JOURNAL OF THE KOREAN SOCIETY OF AGRICULTURAL ENGINEERS, MAR. 2006, pp. 37-43

한국농공학회논문집
제48권 제2호

Evaluation of Semi-Distributed Hydrological Drought using SWSI (Surface Water Supply Index)

SWSI를 이용한 준분포형 수문학적 가뭄 평가

Kwon, Hyung Joong* · Kim, Seong Joon**
권 형 중 · 김 성 준

Abstract

A hydrological drought index, MSWSI (Modified Surface Water Supply Index) was suggested based on SWSI (Surface Water Supply Index). With the available data of spatially distributed observation station of precipitation, dam storage, stream water level and natural groundwater level, South Korea was divided into 32 regions. This was conducted to represent the calculated index as a spatially distributed information. Monthly MSWSI was evaluated for the period of 1974 and 2001. It is necessary to compare this result with PDSI (Palmer Drought Severity Index) and SPI (Standard Precipitation Index), and check the applicability of the suggested index in our hydrological drought situation.

Keywords : MSWSI, Hydrological drought, PDSI, SPI

I. Introduction

Many definitions of drought are adopted in various fields, with reference to the components of the hydrological cycle considered in the analysis and to the different impacts on water users and ecosystems (Yevjevich et al., 1983; Easterling, 1988; Rossi et al., 1992; Wilhite et al., 2000). In special from a hydrological point of view, drought is defined as a period of abnormally dry weather sufficiently prolonged for the lack of precipitation to cause serious water deficits in water bodies.

During the past four decades in Korea, extreme drought has happened with the interval of about five years. Especially, the case of 1994-1995 and 2001 drought of one hundred years frequency caused severe shortage of water supply and crop damage due to little rainfall from March to June. The drought events have provoked

* Graduate School, Konkuk University, Seoul, Korea
** Dept. of Civil & Env. System Engrg., Konkuk University, Seoul, Korea
** Corresponding author. Tel.: +82-450-3749
Fax: +82-444-0186
E-mail address: kimsj@konkuk.ac.kr

attention to mitigate and prepare for the next drought.

The purpose of this study is to develop hydrological drought index, MSWSI (Modified SWSI), based on SWSI (Surface Water Supply Index) and evaluate drought using national hydrological monitoring system in KOREA.

Ⅱ. Hydrological Drought Index Based on SWSI

Shafer and Dezman (1982) developed the SWSI to complement the Palmer Index for moisture conditions across the state of Colorado. The Palmer Index is basically a soil moisture algorithm calibrated for relatively homogeneous regions, but it is not designed for large topographic variations across a region and it does not account for snow accumulation and subsequent runoff. Shafer and Dezman designed the SWSI to be an indicator of surface water conditions and described the index as mountain water dependent, in which mountain snowpack is a major component. The objective of the SWSI was to incorporate both hydrological and climatological features into a single index value resembling the Palmer Index for each major river basin in the state of Colorado (Shafer and Dezman, 1982). These values would be standardized to allow comparisons between basins. Four inputs are required within the SWSI: snowpack, streamflow, precipitation, and reservoir storage. Because it is dependent on the season, the SWSI is computed with only snowpack, precipitation, and reservoir storage in the winter. During the summer months, streamflow replaces snowpack as a component within the SWSI equation.

MSWSI was developed based on SWSI. MSWSI included groundwater level component instead of snowpack. This index was formulated as follow.

$$MSWSI = \frac{a \times PN_{pr} + b \times PN_{st} + c \times PN_{rs} + d \times PN_{gr} - 50}{12}$$

where a, b, c and d are experience-based weighting factors which must sum to 1; PN is probability of non-exceedance (%); PR, ST, RS and GR refer to precipitation, streamflow, dam inflow and groundwater level, respectively.

Ⅲ. Input Data Preparing and Manipulating

Precipitation data was acquired from 61 meteorological stations in Korea. In order to calculate average precipitation in each particular watershed, point data was converted into spatial distributed map using surface interpolation method. Streamflow data was acquired from 14 streamflow level observation stations according to reaction degree of streamflow level on drought. Dam inflow data was obtained from 7 large dams. These dams were controlled by KOWACO (Korea Water Resources Corporation). Groundwater level data was obtained from 21 groundwater level observation stations in GIMS (National Groundwater Information Management and Service Center). Table 1 and Table 2 summarize the selected stream water level observation stations and groundwater level observation stations sensitive to drought situation, respectively.

Ⅳ. Application of SWSI

MSWSI is applicable to watershed unit. In order to apply MSWSI, South Korea was divided into 32 subwatershed based on several foundations:

Table 1 Selected stream water level observation stations sensitive to drought situation.

Basin name	Station name	Station code	Distance form dam* (km)	Reaction degree to drought	Statistical data (m) (2001. 1~2001. 5)			Start of recoding
					Min.	Max.	Ave.	
Han River	Jeonru	HS-1	160.3	normal	-0.67	0.50	-0.09	1962
	Ganhyun	HS-9	64.9	normal	1.19	1.50	1.33	1962
	Yeoju	HS-11	60.2	sensitive	0.66	1.41	0.79	1962
Anseong-cheon	Yangyeong	AS-6	28.9	sensitive	0.35	1.74	0.71	1962
Nakdong River	Dalji	NS-1	62.2	sensitive	0.55	1.43	0.91	1962
	Gumi	NS-4	129.2	sensitive	-1.62	-0.12	-1.19	1962
	Jeongam	NS-9	103.2	normal	0.19	1.91	0.90	1962
Geum River	Gongju	GS-2	48.6	sensitive	0.32	1.41	0.60	1915
	Jindu	GS-3	62.4	sensitive	-1.74	-0.28	-1.46	1962
Sapgyo-cheon	Suchon	SGS-4	31.2	normal	0.16	0.65	0.27	1955
	Guman	SGS-5	24.9	normal	-0.99	0.86	-0.06	1962
Seomjin River	Daegang	SJS-4	45.7	normal	-0.18	0.68	0.03	1962
	apnok	SJS-5	72.1	normal	0.01	1.32	0.38	1917
Yeongsan River	Naju	YS-5	65.1	normal	0.58	0.58	0.58	1945

*Note: Used dams are Soyanggang(Han), Andong(Nakdong), Daecheong(Geum) and Seomjingang(Seomjin)
Values of other stations are distance from tide embankments

Table 2 Selected ground water level observation stations sensitive to drought situation.

Basin name	Station name	Station code	Distance form main stream* (km)	Reaction degree to drought	Reaction degree for streamflow level	Statistical data (m) (2001.1~2001.5)			Start of recoding
						Min.	Max.	Ave.	
Han River	Gimpo	HG-1	1.9	sensitive	sensitive	0.23	1.36	0.80	1997.04
	Singok	HG-2	4.8	normal	normal	33.59	33.74	33.67	1996.04
	Yulhyeon	HG-6	0.1	sensitive	sensitive	46.40	46.94	46.65	1997.04
	Munmak	HG-7	0.3	normal	normal	53.91	54.58	54.14	1997.04
	Gageum	HG-8	0.3	normal	normal	51.39	52.11	51.65	1996.01
	Goam	HG-10	8.7	sensitive	sensitive	265.04	265.91	265.53	1997.07
	Guiun	HG-11	6.1	normal	normal	5.34	8.17	7.14	1997.04
Anseong-cheon	Seonggeo	AG-1	10.1	normal	normal	46.07	46.36	46.21	1997.04
Nakdong River	Myungho	NG-1	0.1	normal	normal	196.88	197.27	196.99	1997.04
	Yecheon	NG-3	3.5	sensitive	normal	84.08	85.70	85.24	1996.04
	Gongseong	NG-4	17.4	sensitive	normal	77.80	78.36	78.15	1997.04
	Namsan	NG-7	9.9	normal	normal	63.81	66.58	65.04	1997.04
	Hapcheon	NG-8	2.1	normal	normal	44.19	44.76	44.45	1997.04
	Chojeon	NG-10	0.1	normal	normal	15.23	15.68	15.36	1996.04
	Sanne	NG-12	21.3	normal	normal	198.46	198.88	198.61	1997.04
Geum River	Daeso	GG-1	12.6	normal	normal	84.68	86.06	85.64	1997.04
	Gadeok	GG-3	1.9	sensitive	sensitive	73.68	75.19	74.18	1996.04
Sapgyo-cheon	Yesan	SGG-1	0.1	normal	normal	7.38	7.85	7.64	1997.04
Seomjin River	Ipmyeon	SJG-2	1.8	normal	normal	77.09	79.26	77.56	1997.04
Yeongsan River	Yudeok	YG-2	0.1	normal	normal	15.76	16.14	16.03	1996.01
	Samdo	YG-3	0.1	normal	normal	3.37	4.04	3.54	1997.04

*Note: Used main stream is national stream

7 large dams watershed, streamflow level observation station watershed, groundwater level observation station watershed, same characteristic of precipitation. Figure 1 and Table 3 show the state of subwatershed division.

The procedure to determine the MSWSI for a particular watershed is as follows: monthly data are collected and summed for all the precipitation stations, dam inflow, and groundwater level/ streamflow measuring stations over the watershed. Each summed component is normalized using a frequency analysis gathered from a long-term data set. The probability of non-exceedence the probability that subsequent sums of that component will not be greater than the current sums determined for each component based on the frequency analysis. This allows comparisons of the probabilities to be made between the components. Each component has a weight assigned to it depending on its typical contribution to the surface water within that watershed, and these weighted components are summed to determine a MSWSI value representing the entire watershed. Like the Palmer Index, the MSWSI is centered on zero and has a range between −4.2 and +4.2.

Figure 2 and 3 show MSWSI map of 2001 year and results from 1974 to 2001 years, respectively.

In order to check the applicability of the suggested drought index, the results were compared with historical drought records in 1994. From June to September in 1994, severe drought occurred mainly in the southern part due to the low stream flow and storage. The rate of stream flow and storage was 3.7% and 9% in the Seomjin basin, respectively. Especially, extreme drought was happened in July. However, PDSI did not reflect the water deficit in the southern part because it only showed the moderate drought with from −2.2 to −1.2 (Table 4).

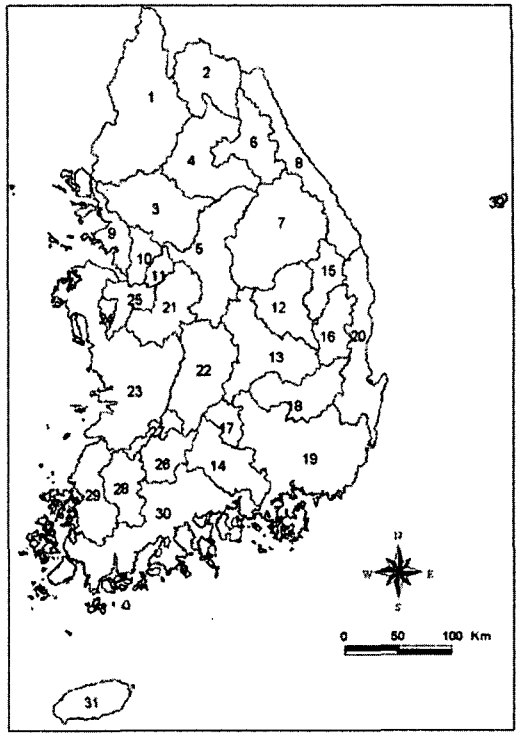

Fig. 1 Subwatershed division for applying MSWSI

V. Conclusions

The states of hydrological drought were assessed by suggested methods in South Korea. Developed method for assessment of hydrological drought is based on SWSI using national hydrological monitoring system. In order to apply this index, South Korea was divided into 32 subwatersheds. Semi-distributed hydrological drought map can be mapped through subwatershed division. A strong point of MSWSI is to consider hydrological characteristics of sur-

Table 3 Characteristics of each subwatershed

Basin name	Watershed No.	Watershed type	Station existence			Input data
			Dam	Stream	Ground water	
Han River	1	Groundwater	-	-	-	P
	2	Groundwater	-	-	-	P
	3	Stream	-	O	O	S, G, P
	4	Stream	-	O	-	S, P
	5	Stream	-	O	O	S, G, P
	6	Dam	O	-	-	D, P
	7	Dam	O	-	O	D, P, G
	8	Groundwater	-	-	O	G, P
	9	Groundwater	-	-	-	P
Anseong-cheon	10	Groundwater	-	-	-	P
	11	Stream	-	O	O	S, G, P
Nakdong River	12	Stream	-	O	O	S, G, P
	13	Stream	-	O	O	S, G, P
	14	Stream	-	O	O	S, G, P
	15	Dam	O	-	O	D, P, G
	16	Dam	O	-	-	D, P
	17	Dam	O	-	-	D, P
	18	Groundwater	-	-	O	G, P
	19	Groundwater	-	-	O	G, P
	20	Groundwater	-	-	-	P
Geum River	21	Stream	-	O	O	S, G, P
	22	Dam	O	-	-	D, P
	23	Groundwater	-	-	-	P
Sapgyo -cheon	24	Stream	-	O	-	S, P
	25	Groundwater	-	-	O	G, P
Seomjin River	26	Stream	-	O	O	S, G, P
	27	Dam	O	-	-	D, P
	30	Groundwater	-	-	-	P
Yeongsan River	28	Stream	-	O	O	S, G, P
	29	Groundwater	-	-	-	P
Jeju-do (Ulleung-do)	31	Groundwater	-	-	-	P
	32	Groundwater	-	-	-	P

P: precipitation, S: streamflow, G: groundwater, D: dam inflow

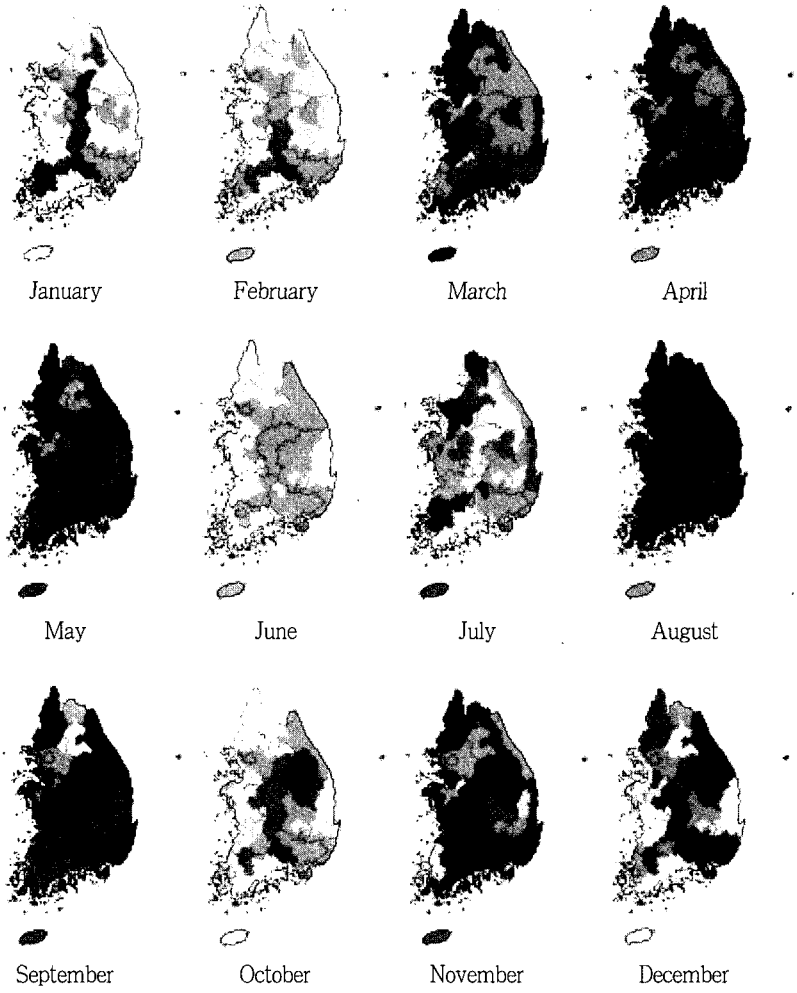

Fig. 2 Monthly MSWSI map

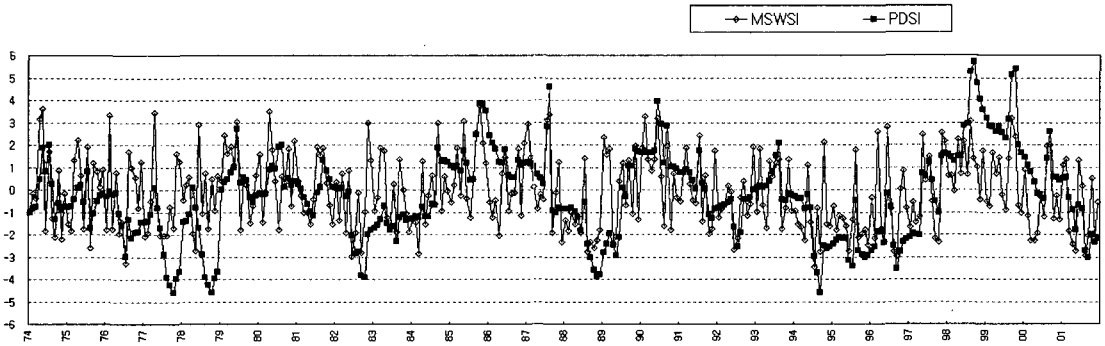

Fig. 3 Average MSWSI from 1974 to 2001

Table 4 Comparing PDSI and MSWSI from June to September in 1994

Month		Gyeonggi	Gangwon	Chungbuk	Chungnam	Jeonbuk	Jeonnam	Gyeongbuk	Gyeongnam
PDSI	6	0.77	0.96	1.22	0.30	-1.33	-1.37	1.32	-0.62
	7	-0.55	-0.34	-0.06	-0.79	-2.20	-2.05	0.03	-1.29
	8	-0.88	-0.55	-0.27	-0.75	-2.40	-2.09	-0.96	-1.75
	9	-0.99	-1.67	-0.73	-1.20	-2.88	-2.43	-2.43	-2.37
MSWSI	6	-1.34	-1.15	-1.91	-2.34	-1.39	-1.79	-1.05	-0.04
	7	-3.51	-3.10	-3.35	-3.68	-3.55	-3.75	-3.25	-3.57
	8	-1.61	-1.10	-1.02	-0.01	-1.83	0.45	1.29	2.49
	9	-3.04	-2.61	-2.68	-3.21	-2.99	-2.91	-3.09	-1.68

face and subsurface, while SWSI considers only surface water supply.

This index could be conducted to represent the calculated index as a spatially distributed information. Monthly MSWSI was evaluated for the period of 1974 and 2001. This result had 0.49 and 0.58 correlation coefficients compared with PDSI and SPI, respectively. It is necessary to check the applicability of the suggested index in our hydrological drought situation.

Acknowledgements

This work was funded by the KOWACO (Korea Water Resources Corporation) for ten months from June 2004 to April 2005 (Research Number: IPD-2004-1)

References

1. Chow, V. T., 1984. Handbook of applied hydrology, McGRAW-HILL Inc..
2. Easterling, W. E., 1998, Coping with drought hazard: recent progress and research priorities, In: Siccard, F. and Bras, R. L. (Eds), Natural disasters in European Mediterranean countries, NSF and NRC, Perugia (Italy), pp. 231-270.
3. MeKee, T. B., Doesken, N. J. and Kleist, J., 1993, The relationship of drought frequency and duration of time scales, 8th Conference on Applied Climatology, Jan., Aneheim, CA, pp. 179-184.
4. Rouse, J. W., Haas, R. H., Schell, J. A. and Deering, D. W., 1974. Monitoring vegetation system in the great plains with ERTS, Proceedings, Third Earth Resources Technology Satellite-1 symposium, Greenbelt, NASA SP-351, pp. 3010-317.
5. Rossi, G., 2002, Requisites for a drought watch system.
6. Rossi, G., Benedini, M., Tsakiris, G. and Giakoumakis, S., 1992, On regional drought estimation and analysis, Water Resour. Manage., Vol. 6, pp. 249-277.
7. Shafer, B. A. and Dezman, L. E., 1982, Development of surface water supply index to assess the severity of drought condition in snowpack runoff areas, Proc. Western Snow Conf., pp. 164-175.
8. Wilhite, D. A., 2000, Drought. A global assessment for drought, Westview Press, Boulder.
9. Yevjevich, V., Da Cunha L. and Vlachos, E., 1983, Coping with droughts, Water Resources Publication, Littleton, Colorado.