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ORIGINAL PAPER

Definition and characteristics of the water abundant season in Korea

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Abstract In contrast to the normal seasons that are classified by the distribution of temperature and precipitation, this study defines a new concept of the water abundant season (WAS) when water is more abundant than in other seasons. We investigated its characteristics on 60 stations in Korea, and compared it with Changma (the rainy season). In this study, Available Water Resources Index (AWRI), which is a summed daily precipitation accumulated for more than 365 days with a time-dependent reduction function and reflects the current water condition, was used to quantify the water amount. In addition, the median value of 30 year's daily AWRI was used as the criterion value dividing WAS from other seasons. The results show that the terminologies on water resources have changed from qualitative concepts such as abundance, deficit, and continuous rainfall, to quantitative values using AWRI. In detail, it was known that the WAS in Korea starts on 2 July and ends on 25 December, lasting for 176 days. The onset date of WAS in Korea is getting earlier, with a trend of 2.9 days/decade. The end date does later with a delay of 7.5 days/decade, and the duration is increasing at 10.4 days/decade. We looked at the WAS by stations and saw, on average, that 14 June was the earliest onset date in Seogwipo and 29 July was the latest one in Sokcho, representing a difference of 45 days. The earliest end date was in Tongyeong at 5 December and the latest one is in Uljin at 16 January of the following year, a difference of 41 days. Tongyeong had the shortest (166 days) WAS duration and Uljin had the longest (207 days) on average. The big spatial differences of the criterion values per station were detected and quantified. The largest criterion value for WAS were recorded in Seongsan with 270.7 mm, which is almost double of the smallest value, which was recorded in Uiseong (135.9 mm). Comparing WAS with the Changma (the rainy season in Korea) showed that the onset date of WAS is close to that of Changma, but the end date shows a big difference. It is also known that WAS was more useful than Changma in detecting and demonstrating both of the season's progress and the seasonal state of water climates.

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1 Introduction

Korea has large variations in precipitation by season, and almost half the annual precipitation falls in summer (Ho and Kang 1988). In season with large precipitation, some agricultural activities are active because of the rich water resources and some parts of them are saved up to be used when water is insufficient (Oh et al. 1997). Commonly, it is simply known that water becomes abundant as soon as the rainy season (the Changma) begins.

The rainy season is understood as a season with large rainfall. The Changma has been used synonymously with the rainy season, but the former has a unique distribution of atmospheric pressure that has sometimes been used to differentiate it from the rainy season. However, both terms focus on the rainy period. Some previous studies (Kung and Sharif 1980; Nicholls et al. 1982; Nicholls 1984; Matsumoto 1995, 1997; Samel et al. 1999) defined the rainy season according to daily precipitation, but others used atmospheric circulation data (Ha et al. 2005; Seo et al. 2011) or only the dates during which rain falls continuously (Ryoo 2001) to define the Changma or the rainy season. Despite these studies, there is no official definition of the Changma (Park et al. 2008). As the Changma is defined in various ways, its onset and end dates are determined by subjective methods rather than objective methods, and the onset and the end dates vary by researcher (Table 1).

Meanwhile, the rainy season has been defined by the duration of continuous rainfall rather than by abundant water resources so the onset and the end dates of it also vary by researcher as with the Changma. As a matter of fact, rainwater does not disappear quickly but remains for a considerable period and exists as a water resource including a groundwater resources. Even though it does not rain at the moment, there are seasons with abundant water resources due to rains that fell before, which are not short. Therefore, there is a need to distinguish the period with abundant water resources from other period. In other words, distinguishing between periods not by the rainy day or rainfall amount but by the amount of water available to be used is necessary. However, this point has not been considered in previous studies of water resources and subjective decisions have been made regarding the rainy season and the Changma. Therefore, this study was conducted to address this problem. In the present study, the period of abundant water resources was labeled the water abundant season (WAS), and it was defined as objectively as possible.

Table 1 Comparison of the Changma onset dates obtained from previous studies and this study

Year	KMA	Ha et al. (2005)	Choi et al. (2012)	This study (2013)
1985	21 Jun	21 Jun	23 Jun	23 Jun
1986	20 Jun	12 Jun	22 Jun	23 Jun
1987	23 Jun	5 Jul	11 Jul	11 Jul
1988	22 Jun	23 Jun	12 Jul	13 Jul
1989	23 Jun	13 Jun	8 Jun	8 Jul
1990	18 Jun	18 Jun	19 Jun	15 Jun
1991	15 Jun	27 Jun	7 Jul	4 Jul
1992	22 Jun	9 Jul	13 Jul	12 Aug
1993	18 Jun	21 Jun	28 Jun	28 Jun
1994	17 Jun	26 Jun	30 Jun	–
1995	21 Jun	30 Jun	8 Jul	8 Aug
1996	19 Jun	16 Jun	17 Jun	24 Jun
1997	20 Jun	24 Jun	25 Jun	25 Jun
1998	12 Jun	11 Jun	25 Jun	24 Jun
1999	17 Jun	16 Jun	1 Jul	23 Jun
2000	16 Jun	21 Jun	27 Jun	14 Jul
2001	21 Jun	17 Jun	24 Jun	24 Jun
2002	19 Jun	23 Jun	5 Jul	5 Jul
2003	22 Jun	17 Jun	27 Jun	24 May
2004	22 Jun	22 Jun	19 Jun	19 Jun

In the other point of view, it is difficult to quantify the available water resources based on precipitation alone because a large portion of it is lost. In detail, the total amount of water resources in Korea is 13.2×10^{10} m^3 per year, but 57.4×10^9 m^3 (43 %) are evaporated or lost by subsurface seepage, and another 44.5×10^9 m^3 (34 %) are lost to sea in a short time during floods. To solve this problem, various water resource indices have been used, such as the Surface Water Supply Index (Shafer and Dezman 1982), the Water Scarcity Index (Falkenmark 1989), the Water Poverty Index (Sullivan 2002), the Arctic Water Resource Vulnerability Index (Alessa et al. 2008), the Water Resource Index (Khan and Anwar 2008), and the Water re-use index (Vörösmarty et al. 2000). However, these indices are not sufficiently successful in that they consider the changes of evaporation and outflow volumes over time because they were not created to quantify the abundance of water resources at a certain time. Thus, a new attempt must be made to develop a new concept.

The Available Water Resource Index (AWRI) developed by Byun and Lee (2002) is different from other indices that simply add up precipitation. It also considers daily reductions in volumes because of outflow, evaporation, seepage, etc. Furthermore, through several studies, it was verified that AWRI is very convenient and suitable to represent the amount of water resources.

For example, Han and Byun (2006) revealed that water shortages occurred when the AWRI was below a certain value. The comparison of predicted water level of dam using regression equation of AWRI was in good concordance with the observed water level of dam (Lee 2012). Furthermore, AWRI was effective in dividing the rainy seasons of Korea into three types (spring Changma, Changma, and fall Changma) (Byun and Lee 2002) and in defining a new onset date of the Changma (Choi et al. 2012).

In the viewpoint of terminology, expressions such as "seasons with abundant water resources" or "water abundant season" are rarely found in previous studies. Yang (2006) and Wang and Wang (2008) used only the word named the WAS, and Kang et al. (2008) investigated the period in which water is abundant in specific years, but they did not provide any specific definition of the WAS. Choi et al. (2007) defined the period from July to October as the WAS based on changes in the water temperature and the salinity on the southern coast of Korea only in the year 2000. However, this study left room for further work because it did not include water resources in its definition of the WAS. Another study defined the WAS as the period (late May to late August) when rainfall was concentrated and the groundwater level increased (Yang and Ahn 2007). However, this study only investigated the Nakdong River Basin over a 3-year period (2003–2005), and it did not use a quantitative definition of the WAS. Therefore, the WAS is a new concept that this study defined and quantified first using the AWRI to demonstrate the amount of daily water resources. To determine the pattern of the WAS in Korea, their onset and end dates, duration, change of intensity, and its correlation with the Changma were investigated.

2 Data and calculation

Daily precipitation data from 60 stations from January 1980 to April 2013 were obtained from the Korean Meteorological Administration. It is the precipitation data including the amount of snowfall. Uleungdo was excluded from this study due to its unique climatic environment.

The AWRI was used to calculate the daily precipitation data was developed by Byun and Wilhite (1999) and improved by Byun and Lee (2002). It subtracts the estimated losses (outflow, evaporation and diffusion, seepage, etc.) from the precipitation, and the results are accumulated, which is then turned into an index. The equations are given below.

$$E = \sum_{N=1}^{D} \left(\sum_{M=1}^{N} P_M / N \right), \quad (1)$$

where P_M is the daily precipitation of previous M days and E is the representative value of the water resources accumulated for D days. Here, D represents the 365 days and N is a dummy variable. Byun and Lee (2002) performed two experiments to find the best value of D and found that 365 days is the most suitable. Also, 365 days is the appropriate period for rainfall cycle in most of the world. E is the effective precipitation, which is a cumulative value that takes into account losses over time.

$$\mathrm{AWRI} = E / \left(\sum_{N=1}^{D} 1/N \right) \quad (2)$$

Equation (2) represents the AWRI (unit: mm), which indicates the current level of the water resources. AWRI can show diurnal change of water more efficiently than other values or indexes made by simply accumulated precipitation because it takes into consideration the daily reduction of water resources after precipitation (Byun and Lee 2002). This fact has already been proved in many previous studies (Yamaguchi and Shinoda 2002; Lee 2012; Deo and Byun 2014).

3 Definition of the water abundant season

3.1 Water abundant seasons in the Korean Peninsula

The WAS was developed to indicate the period when water resources are abundant. First, the WAS was defined as a continuous period with a daily AWRI that is equal to or higher than the criterion value. At this time, the criterion value for WAS was determined as the median of the daily AWRI for 30 years (from 1981 to 2010). The AWRI contains a very large deviation of extreme values, such as the maximum and the minimum by year. The use of the median values is better than the mean values because they reduce the effects caused by the abnormal extreme values. Furthermore, water suddenly becomes abundant at the beginning of the summer rainy season in Korea, and this characteristic is expressed well by the median value. Second, the WAS should be continued more than 75 days after the beginning. The summer rainy season in Korea refers to the period from the onset of Changma (the end of June on average) to the end of the second Changma (fall Changma) (September 5). This period is approximately 75 days, and the AWRI gradually increases during this time (Byun and Lee 2002). As it is clear that this period has an abundant water resources, the WAS must continue for at least 75 days. On the other hand, in Korea, heavy rains with over 100 mm of daily precipitation occur even in the fall and spring, which are not rainy seasons (Byun et al. 1992; Jung 2002). Because during these periods the water resources temporarily increase independent of the season, we set a limit of 75 days to exclude these periods. Third, when two WASs occur less than 3 days apart, they are regarded as one WAS because the 3-day interval would rarely have an adverse effect on agriculture and human activities. In Korea, rainy seasons are usually divided into a Changma and a second Changma (Byun and Lee 2002), and the interval between these two periods is sometimes extended. However, as there are too many variations of interval, the problem of differentiating these two seasons should be addressed in a separate study.

Figure 1 shows the definition process of the onset dates and the end dates of the WAS for the 60 stations in Korea, using the criterion value and the AWRI curve of the 32-year average. The dates when the AWRI value becomes greater/smaller than the median value (185.32 mm) are defined as the onset/end dates of the WAS (2 July and 25 December, respectively).

The onset date of the WAS is a little later than the onset date of the Changma, and the end date of WAS is completely unrelated to the end date of the Changma, which will be analyzed separately in Section 4. The end dates differ because the water disappears gradually rather than immediately after it rains. Unlike typical daily precipitation analyses, the current

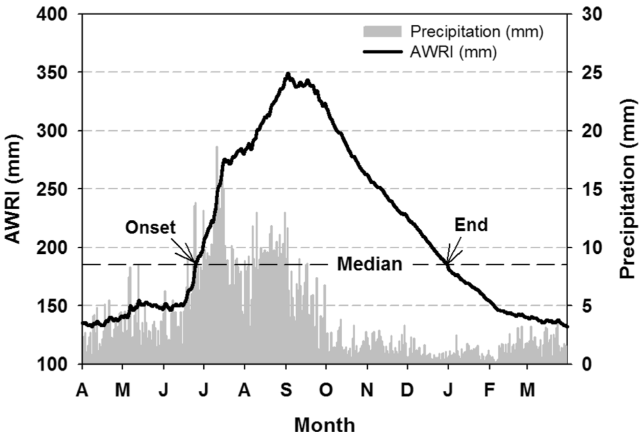

Fig. 1 The daily AWRI (*black line*) and the daily precipitation (*gray bar*) averaged for the 60 stations per date from 1981 to 2012 in Korea. The *long dash line* and the *arrows* denote the criterion value for the WAS (median) and the onset and the end date of WAS, respectively

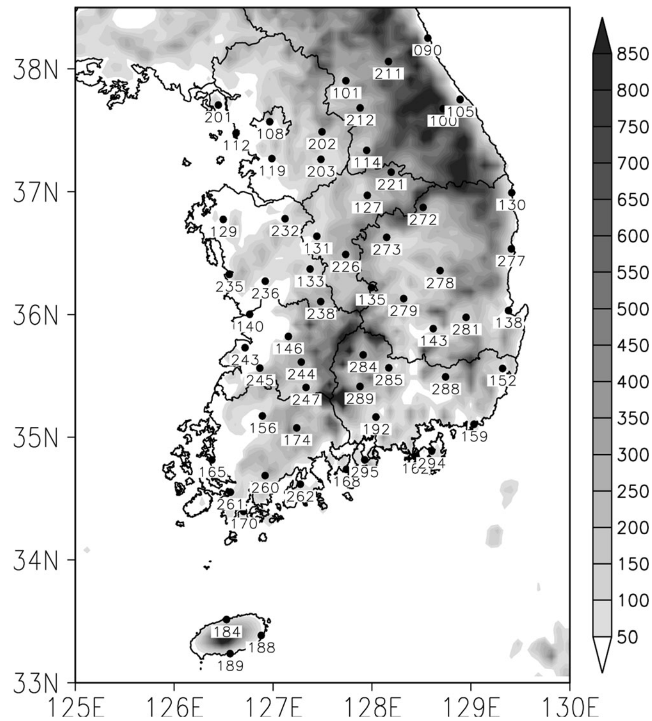

Fig. 2 Distribution of the 60 stations used in the present study. *Shaded contours* denote topography (m). The numbers represent the number of station and "47" was omitted in front of number

approach takes this factor into consideration. The distribution of daily precipitation (Fig. 1) shows a period from October to June of the following year that has low precipitation. However, the AWRI shows that there is no water shortage until late December. This finding correlates well with the reality in Korea, which has an agricultural society.

3.2 Water abundant season by station

Precipitation shows great deviations by region due to climatic factors such as topography, and the amount of water resources varies widely among regions. Thus, when the national criterion value (185.3 mm) for WAS was applied to every station, some stations do not have any WAS, whereas other locations have WASs of several years' duration. Consequently, the WAS criterion value (median of daily AWRI for 30 years) was adjusted for the individual stations to take into account of the variation in the water resources in the respective region. The distribution of these values is shown in Figs. 2 and 3. This distribution is similar to that of the mean precipitation in the summer (Park et al. 2008). This suggests that the various numbers quantified later are meaningful.

The criterion values were high in Jeju Island, southern coastal areas, and the eastern coastal (they call it Yeondong) region, whereas they were low in central regions, including Seoul and Gyeongsangbukdo. Yeongcheon (47281, hereafter the number means a station in Fig. 2 without "47") had the smallest criterion value (118.59 mm), and Seogwipo (47189) had the largest (281.18 mm). The difference between these two stations (162.59 mm) was greater than the criterion value of the Yeongcheon station (47281). This means that the water resources vary greatly by location in Korea and that the effect of these variations on different types of industries can be quantitatively considered.

4 Characteristics of WAS

4.1 Onset and end dates of WAS

The average WAS for the entire country was 174 days from July 2 to December 22 (Fig. 1). When divided into stations, the onset date of WAS was earlier in Jeju Island and the southern region and later in the central region and the northeastern coastal region (Fig. 4a). Seogwipo (47189) had the earliest WAS onset date of June 14 (hereafter average during 32 years), followed by Goheung (47262, 17 June), Geoje (47294, 21 June), and Wando (47170, 22 June), all of which are in the southern region. On the other hand, Sokcho (47090) had the latest WAS onset date (28 July), with a 45-day difference compared with Seogwipo (47189). The distribution of the onset dates as shown above was due to that the summer rainfall began from the south under the influence of the Changma front.

In terms of the WAS end date by region (Fig. 4b), it tends to end earlier in regions with a high criterion value, such as the southeastern coast, including Busan (47159), Tongyeong (47162), and the Jejudo region (47175). The end date of the WAS was generally later in inland areas, including the west coast and eastern coastal region, but it was earlier in inland areas in the Gyeongsangbukdo region, such as Yeongju (47272) and Uiseong (47278). Specifically, the end date was earliest in Tongyeong (47162, 7 December), followed by Busan (47159, 9 December) and Geoje (47294, 9

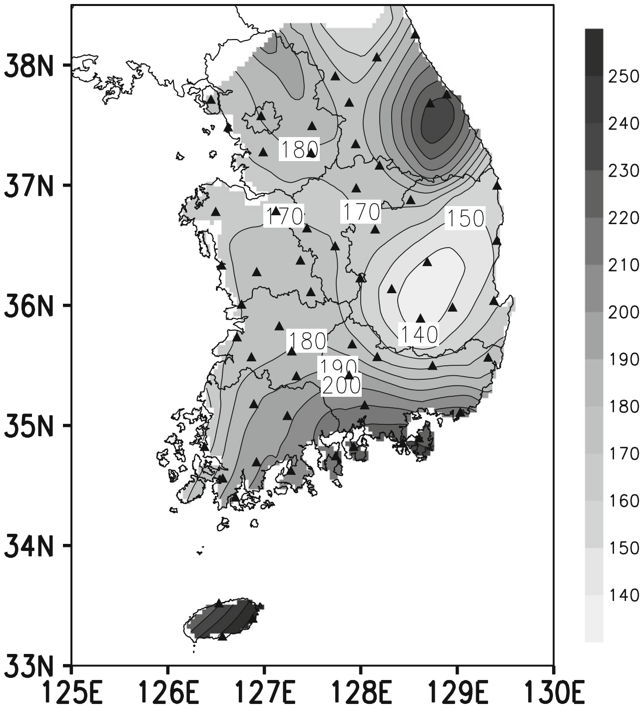

Fig. 3 Spatial distribution of the criterion value of the WAS (unit: mm) in 60 stations

December) and Yeosu (47168, 12 December), and whereas it was much late in Uljin (47130, 17 January the next year). The difference between the earliest and latest WAS in the regions was 42 days.

In the eastern coastal region, during winter, orographic precipitation occurs when the modified air from the East Sea meets with the Taeback, the mountain range along eastern coast (Jhun et al. 1994; Lee 1999). Heavy snowfall often occurs when humid air from the East Sea reaches the coast (Song 1993). Meanwhile, the west coast, including the Honam region, is subject to the "lake effect," which causes heavy snow when the Siberian high expands to Korea and the cold air current passes above the relatively warm lake. Furthermore, the area from the west slope of the Noryung Mountain range, which is directly exposed to the northeasterlies of winter seasonal wind, to the west coast experiences heavy snowfall; meanwhile, the Yeongnam region, which is located on the downwind side of the Noryung Mountain range, and the southern coast experience low snowfall or rainfall in winter (Lee and Chun 2003). Thus, the WAS end date is earlier in the southeastern region and later in the eastern coastal region and the west coast.

4.2 Duration of WAS

The duration of the WAS (Fig. 4c) is longer in the inland areas of Yeongnam and Honam and in the eastern coastal region, and it is shorter in the southern coast and the central region. In the regions with a long WAS, the WAS started early and ended late in some regions (Honam and some inland areas of Gyeongsangdo), or it started late and ended late in others. Tongyeong station (47162) had the shortest WAS (166 days, 24 June to 7 December). The following also had a short WAS: Yoesu (47168, 167 days), Seongsan (47188, 168 days), and Ulsan (47152, 169 days). Uljin station (47130) recorded the longest WAS (207 days, 3 July to 17 January the following year), followed by Sancheong (47289, 202 days), Geochang (47284, 197 days), and Hapcheon (47285, 194 days). The difference between the longest and the shortest durations was 41 days. The difference between the earliest/latest onset date and the latest/earliest end date was quite large at 217/132 days, suggesting that the spatial distribution of water resources is not simple, even within the Korean Peninsula. The stations with extreme WAS criterion values, onset and end dates, and durations are summarized in Table 2.

Figure 5 shows the occurrence frequency of the WAS which occurred at 60 stations from 1981 to 2012 by the

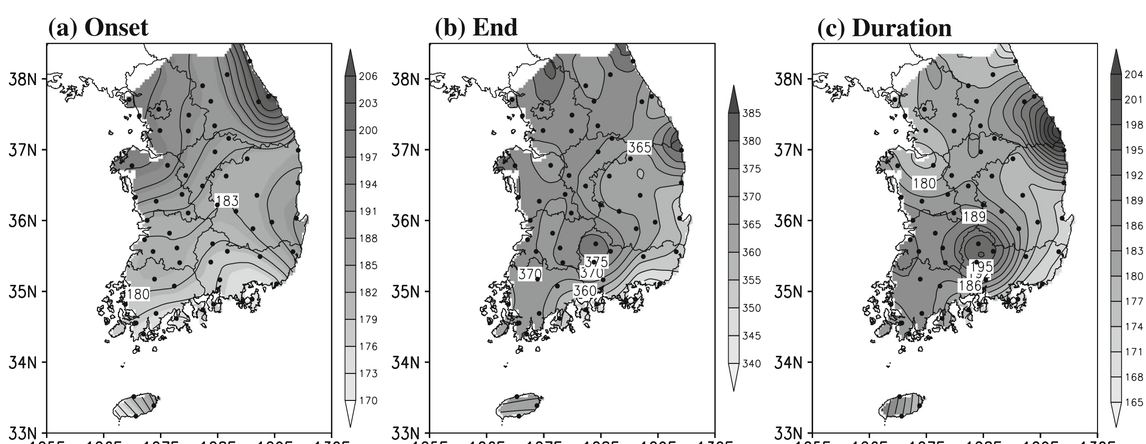

Fig. 4 Spatial distribution of **a** the onset date, **b** the end date and **c** the duration of WAS in Korea. Numbers of **a** and **b** are Julian day and number of **c** is day. A number greater than 365 in **a** indicates the following year (366 Julian day equals to 1 January of the following year)

Table 2 Extreme values on WAS in Korea

	Criterion		Onset date		End date		Duration	
	The smallest	The biggest	The earliest	The latest	The earliest	The latest	The shortest	The longest
Station	Uiseong	Seongsan	Seogwipo	Sokcho	Tongyeong	Uljin	Tongyeong	Uljin
Value	135.88 mm	270.72 mm	14 June	29 July	5 December	16 January (following year)	166 days	207 days

duration (the 25-day interval from 75 days). The WAS mostly lasted 225 days or less (73.3 % of all) and rarely lasted 275 days or longer. Furthermore, the frequency of WAS by duration was the highest between 175 and 200 days.

Figure 6 shows the scatter plot of the onset date and duration of the WAS in Korea (60 stations) for the 32 years. Each radial axis denotes the first day of the month (for the onset date of the WAS), and each circular line denotes the duration. An earlier onset date is associated with a longer duration, and a later onset date is associated with a shorter duration. Furthermore, the WAS in the fall (SON) and the winter (DJF) tended to end sooner than other WASs.

When the onset date was in April or May, the WAS lasted at least 200 days in most cases, whereas when it was in June or later, the duration was shorter, with a high frequency of 200 days or less. Thus, the WAS usually ends in winter, and there is always a dry season in the spring. WAS of 500 days or longer were found in Daegwallyeong (47100, 604 days), Gangneung (47105, 569 days), and Uljin (47130, 501 days). The WAS commenced on 6 August 2002 and 5 July 2002, in Daegwallyeong (47100) and Gangneung (47105), respectively. In 2002, there was a lot of rainfall in the Gangneung and eastern coastal regions due to the typhoon "Rusa." The typhoon resulted in the highest daily rainfall recorded in the history of observations in Korea in Gangneung (47105, 870.5 mm) and Daegwallyeong (47100, 715.5 mm) on 31 August 2002. As a result, water became very abundant and gave rise to a very long WAS. In the case of Uljin (47130), the WAS started on 21 August 1989, which was also due to heavy rains in the Yeongnam and Honam regions in 1989. (In the lower latitude of 36N, the western half is Honam and eastern half is Yeongnam.)

The following four unique WASs (not shown) were observed in winter (DJF): Gangneung (47105, 7 January 1989 and 7 December 1991), Uljin (47130, 7 January 1989), Jeju (47184, 28 February 2012), and Yeongdeok (47277, 8 February 1990). In all these cases, two WASs occurred in 1 year. A high amount of water resources remained even after the summer WAS. As the winter precipitation increased, the amount of water resources exceeded the criterion value for WAS. Six WASs also occurred in November for the same reason. The results provided quantitative information on the changing water resource environment in years with high precipitation.

4.3 Annual variation in WAS

Annual variations in the onset date, the end date, and the duration of WAS in Korea (Fig. 7) show that the earliest and the latest onset dates of the WAS were observed in 24 May and 12 August, respectively. The onset date is becoming earlier at rate of 2.9 days/decade. The end date was the earliest

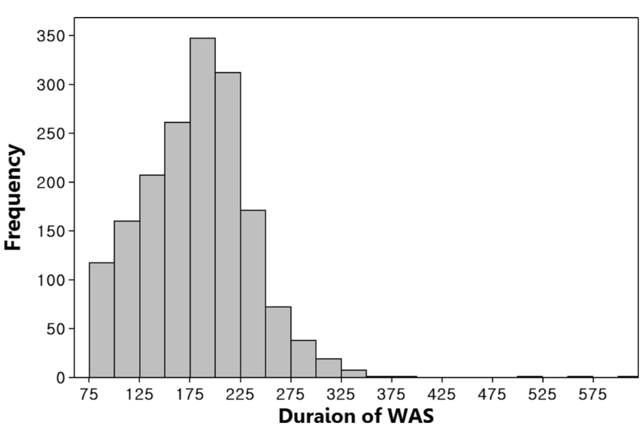

Fig. 5 Histogram of the WAS duration calculated from the data of 60 stations for 32 years

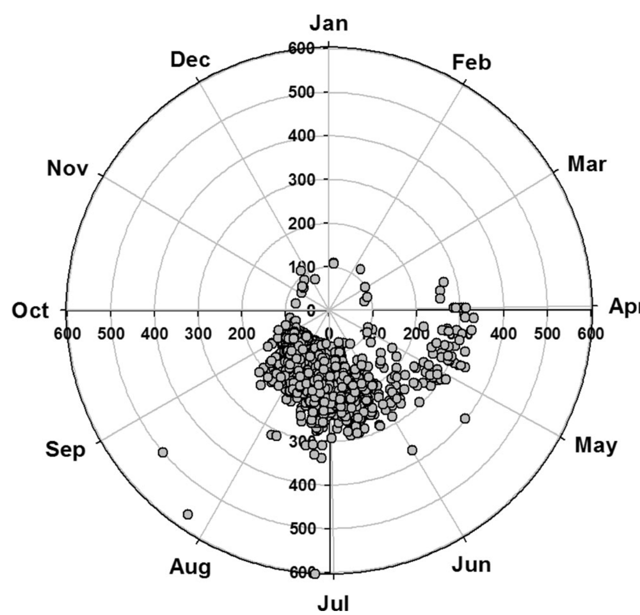

Fig. 6 Scatter plot of the WAS onset date against the duration. The WAS defined by the criterion value from 1981 to 2012 for the 60 stations. Each radial axis denotes the first day of the month

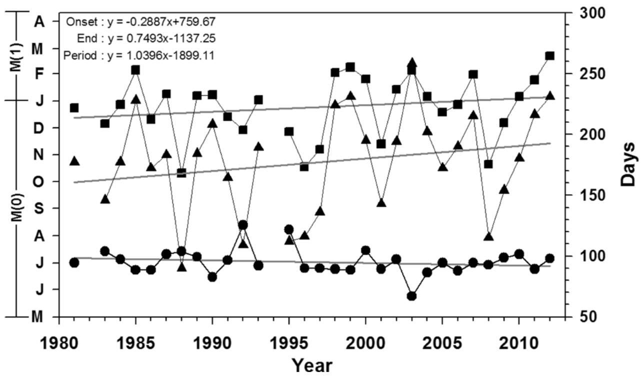

Fig. 7 The time series of the onset date (*circle*), the end date (*square*) and the duration (*triangle*) of the WAS in Korea from 1981 to 2012. M(0) and M(1) of the left axis represent the months of the current and the following year, respectively. In 1982 and 1994, WAS was not detected due to drought

in 1988 (10 October) and the latest in 1999 (8 February the following year), with the rate of delay 7.5 days/decade. The duration is increasing at a rate of 10.4 days/decade. However, these trends are statistically insignificant at the 90 % confidence level. At this time, we used statistical testing method named two-tailed test to indicate whether or not it is statistically significant.

The longest duration was observed in 2003, and this was because of typhoon "Maemi." No WAS occurred in 1982 and 1994, which were drought years (Byun et al. 2008). Figure 8 shows the spatial distributions (60 stations) of the linear trends of the onset date (Fig. 8a), the end date (Fig. 8b), and the duration (Fig. 8c) of WAS for 32 years. The triangles and circles indicate a positive linear trend and a negative linear trend, respectively. Furthermore, the size of the figures increases in intervals of 0.5. The linear trend for the onset dates tends to become earlier in the majority of the stations (positive, 17; negative, 43), with relatively large trends observed, in particular, for the eastern coast, the southern coast, and Jeju station (47184). The largest negative trend, which occurred in Jeju (47184), was −1.56 days/year. The trends for three stations (Incheon: 47112, Wando: 47170, and Jeju: 47184) were statistically significant at the 90 % confidence level. The linear trends for the end dates showed positive values at most of the stations (positive, 45; negative, 15). The most positive trend of 1.71 days/year occurred in Seogwipo (47189). The trends in only five stations (Incheon: 47112, Suwon: 47119, Seogwipo: 47189, Yeongju: 47272, and Mungyeong: 47273) were statistically significant at the 90 % confidence level. The linear trends of the onset date (Fig. 8c) were positive at most of the stations (positive: 48; negative: 12). The greatest positive and negative trend, which appeared at Incheon (47112) and Boryeong (47235), was 2.16 and −1.18 days/year, respectively. Only the trends at Incheon (47112), Suwon (47119), Tongyeong (47162), Yeongju (47272), and Mungyeong (47273) were statistically significant at the 90 % confidence level.

4.4 Comparison with the Changma

The Changma generally refers to the phenomenon of continuous rainfall for several days in the summer (Ryoo 2001). As it is very similar to the WAS when water resources become abundant due to continuous rainfall, the Changma was compared with the WAS as it is defined in this study (Table 1, Fig. 9). For this comparison, the Changma onset dates by Ha et al. (2005) for 20 years (1985–2004) were used.

First, although the onset date of the Changma change with small range around the period when summer rainfall start to occur frequently, it often does not match the rainfall onset date. Specifically, in some years (1986, 1988, 1993, 2001), a date with no rainfall was recorded as the Changma onset date. Although it has been regarded as the Changma onset date, in some years (1989, 1993, 1999, 2002) a continuous day with

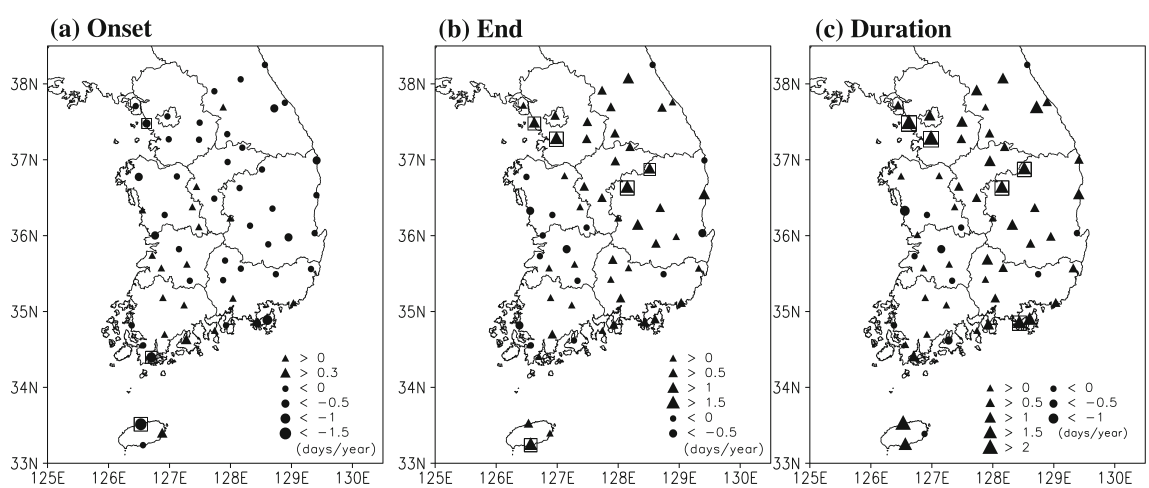

Fig. 8 The spatial distribution for linear trends of **a** the onset date, **b** the end date and **c** the duration of WAS at the 60 stations from 1981 to 2012. The squares indicate stations with statistically significant trends at the 90 % confidence level and it was examined through two-tailed statistical test. Unit: days/year

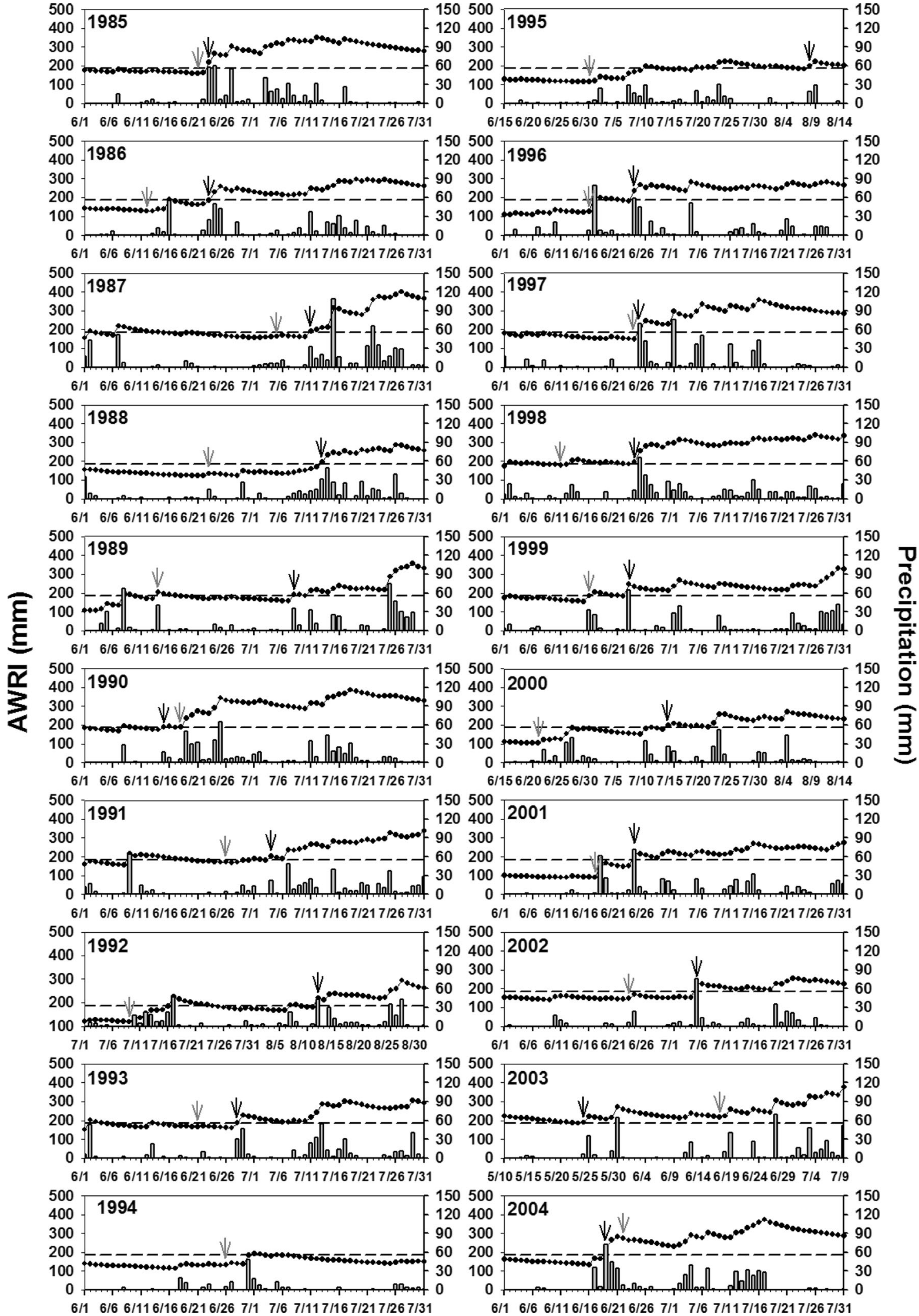

Fig. 9 The onset date of Changma (Ha et al. 2005) (*gray arrow*) and WAS (*black arrow*) in each year. The *dashed lines* denote the criterion value of AWRI of WAS

no rainfall appeared after the onset date. These are considered unusual years, and it is suggested that the Changma was not defined definitely by universal standard of judgment (Park et al. 2008).

On the other hand, the onset dates of WAS quantitatively and objectively represent a time when water resources increase but there are large variations in the onset date by year, with no WAS occurring in some years. Thus, it may be inconvenient to use. For example, no WAS was observed in 1982 and 1994 due to drought. However, even in these years with no WAS, the Korean Meteorological Administration and other studies specified Changma onset dates (Table 1). Furthermore, in 2003, due to the rainfall that started from late May, the WAS started on May 24, but the Changma allegedly occurred in late June (Table 1). Based on this example, it appears that the beginning day differs year by year; however, it is another characteristic of the WAS caused by the fact that the WAS diagnoses the state of water resources accurately and sensitively.

The WAS and the Changma show great differences in end dates. The Changma end date means the time when precipitation decreases, but the end date for the WAS means the ending of a season when no water shortage is reported. In other words, there is a clear difference between these two concepts, with the Changma denoting a period of much rainfall and the WAS denoting a period of abundant water.

From the aspect of water resources, the disadvantages of the Changma are as follows. Previous studies defined Changma periods every year, but there were years (drought years) when water resources were not abundant even when the Changma occurred. The WAS clearly shows the years when there was a drought, and the Changma does not. Another disadvantage of using the term Changma is that it cannot express characteristics such as when water resources increase as much as in Changma or more than in Changma as a result of precipitation due to other factors (cyclone, typhoon, etc.). Therefore, the WAS is more useful than the Changma to determine the abundance of water resources. Moreover, Changma uses qualitative concepts as “continuous rainfalls,” “increased water resources,” or “unique pressure pattern,” while the WAS presents these parameters as quantitative concepts using the AWRI.

5 Summary and discussion

In this study, the AWRI was used to quantitatively define the WAS, defined as a period with abundant water, using 32 years (1981–2012) of data from 60 stations in Korea, and the temporal and spatial distributions of the WASs were analyzed using this method. The WAS in Korea was defined as a period when the average AWRI for the 60 stations (1981–2012) was more than 185.32 mm. Using this method, 176 days from 2 June to 25 December were defined as the WAS. The criterion values, the onset dates, the end dates, the durations, and the annual variations by region were then comparatively analyzed. The results showed that although Korea is small, there are great variations in water resources among the regions. These major differences in water resource volumes by region and year have not been investigated in depth until now. This study quantified the water resource characteristics of each region and presented more detailed data. The findings of this study can contribute greatly to water-level control of dams in preparation against floods. They can also be used in various agricultural and industrial applications.

The results also revealed that the duration of the WAS has increased in almost every region in Korea in the past 32 years. This suggests that the onset date, the end date, and the duration of WAS can be exploited to detect climate change. The comparison of the Changma and the WAS showed that the WAS not only reflects water resources more sensitively, but it is also more objective. The WAS will be more useful than the Changma for predicting water resources relevant to daily living and industrial activities because the AWRI describes the water resource environment better than other indices. However, the calculation method of AWRI has no comparison target, and this needs to be addressed in future studies.

The AWRI must be more precisely calculated because it has been developed as an index for identifying the danger of flood and drought. At present, it can be used to quantify daily water resource volumes. If it could quantify hourly water resources, it could be a good index for preventing landslides or unforeseen floods. Meanwhile, the 75-day (minimum duration) and the 3-day intervals that were used to define the WAS in this study need to be handled more precisely in future studies. In addition, this study did not consider the snow melting process.

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