Development of A Single Reservoir Agricultural Drought Evaluation Model for Paddy

단일저수지 농업가뭄평가모형의 개발

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Abstract

This study aimed to develop an agricultural drought assessment methodology for irrigated paddy field districts from a single reservoir. Agricultural drought was defined as the reservoir storage shortage state that cannot satisfy water requirement from the paddy fields. The suggested model, SRADEMP (a Single Reservoir Agricultural Drought Evaluation Model for Paddy), was composed of 4 submodels: PWB (Paddy Water Balance Model), RWB (Reservoir Water Balance Model), FA (Frequency and probability Analysis model), and DCI (Drought Classification and Indexing model). Two indices, PDF (Paddy Drought Frequency) and PDI (Paddy Drought Index) were also introduced to classify agricultural drought severity. Both values were divided into 4 steps, i.e. normal, moderate drought, severe drought, and extreme drought. Each step of PDI was ranged from +4.2 to -1.39, from -1.39 to -3.33, from -3.33 to -4.0 and less than -4.0, respectively. SRADEMP was applied to Jangheung reservoir irrigation district, and the results showed good relationships between simulated results and the observed data including historical drought records showing that SRADEMP explains better the drought conditions in irrigated paddy districts than PDSI.

Keywords : Agricultural drought, Drought assessment, Water Balance Model

I. Introduction

Drought is a normal, recurrent feature of climate, although it is regarded as a rare and random event. Basically it originates from a deficiency of precipitation over an extended period of time. This deficiency results in a water shortage for some activity, group, or environ-

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Fig. 1 Definition of drought (NDMC, <http://www.drought.unl.edu/>)

mental parts. So, drought should be considered with a relationship to some long-term average condition of water balance in a particular area. Fig. 1 describes various foci for drought definition.

Historically, droughts during the irrigation period have been occurred as the accumulated rainfall was less than 50% of normal precipitation amount during June through August, or the continuous dry days were more than 20 days during the same period (Chung, 1997).

Although it is difficult to identify drought only about agriculture, abundant studies have suggested various methods and indices to evaluate agricultural drought. Park (1982) suggested a concept of drought duration in terms of meteorological drought. Kim (1998) developed IRWSI (Irrigation Reservoir Water Supply Index) to assess the

water supply ability of irrigation reservoir based on field measurements. Chung et al. (1997) devised NDI (Normal Drought Index), one of decile methods, in order to evaluate monthly drought using only rainfall data. The MAF (Ministry of Agriculture and Forest) has used two indices the percentage of accumulated rainfall to normal precipitation and the average storage ratio of irrigation reservoirs (Chung et al. 1997). However, it was difficult to explain drought state properly with both indices for a region because irrigation districts have different characteristics in terms of paddy fields properties and irrigation reservoir sizes. Nevertheless, both indices have been used in convenience to describe general condition of drought severity, especially to establish a drought re-

sponse plan for the multiple regions.

In Korea, a reservoir is the main water resources to supply irrigation water to paddy fields. A shortage of water supply from a reservoir can be occurred at any period during crop growing, and it may cause a stress on crops and likely results yield decreasing, even though the average reservoir storage demonstrates above a normal condition for a long-term period. Therefore it is required to pay attention to water supply possibility over all growth stages, and in reservoir irrigation districts, the severity of agricultural drought has to be analyzed with a relationship between available reservoir storage conditions and water requirement in the demand paddy fields.

Therefore, the purpose of this study is to analyze the relationship for a practical description of agricultural drought, particularly on irrigated paddy fields utilizing a single reservoir

agricultural drought evaluation model, SRADEMP, to evaluate and classify the relative and quantitative severity of agricultural drought.

II. Model Formulation

This SRADEMP (Single Reservoir Agricultural Drought Evaluation Model for Paddy) works with 4 submodels, i.e. PWBM (Paddy Water Balance Model), RWBM (Reservoir Water Balance Model), FA (Frequency and probability Analysis model), and DCI (Drought Classification and Indexing model) as shown in Fig. 2.

1. Data Preparation and Pre-processing

The data used in this SRADEMP are categorized as 3 parts as shown in Table 1. 1) Meteorological data. 2) Reservoir specification data. 3) Farming practice data.

Fig. 2 Procedure of SRADEMP

Table 1 Input data for SRADEMP

Categories	Data		
	Symbol	Unit	Description
Farming practice data	KC	-	10-days crop coefficients of paddy rice
	PD	mm	Reference ponding depth by growth stages
	CAL1,2	-	Date of pre-planting and transplanting
	SH	mm	Sluice height
Meteorological data	ALT, LAT	°	Altitude / Latitude (observation location)
	ANEH	m	Anemometer height
	SLH	m	Sea level height (observation location)
	TEMP*	°C	Daily temperature(max, min, mean)
	DEW	°C	Daily dew point
	RH*	%	Daily relative humidity(mean, min)
	WDS	m/s	Daily wind speed
	VAP	mb	Daily vapor pressure
	SUH	h	Daily sunshine hours
	PAN	mm	Daily pan evaporation
	RAIN	mm	Daily rainfall
Reservoir specification data	FWC	m ³	Full water storage capacity
	FWA	m ²	Full water level area
	DSC	m ³	Dead storage capacity
	ESC	m ³	Effective storage capacity
	WAREA	m ²	Reservoir watershed area
	BPA	m ²	Benefited paddy area
	URATIO	%	Area ratio by land use within the watershed

2. PWBM (Paddy Water Balance Model)

This model was developed to estimate daily water demand and supply in paddy fields. The daily water requirement and ponding depth are simulated successively using the climate and farming practice data. The water balance system for paddies can be generally depicted as in Fig. 3. Among the components, paddy bund seepage, surface inflow over bund, and groundwater rise were not considered in this model because these flux are so difficult to be measured quantitatively and those components can be obstacles to utilize this model to the ungauged area.

The daily water requirements is defined by the following equation.

$$REQ(t) = PD(t) - D(t-1) + ETa(t) + DP(t) - ER(t) \dots \dots \dots (1)$$

where REQ = daily water requirement (mm), PD = reference ponding depth by each growth stage (mm), D = ponding depth (mm), ETa = actual crop evapotranspiration (mm), DP = deep percolation (mm), ER = effective rainfall (mm), and t = time (day). Here, ETa is determined by multiplying potential evapotranspiration by 10-days crop coefficients of paddy rice. The potential evapotranspiration is computed by the modified FAO Penman equation and the 10-days crop coefficients are used with the values by Chung (1997). DP is defined as 5mm/day known as a mean value. Also PD was selected from Chung (1997) that suggested to manage water

Fig. 3 Water balance system for paddies

supply efficiently and to maximize the yields (Table 2). ER, the quantity of rainfall infiltrated into soils and used for crops, is derived from the relationship between the ponding depth and the amount of rainfall as equation (2).

$$FD(t) = PD(t) - D(t-1) + ETa(t) + DP(t) \dots\dots(2)$$

$$ER(t) = FD(t), \text{ If } FD(t) < RAIN(t)$$

$$ER(t) = RAIN(t) \quad \text{otherwise}$$

where FD = free board height (mm), RAIN = daily rainfall (mm).

And 140mm of lot-management water is totally required during pre-planting and transplanting periods ranging from May 21 to June 10.

3. RWBM (Reservoir Water Balance Model)

The daily available water storage of a reservoir

can be estimated as shown in Fig. 4. The available water storage, defined as the difference between current storage and dead storage, is estimated by equation (3).

$$AS(t) = AS(t-1) + RI(t) + RP(t) - RL(t) - RO(t) - RE(t) \dots\dots\dots(3)$$

where AS = available storage (m^3), RI = inflow (m^3), RP = rainfall to the reservoir surface (m^3), RL = release (m^3), RO = overflow (m^3), and RE = evaporation losses (m^3). Here, RI is estimated from the modified TANK model by Kim (1988), who simply defined input data of the TANK model as area ration of each land use type. RL depends on the amount of daily water requirements induced by the PWBM and it also includes the water delivery requirement, that is, 20% of the amount of release.

Table 2 Reference ponding depth by growth stages at paddy fields

Date	4/21~5/20	5/30	6/1~6/30		7/1~7/20		7/21~8/20			8/30	9/10
Growth stages	Pre-planting	Trans-planting	Tillering		Elongation		Heading			Ripening	
Ponding depth	20	60	40	0	20	30	30	30	40	40	0

Fig. 4 Water balance process of SRADEMP

4. FA (Frequency and probability Analysis model)

The recurrence year of agricultural drought, which is useful to evaluate the relative drought severity, can be analyzed by the time series data of available reservoir storage that is obtained from water demand and supply analyses result using the both water balance models. This study defined 10-days as an analysis unit, so that the 36 time series data for minimum available storage

are generated. An optimal probability distribution for a time series data is selected by a Kolmogorov-Smirnov test. The PDF(Paddy Drought Frequency) is calculated from nonexceedance probability of the optimal probability distribution.

5. DCI (Drought Classification and Indexing model)

This study defined PDI(Paddy Drought Index) as the following formulation that refers to the

SWSI (Surface Water Supply Index: Shefer & Dezman, 1982) and IRWSI (Irrigation Reservoir Water Supply Index: Kim, 1998).

$$PDI = (P_{AS} - 50) / 12 \dots \dots \dots (4)$$

where PDI = paddy drought index and P_{AS} = nonexceedance probability of the optimal probability distribution for minimum available storage. Here the PDI that has a range from -4.2 to +4.2 like the SWSI is classified as shown in Table 3. The drought severity is divided into 4 steps including normal, moderate drought, severe drought, and extreme drought and the corresponding steps by PDI are defined as 4 steps.

The steps are also classified as the paddy drought frequency (PDF) including from 1 to 3, from 3 to 10, from 10 to 50, and more than return period of 50 years, respectively.

Table 3 PDI classification

PDF	PDI	Classification
3 years below	+4.20~-1.39	Normal
10~3 years	-1.39~-3.33	Moderate drought
50~10	-3.33~-4.00	Severe drought
50 years above	-4.00~-4.20	Extreme drought

III. Model Application and Results

The developed model was applied to Jangheung reservoir district in Yeosu-gun, Kyungki-do, Korea. Yeosu-gun has been vulnerable to water shortage and experienced severe droughts in the past, particularly in 1972, 1982, and 1994.

1. Data Collection

Jangheung reservoir was founded in 1989 with 400ha of demand area, 2,980,000m³ of full storage capacity, and 90,000m³ of dead storage capacity. The watershed area is 977ha in size with 90.2% forest, 6.3% paddy fields, and 3.5% upland fields.

The meteorological data were collected at Suwon weather station from 1973 to 1998. The observed reservoir storage ratio records since 1994 were used for the model application and validation.

2. Water Requirement Estimation

First, daily crop evapotranspiration was simulated and Fig. 5 shows a similar pattern in the major drought years. Daily water requirement from 1973 to 1998 was calculated using the water balance model, PWBM, and the results for annual rainfall and annual water requirement, just during irrigation seasons, were listed in Table 4 showing the smallest year was 1982. Fig. 5 shows the major historical years have a similar pattern of temporal variation in crop evapotranspiration. In general the annual rainfall is one of the most important factors affecting drought and implying the number of rainy days, thus inverse proportion between annual water requirement and annual rainfall seems reasonable. However, determination coefficient (R^2) between annual effective rainfall and annual rainfall resulted as a weak relationship with 0.22 (Fig. 6). It means that the rainfall distribution over the growth stages is more important than the quantitative scale all over the growing period.

Table 4 Annual effective rainfall and water requirement for irrigation season

Year	Annual rainfall (mm)*	Annual rainfall (mm)	Annual effective rainfall (mm)	Annual water requirement ($\times 1000 \text{ m}^3$)	Year	Annual rainfall (mm)*	Annual rainfall (mm)	Annual effective rainfall (mm)	Annual water requirement ($\times 1000 \text{ m}^3$)
1973	1072.1	843.0	300.3	3,891	1986	1084.8	894.2	216.7	3,452
1974	1108.8	805.9	248.1	3,909	1987	1575.8	1606.0	256.6	2,778
1975	1263.5	915.7	224.9	3,741	1988	969.0	833.2	144.1	3,749
1976	1229.5	894.8	186.7	3,347	1989	1243.9	799.5	174.0	3,353
1977	997.5	696.4	198.9	4,388	1990	2154.1	1615.7	270.5	3,042
1978	1138.3	931.6	194.7	3,250	1991	1287.3	1018.8	199.3	3,475
1979	1353.3	1023.6	244.9	3,369	1992	1193.7	800.1	200.1	3,461
1980	1361.3	1016.8	214.1	3,075	1993	1172.5	947.2	190.8	3,158
1981	1309.4	1079.8	231.2	3,306	1994	951.8	666.0	158.3	4,023
1982	901.0	577.0	160.5	4,023	1995	1396.9	1278.4	178.9	3,388
1983	935.1	665.2	193.8	3,593	1996	995.1	773.0	160.0	3,598
1984	1160.2	935.2	144.8	3,426	1997	1264.9	966.0	240.0	3,434
1985	1401.1	842.3	197.6	3,718	1998	1770.8	1384.8	217.2	2,693

■ : the major historical drought year

* : for full season (12months)

Fig. 5 Daily actual ET in 1977, 1982, and 1994

Fig. 6 Comparison between annual water requirement and effective rainfall

3. Available Reservoir Storage Estimation

Daily and annual inflow to the reservoir was estimated as depicted in Fig. 7 and Fig. 8. The smallest annual inflow was computed in 1983

with 946.3 mm/yr annual rainfall, nevertheless there was no historical drought reported during this year, because about 70% of annual rainfall during 45 rainy days was well distributed over the paddy rice growing seasons increasing

Fig. 7 Annual inflow of Jangheung reservoir

Fig. 8 Daily inflow of Jangheung reservoir in 1982

(a) 1994 ($R^2=0.90$)

(b) 1995 ($R^2=0.70$)

(c) 1996 ($R^2=0.64$)

(d) 1998 ($R^2=0.63$)

Fig. 9 Comparison of observed and simulated reservoir storage

Fig. 10 The simulated daily available storage by the RWBM (0: dead storage)

effective rainfall, it provides a fact that the time-distribution of rainfall is a critical factor to resist a drought increasing water supply capability from a reservoir and to increase the effective rainfall for the rice use.

The simulated available storage by the RWBM was compared with the observed data during the period from 1994 to 1998. The correlation coefficients were a range from 0.63 to 0.9 as shown in Fig. 9 showing the RWBM can be used to simulate available reservoir storage.

The Fig. 10 shows daily available storages from the RWBM during the major historical drought years, 1977, 1982, and 1994.

4. PDF and PDI Analysis

1) Determination of an optimal probability distribution function

The probability and frequency analysis model, FA, was conducted with the time series data that were arranged with simulated 10-days minimum available storage during 1973 to 1998. To find an optimal distribution function, the K-S test was carried out for 3 probability distributions including Gamma, Pearson type III, and normal distribution. Normal distribution was selected as an optimal probability distribution for the time series as shown in Table 5. The maximum deviation was ranged from 0.243 to 0.088, which is less than the lower limit 95% confidence level value, 0.264.

2) Estimation of 10-days PDF and PDI

As mentioned in the previous section, the PDF and PDI of 10-days available storage were calculated using the normal probability function, and compared with the historical drought records. PDSI (Palmer drought severity index) was also computed to compare with PDF and PDI as shown in Table 6.

Fig. 11 shows that the selected area has

Table 5 Comparison of probability distributions by K-S test

Time		Normal distribution	Gamma distribution	Pearson type-III	Time		Normal distribution	Gamma distribution	Pearson type-III
5	L	0.226	0.283	0.275	7	L	0.243	0.325	0.281
	E	0.154	0.220	0.193		E	0.231	0.297	0.330
6	M	0.178	0.185	0.169	8	M	0.204	0.268	0.307
	L	0.148	0.149	0.134		L	0.159	0.283	0.245
7	E	0.088	0.097	0.091	9	E	0.197	0.215	0.205
	M	0.117	0.137	0.122	Avg.		0.180	0.220	0.200

experienced about 5 severe drought events over the past 26 years since 1973. Especially, 1977, 1982, and 1994 droughts were well illustrated with the results from the model developed in comparison to government reports that were published by MAF and MOGAHA (Ministry of Government Administration and Home Affairs). For the three years, the generated PDF exceeded 100 years and the PDI was less than -4.0 . The PDIs were -4.11 in late July, 1982 and -4.14 in early September, 1977, as a smallest value reflecting a severe water shortage during the period.

During 1982, it had experienced the severest drought due to the lack of water supply capability of the reservoir in July, and the condition had been recovered around the end of the year. In

1977, a severe drought also came and resulted the worst condition in July in similar to 1982 carrying over to the next year. A drought also accounted in early 1978 due to the carry-over effect that the water shortage of the previous year can effect water availability in the next year, even though the total rainfall during growing season in 1978 was 235mm more than that in 1977.

The winter drought in 1984 seemed much severe in terms of meteorological or hydrological drought. However, it was not accounted as an agricultural drought because it occurred before the transplanting and the reservoir was restored with melted snow and spring rainfall, so that agricultural drought was not observed in 1984 and the farming was not impeded from the wintry scarce rainfall.

From Table 6 it is shown that this pilot area haven't experienced any water deficit during representatively 3 periods from 1978 to 1980, from 1986 to 1988 and 1990–1992.

5. Comparison of PDI and PDSI

PDSI (Palmer Drought Severity Index) was designed as a function of soil moisture deficit and the period of the deficit time by Palmer(1965), and has been used widely as a quantitative agricultural drought analysis method to account upland field drought. Even though PDI was not developed on the same basis of PDSI, a comparison between two indices was conducted to investigate applicability of PDI and to find discrepancies while accounting the agricultural droughts.

Although the fluctuation trend of two indices showed a similar pattern during drought and wet season, PDI accounted 1978–79, 1987–88, and

Fig. 11 PDI and PDSI from 1973 to 1998

Fig. 12 PDI and PDSI in the major drought years: 1977, 1982, and 1994

Table 6 PDF, PDI, and PDSI during irrigation season

Year	June									July					
	E			M			L			E			M		
	PDF	PDI	PDSI	PDF	PDI	PDSI	PDF	PDI	PDSI	PDF	PDI	PDSI	PDF	PDI	PDSI
1973	4	-2.0	0.9	3	-1.4	1.1	3	-1.1	1.4	2	0.7	-0.2	6	-2.7	-0.6
1974	1	2.8	2.9	1	2.4	2.6	1	1.5	2.3	2	-0.2	2.8	1	3.0	-0.3
1975	2	0.5	-1.2	3	-1.1	-1.4	4	-1.7	-1.57	7	-2.8	-1.4	5	-2.2	-1.6
1976	3	-1.2	-0.3	2	-0.7	-0.5	3	-1.3	-0.7	4	-1.9	-0.7	4	-2.1	-1.0
1977	2	1.0	1.5	3	-1.0	-0.2	3	-1.6	-0.4	6	-2.5	-0.1	2	-0.6	-0.4
1978	543	-4.2	-2.3	104	-4.1	-2.5	94	-4.1	-1.4	2	0.8	-1.3	2	1.0	-1.1
1979	1	1.8	1.2	1	2.8	1.6	1	3.1	2.0	1	3.4	1.8	1	2.9	1.6
1980	1	1.9	1.5	1	1.9	1.8	1	2.6	1.9	1	2.8	1.5	2	1.1	1.6
1981	4	-1.8	-0.6	5	-2.5	-0.7	6	-2.6	-0.8	3	-0.7	1.4	1	3.5	1.5
1982	3	-1.2	-0.7	6	-2.5	-1.0	7	-2.8	-1.2	32	-3.9	-1.5	119	-4.1	-1.9
1983	4	-2.0	-0.7	5	-2.4	-0.6	5	-2.4	-0.8	5	-2.5	-0.9	8	-3.0	-0.8
1984	7	-3.0	-2.9	3	-1.4	-2.8	2	-1.1	-2.9	3	-1.6	-2.3	1	2.7	-2.5
1985	3	-1.5	-0.2	5	-2.3	-0.4	6	-2.6	-0.4	7	-2.8	-0.4	6	-2.6	-0.7
1986	4	-2.0	1.0	4	-1.7	1.1	3	-1.3	1.2	3	-1.6	0.7	4	-2.1	1.1
1987	1	4.0	2.1	1	4.1	1.9	1	3.8	1.5	1	2.3	1.1	2	1.2	1.1
1988	1	1.4	-1.7	2	0.2	-1.7	2	-0.2	-1.9	3	-1.0	-1.6	2	0.1	-0.5
1989	2	-0.1	-0.4	1	3.5	-0.1	1	3.4	-0.4	2	1.5	-0.7	2	0.7	-0.9
1990	2	0.1	3.2	2	1.0	3.9	1	3.5	4.9	1	3.9	4.6	1	3.5	4.8
1991	1	3.9	3.0	1	3.9	2.9	1	3.5	2.8	1	3.0	2.5	1	2.3	2.6
1992	2	0.4	-0.2	3	-0.7	-0.4	3	-1.4	-0.6	8	-3.0	-0.8	10	-3.3	-0.9
1993	2	1.3	0.5	1	2.5	0.6	1	1.9	0.5	2	0.8	0.2	2	0.2	0.7
1994	2	0.3	-1.8	3	-1.1	-2.0	4	-1.7	-1.7	2	-0.4	-1.8	6	-2.7	-2.2
1995	3	-1.1	-2.2	4	-1.8	-2.2	5	-2.3	-2.5	10	-3.2	0.3	4	-1.6	0.4
1996	4	-2.0	-1.0	3	-1.6	1.0	1	2.8	1.1	1	3.3	-0.1	1	2.2	-0.4
1997	1	2.8		2	1.2		2	0.3		1	3.8		1	3.5	
1998	2	0.5		1	1.6		2	1.0		1	3.8		1	3.6	

1994 as wet state when PDSI indicates as droughts. However, PDI indicated the first half of 1983 as a severe drought while it is estimated as a wet state by PDSI. Also PDI showed an extreme drought in July, 1994 that was withdrawn to normal state in September while PDSI extends the severe drought condition until the end of the year. These differences mean that PDI drought condition is sensitive to the reservoir storage rather than the soil moisture condition for the PDSI that causes seasonal discrepancies between two indices to define the agricultural

drought indication PDI can be an affordable drought index to evaluate the agricultural drought in a region having irrigated paddy fields.

IV. Summary and Conclusion

Agricultural drought model for the irrigated paddy fields from a single reservoir was developed. The SRADEMP in which determines drought frequency and index was composed of PWBM for paddy water balance computation, RWBM for reservoir water balance calculation,

Table 6 PDF, PDI, and PDSI during irrigation season (continued)

Year	July						Aug						Sep.		
	L			E			M			L			E		
	PDF	PDI	PDSI	PDF	PDI	PDSI	PDF	PDI	PDSI	PDF	PDI	PDSI	PDF	PDI	PDSI
1973	10	-3.2	-0.8	9	-3.1	-0.9	14	-3.5	-0.7	6	-2.6	-0.8	4	-1.8	-0.8
1974	1	1.6	-0.4	1	1.8	-0.5	2	0.5	-0.8	2	-0.3	-1.1	4	-1.8	-1.3
1975	3	-1.6	0.6	1	2.7	0.6	1	2.7	-0.1	2	1.1	-0.3	2	1.0	-0.5
1976	11	-3.3	-1.3	12	-3.4	0.1	3	-1.6	0.9	1	2.9	1.1	1	2.3	-0.2
1977	5	-2.3	-0.6	7	-2.8	-0.8	13	-3.4	-1.2	86	-4.0	-1.6	359	-4.1	-1.5
1978	1	1.5	-1.3	2	0.4	-1.4	1	1.6	-0.7	1	2.5	-1.0	1	1.9	-1.1
1979	1	2.2	1.4	1	2.4	1.8	1	2.6	-0.1	1	2.5	-0.2	1	1.6	-0.4
1980	1	2.7	1.8	1	1.6	1.5	1	1.5	1.6	1	2.7	1.6	1	2.7	1.6
1981	1	1.6	-0.2	2	0.9	-0.2	2	1.0	-0.3	2	1.4	0.1	1	2.7	0.2
1982	184	-4.1	-1.9	69	-4.0	-2.2	92	-4.0	-1.9	12	-3.4	-1.9	19	-3.6	-2.2
1983	3	-0.9	-0.9	3	-0.8	-1.1	3	-1.6	-1.4	4	-2.1	-1.7	7	-2.8	-1.8
1984	2	0.5	-2.5	1	1.4	-2.7	2	0.6	-2.8	2	-0.2	-2.9	1	2.7	0.7
1985	10	-3.2	-1.0	10	-3.2	-0.5	3	-0.8	-0.6	3	-1.3	-1.0	4	2.1	0.1
1986	1	1.7	1.0	1	1.7	0.8	1	2.3	0.8	1	2.3	0.8	1	2.5	0.7
1987	1	2.9	2.3	1	3.0	3.1	1	3.0	3.2	1	2.9	3.5	1	2.7	-0.1
1988	1	2.3	-0.6	2	0.7	-0.9	3	-0.7	-1.2	3	-1.2	-1.4	7	-2.9	-1.6
1989	2	1.0	-0.6	1	1.5	-0.9	2	0.6	-1.1	2	1.4	-0.8	1	2.3	-1.1
1990	1	2.6	4.7	1	1.7	4.5	1	2.7	4.3	1	2.4	4.3	1	2.7	5.6
1991	1	2.8	2.8	1	2.7	2.9	2	1.3	-0.3	3	-1.0	-0.6	4	-1.9	0.3
1992	7	-2.8	-1.1	7	-2.8	-1.4	6	-2.7	-1.4	5	-2.3	0.3	1	2.2	-0.1
1993	1	2.3	0.6	1	2.9	1.0	1	2.8	-0.2	1	2.4	-0.3	2	0.7	-0.6
1994	32	-3.8	-2.6	81	-4.0	-2.7	120	-4.1	-2.8	212	-4.1	-2.4	12	-3.3	-2.5
1995	2	1.2	0.1	2	0.4	0.4	1	2.5	1.2	1	2.9	2.2	1	2.6	-0.1
1996	1	2.5	-0.0	1	2.3	-0.2	2	1.0	-0.5	2	-0.1	-0.6	2	-0.3	-0.8
1997	1	2.0		1	2.3		1	2.2		2	0.8		3	-1.1	
1998	1	1.5		1	2.2		1	3.1		1	2.8		1	1.9	

FA for frequency and probability analysis, and DCI for drought classification and indexing. The model uses time series of available storage and derives PDF and PDI from 10-days nonexceedance probability. The indices are classified as normal, moderate, severe, extreme drought to describe drought severity.

The developed model was applied to Jangheung reservoir district, in Yeosu-gun, Kyungki-do, Korea. The results showed a reasonable relationship with historical drought records. In comparison with PDSI, SRADEMP resulted in

different drought period indicating the irrigated paddy fields drought is more dependable to the reservoir storage condition than the climate conditions. It shows that combining reservoir water balance and paddy water requirement is a preferable approach to describe realistic conditions of the irrigated paddy field drought. The models in this study can be used to standardize agricultural drought in irrigated paddy districts and to assist establishing drought-resilient systems.

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