of severe droughts, Andong, Bonghwa, Daegu, Uiseong, Uljin, and Youngju had severe mid-term and long-term droughts; Gumi had severe short-term droughts; Pohang had severe short-term and long-term droughts; and Youngdeok station had severe droughts for all durations. Given the analysis results of this study, it is necessary to evaluate the degree of drought severity depending on the vulnerability, resiliency, and drought index in severe droughts. By evaluating the droughts appropriately, it is possible to come up with suitable systematic alleviation strategies according to the drought duration.

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