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Suggestion of Classification Method for Agricultural Drought Using Groundwater Level Change

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Abstract: Since weather factors such as precipitation and temperature etc. show repeated patterns every year, it can be said that future changes can be predicted by analyzing past weather data. Therefore, when a drought occurs, the groundwater level is also lowered, so it can be seen that a change in the groundwater level can represent a drought. Like precipitation, groundwater level changes also have a high correlation with drought, so many researchers use SGI (standardized groundwater level index) to which the SPI (standardized precipitation index) method is applied to evaluate the severity of drought and predict trends. However, these approaches have the limitations to indicate the real groundwater system because the drought grades for the entire area are defined with the observation data of a single monitoring well without surrounding influences. When analyzing groundwater level fluctuations to understand the correlation with drought, it is necessary to calculate and apply the actual groundwater level that reflects groundwater use interference. Therefore, in this study, based on the long-term groundwater level data at 162 monitoring well installed before 2015 in Korea, the characteristics of groundwater level changes were analyzed and compared with the period of agricultural drought over the past five years. From the results, it can be confirmed that agricultural drought in regions is classified using the percentile of the SPI method by conducting a frequency analysis that the current groundwater level increase or decrease compared to the past average groundwater level.

Keywords: Groundwater Level, SPI, SGI, Agricultural Drought

1. Introduction

Korea is characterized by low temperature and low precipitation in winter, and relatively high temperature and high precipitation in summer. Although extreme droughts have become more frequent in recent years, the overall seasonal climate is the same as in previous years. Therefore, it can be said that future changes can be predicted to some extent by analyzing the changes in various past climate indicators such as precipitation and temperature. The same is true of groundwater level changes. Groundwater level changes are caused by natural or anthropogenic influences such as topographic slope, surface change, impervious area, geological characteristics, precipitation, temperature, river water level, and groundwater usage [3, 5, 7, 19].

A lack of precipitation causes drought, and when a drought occurs, it can be interpreted as a lack of surface water. In addition, when a drought occurs, the groundwater is used more than usual to supply insufficient water, and as a result, the groundwater level in the drought-prone area becomes lower than the normal water level, so it can be said that the groundwater level represents the drought. Therefore, since the standard groundwater level index (SGI) was proposed by Bloomfield and Marchant, many researchers have analyzed the trend of agricultural drought using SGI [4, 8, 9, 11, 14]. Unlike the standardized precipitation index (SPI), which is a widely used index to evaluate and predict the severity of drought, SGI uses a normalization process using a gamma distribution, unlike the SPI suggested by McKee et al [13]. Since there is no need to go through the data processing process, it is possible to quantitatively evaluate changes in groundwater resources when the groundwater level time series observation data are properly normalized [16]. The gamma distribution is a distribution pattern that fits well with rainfall defined by the frequency and probability density function, and indicates a right-skewed distribution with an end of 0 [17].

And drought is usually divided into meteorological drought, hydrological drought, agricultural drought, and socioeconomic drought. In this study, agricultural drought was analyzed. Agricultural drought refers to a case in which damage occurs due to a lack of effective soil moisture required for crop growth. Generally, it is divided into normal, concern, caution, alert, and severe stages, and predictions and warnings are implemented to prevent drought damage.

In addition, comparison result between the groundwater level data of a single monitoring well and the water storage rate of a single reservoir indicated that the correlation between the groundwater level change and the reservoir water rate was very low [14]. Unlike the groundwater level, which rises during rainfall and falls during drought, reservoirs open their sluice gates in advance to prevent flooding in downstream areas even before flooding, and do not open immediately for optimal water supply even during drought. Although the relationship is low, the monthly average water storage rate and groundwater level values of several dams are slightly different, but overall, they tend to decrease during drought, so it can be interpreted that the water level change of all facilities, not a single facility, shows a high correlation [10].

Therefore, when there is a drought, even if there is interference by the use of the surrounding groundwater, the overall average groundwater level of the observation wells installed in the area tends to decrease, so the correlation with the drought is also expected to be high. As a result, it is judged that by analyzing the long-term groundwater level observation data by more observers, it is possible to overcome the influence of use interference and secure representativeness of the local groundwater level change, as well as predict future groundwater level changes and droughts. In addition, since the water retention rate of the reservoir will also tend to decrease overall, this study will use long-term groundwater level observation data to derive a significant correlation with drought and analyze whether it is possible to evaluate agricultural drought.

2. Research Data

The analysis data used in this study were obtained from 162 wells, excluding 43 wells, which could affect the analysis due to partial omission of monitoring data out of 205 out of 582 rural groundwater observation wells managed by the Korea Rural Community Corporation in Korea. Correlation was analyzed with long-term groundwater level monitoring data of 3,423 agricultural reservoirs for the past 5 years and data on water retention rates. The groundwater level monitoring data analyzed in this study were analyzed using daily observation data for the past 5 years provided by RGMS (rural groundwater management system) in Korea (www.groundwater.or.kr). RGMS provided daily low yield data was used (Figure 1), (Table 1).

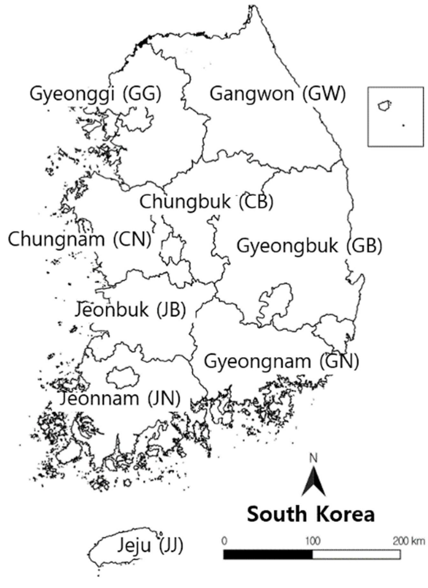


***Figure 1.** Map of study area.*

***Table 1.** Groundwater monitoring wells and agricultural reservoirs using analysis data.*

	Monitoring well	Agricultural Reservoir
Total	162	3,423
GG	21	172
GW	23	186
CB	17	228
CN	21	439
JB	9	1,000
JN	24	669
GB	28	564
GN	19	91

*GG: Gyeonggi, GW: Gangwon, CB: Chungbuk, CN: Chungnam, JB: Jeonbuk, JN: Jeonnam, GB: Gyeongbuk, GN: Gyeongnam.

As for the groundwater level, the average monthly groundwater level up to 2015 was taken as the normal water level, and the change in the groundwater level by region/month for the past 5 years compared to the average level was analyzed, and the correlation with the drought occurrence time prepared based on media articles and drought damage status data was confirmed. Drought stages were classified through groundwater level change, and future groundwater level changes and agricultural drought stages were distinguished. In addition, because the reservoir opens the sluice gate in a timely manner for optimal supply of agricultural water, creation of effects to overcome drought, or prevention of flooding, the correlation may be rather low due to the characteristic that it does not respond quickly to drought, unlike the groundwater level or rainfall. In consideration of the fact that, as in the case of drought, the overall water storage rate decreases as in the case of drought, the correlation with the water storage rate of 3,423 agricultural reservoirs obtained from RIMS (rural infrastructure management system) in the last 5 years was also compared and analyzed by region. In addition, it used groundwater level change to classify agricultural droughts and predict future droughts so that they can be used for regional drought analysis.

3. Research Method

3.1. Analysis of Monthly Average Groundwater Level Changes

As the use of groundwater continues to increase as the public's interest in the spread of well-being culture and the use of clean water increases, the interference with the use of observation data by groundwater use is noticeable. As in the past, only the observation data measuring the background water level can be used to measure the local groundwater level. It became a situation that could not represent change (Figure 1). In addition, hydrological drought takes a little longer than meteorological drought due to soil moisture and the characteristics of the underground medium [18]. It is necessary to measure the groundwater level at various points where possible. However, the groundwater level observation data so far show the groundwater level change for a single well even though the groundwater level changes several times a day due to interference caused by the increase in the development and use of groundwater wells, making it easier to understand the groundwater level in the entire area. There is a limit to the presentation (Figure 2).

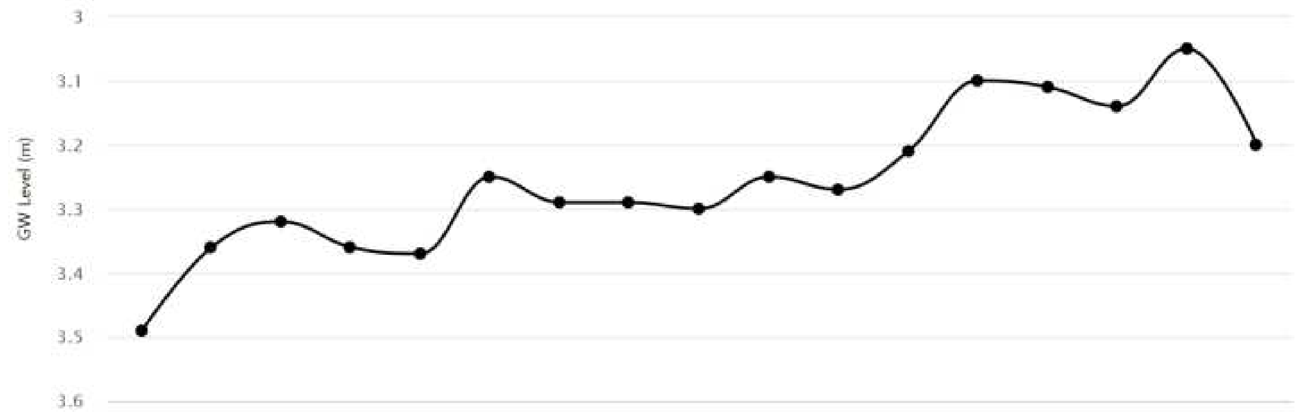


Figure 2. *Groundwater level change graph for one monitoring well.*

Therefore, in order to easily present a representative value of the change in the groundwater level for each observation well installed in the region, it is expected that it will be easy to find out by comparing the level of the current average groundwater level compared to the past average groundwater level of the entire watershed. The average groundwater level was calculated based on the long-term groundwater level observation data of the observers, and the average groundwater level was used as the standard, and the current average groundwater level increased and decreased compared to the normal level, thereby making it easier for the general public to understand the current groundwater level compared to the past (Figure 3).

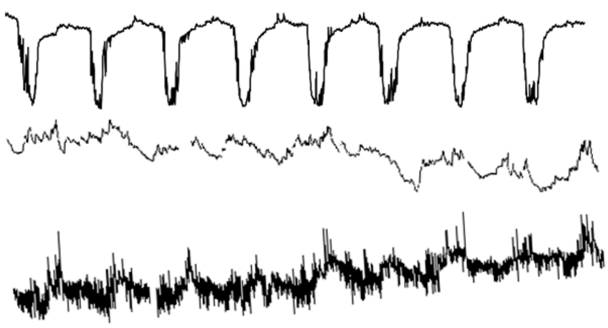
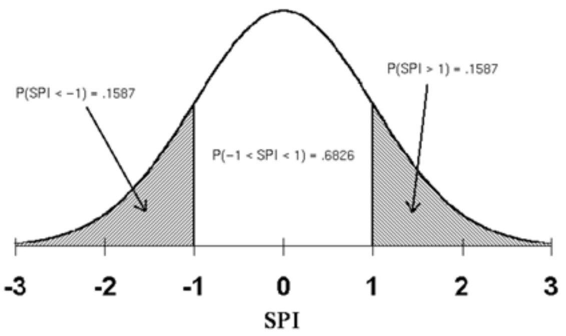


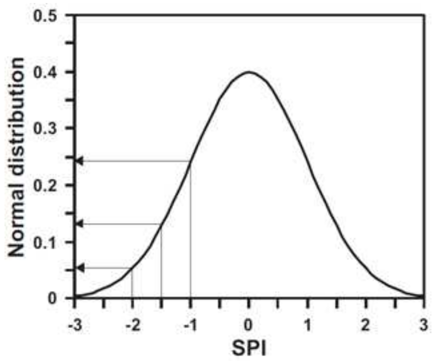
Figure 3. *Groundwater level change graph for one monitoring well.*

For example, in many groundwater wells distributed within a certain range of agricultural land, the groundwater level is falling because some areas are using groundwater, and even if the groundwater level is rising because some wells are discontinued, long-term changes in the groundwater level for the entire area Since it will show a uniform pattern of rising or falling depending on the agricultural period or climatic environment, analysis of more observational data is required to represent the region in order to understand the overall trend. Because, as suggested by Kim et al, the groundwater level does not respond sensitively to weather conditions, so it is expected to be used as a drought evaluation factor [6]. The monthly average value was calculated based on the daily long-term groundwater level observation data.

As Edwards and McKee [2] dealt with the characteristics of the US drought in the climate report, it was converted into a normal distribution so that the mean and standard deviation of the long-term SPI of the observation point were 0 and 1, respectively, and the SPI was positive. As it increases in the (+) direction. It indicates the degree of precipitation, and as it goes in the negative (-) direction, it indicates the degree of less precipitation. SPI is widely used as a meteorological drought index because it is widely used to evaluate the degree of drought based on precipitation and it was correlated with SGI to evaluate the effect of drought on groundwater system in Korea (Figure 4), (Table 2).



(a)



(b)

Figure 4. *Concept of SPI and Percentile: (a) Standard normal distribution with the SPI having a mean of zero and a variance of one, (b) Percentile of SPI in normal distribution [14].*

Table 2. *Classification and Percentile value of SPI.*

SPI value	Classification	Percentile Value
-0.99 ~ 0.99	Near Normal	
-1.00 ~ -1.49	Moderate drought	0.242
-1.50 ~ -1.99	Severe drought	0.1295
-2.00 >	Extreme drought	0.054

In this study, the percentile value of the groundwater level observation data analyzed by frequency analysis of the average monthly groundwater level increase/decrease value over the past 5 years to obtain the range of groundwater level increase/decrease by region corresponding to the SPI percentile (Figure 5). In addition, compared the drought evaluation method using the SGI of a single observation to how accurately it represents the drought that has occurred over the past five years.

3.2. Monthly Average Reservoir Storage Rate Analysis

For the reservoir storage rate (RSR), the monthly average water storage rate was calculated by receiving data from 3,423 agricultural reservoirs nationwide managed by RIMS of the Korea Rural Community Corporation in Korea (Table 3). Unlike the groundwater level, the reservoir does not immediately open the sluice gate even when a flood or drought occurs. In order to prevent flooding of the inhabitants or farmland downstream of the reservoir, water is discharged after being confined as much as possible to the full water level. There is no immediate correlation with drought or flood. In particular, in the case of full water, since the water is discharged immediately after rain, the water retention rate may tend to decrease. Results have also been reported [12].

Looking at the average monthly RSR of agricultural reservoirs for 5 years from 2016 to 2020 analyzed this time, it gradually decreases from the end of April, the farming season, and shows the lowest RSR rate in June. However, it can be seen that the low yield recovers again after the farming season.

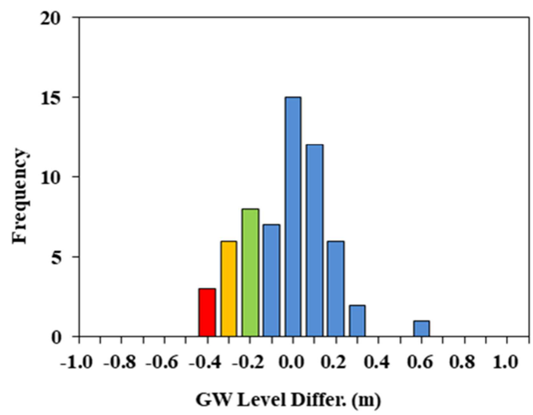


Figure 5. *Calculate the percentile of GWL Difference.*

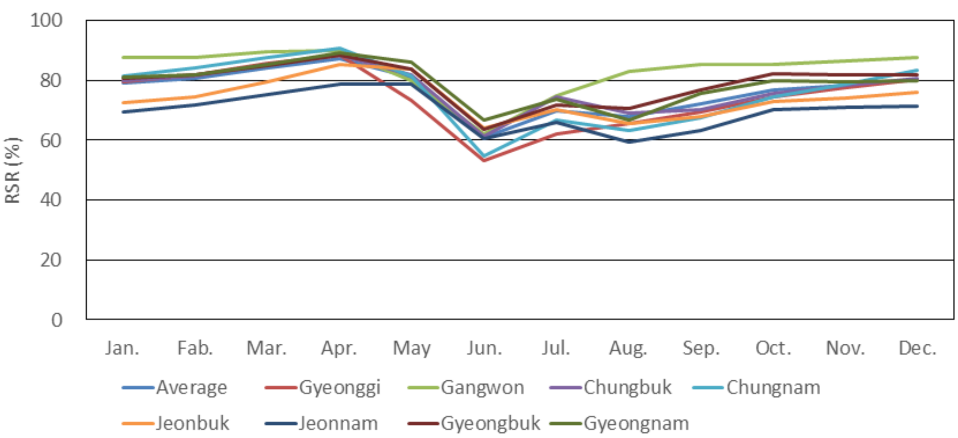


Figure 6. *Monthly average reservoir storage rate graph of agricultural reservoirs.*

Table 3. *Reservoir storage rate by the province for recently 5 years (unit: %).*

	Ave.	Jan.	Fab.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
Average	76.4	79.0	80.7	84.2	87.4	81.2	60.8	70.0	67.9	72.1	77.0	78.5	80.2
GG	79.0	79.7	82.0	85.9	88.3	73.4	53.1	62.1	65.6	69.3	74.5	77.6	80.4
GW	80.7	87.6	87.8	89.8	90.0	79.9	62.3	74.7	82.9	85.4	85.5	86.6	87.5
CB	84.2	79.9	81.6	85.2	88.5	81.8	61.3	74.5	69.0	70.1	75.8	78.2	80.8
CN	87.4	81.5	84.1	87.6	90.6	81.5	54.8	66.7	63.2	67.7	74.6	78.9	83.3
JB	81.2	72.4	74.4	79.4	85.3	83.9	63.9	70.2	65.7	67.8	73.1	74.3	76.0
JN	60.8	69.4	71.6	75.3	78.9	78.6	60.4	66.2	59.4	63.5	70.2	71.1	71.4
GB	70.0	80.8	81.9	85.0	88.5	84.0	63.8	71.8	70.6	77.0	82.1	81.7	81.9
GN	67.9	80.9	82.0	85.5	89.3	86.2	66.8	73.8	66.6	75.6	80.1	79.7	80.0

Nevertheless, in general, RSR decreases during drought and rises during flooding. Therefore, rather than individual reservoirs, the monthly water storage rate of the entire reservoir in the region is used to classify the agricultural drought stage. Agricultural drought refers to a case in which damage occurs due to a lack of effective soil moisture required for crop growth. Generally, based on low yield, it is divided into normal, concern, caution, alert, and severe stages, and predictions and warnings are implemented to prevent drought damage. are doing The interest level is when the average annual low yield in the agricultural period (april to october) is 70% or less, the caution phase is the agricultural average low yield is 60% or less, the alert phase is the agricultural average low yield is 50% or less, and the severe stage is the agricultural average low yield is 40% or less in the case of a low yield exceeding 70%, it is classified as a normal stage (Figure 6).

4. Research Results

4.1. Average Annual Groundwater Level Calculation

Based on the long-term groundwater level observation data of 162 observers installed before 2015, the monthly average groundwater level was calculated for each region. Since the initial observation data is measured every hour, it fluctuates greatly even with small external influences. Therefore, the daily and monthly average values calculated from the hourly observation data, and the monthly average of all the long-term observation data in the region obtained again to minimize the groundwater level change due to external interference. This made it possible to recognize changes in the groundwater level in the region at a glance. This was done in March, June, 12 months, 24 months, 48 months, etc. for the analysis of short-term, medium-term, and long-term droughts analyzed by Edwards and McKee [2]. It is similar to the SPI calculation method that accumulated rainfall data (Figure 7), (Figure 8). Table 4 shows the average groundwater level for each region, and this value was used as the standard for the average annual water level (hereinafter referred to as the normal water level) and used to analyze the increase or decrease of the current monthly average groundwater level compared to the average level (Table 5).

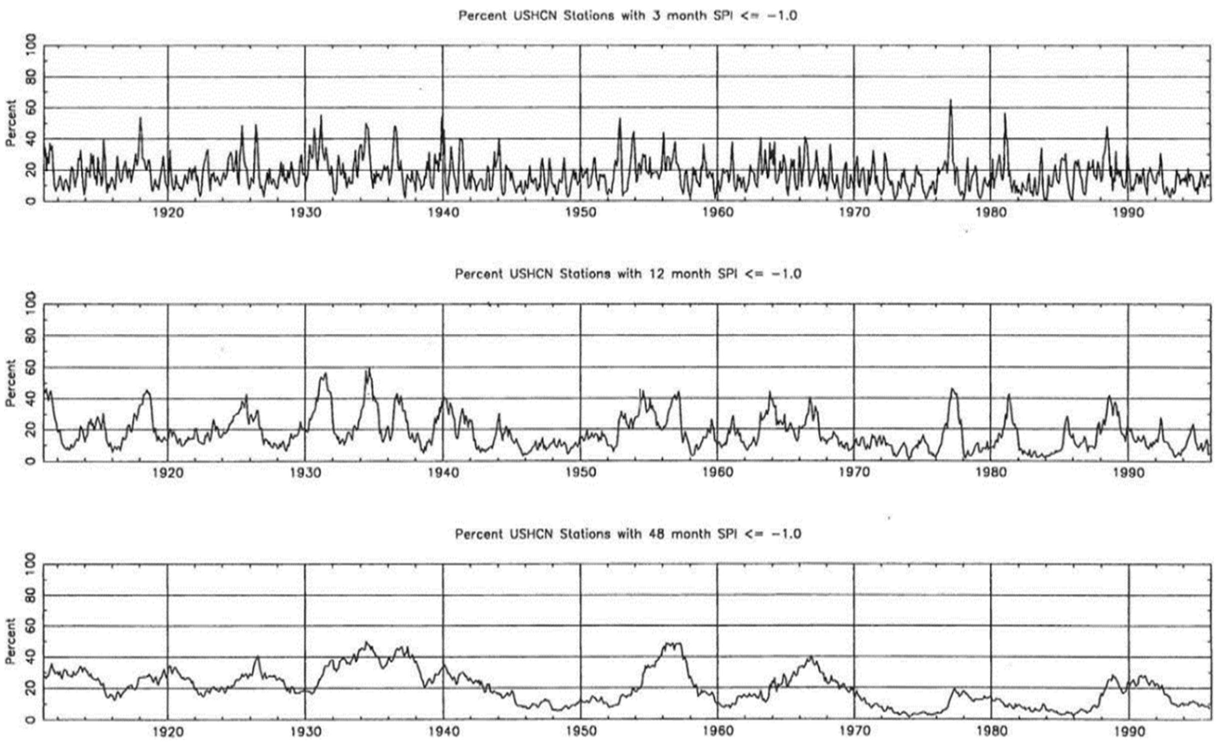
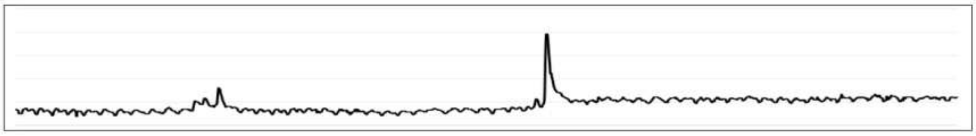
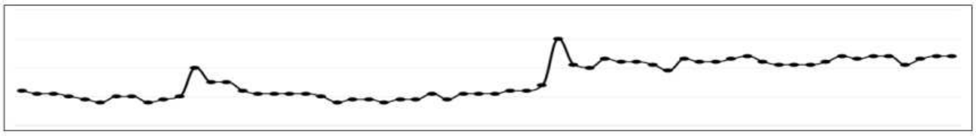


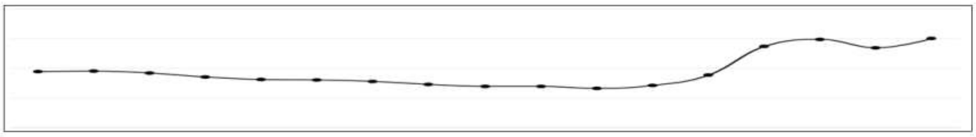
Figure 7. *Example of percent time series of all stations with SPI [2].*



(a) Hourly average monitoring data



(b) Daily average monitoring data



(c) Monthly average monitoring data

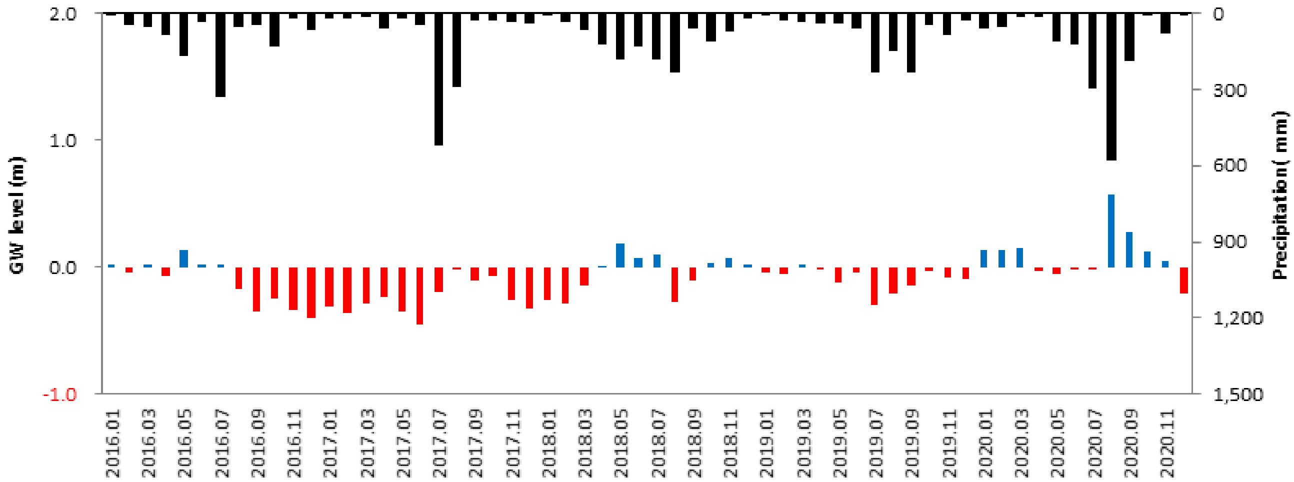
Figure 8. *Example of calculating daily and monthly average data from hourly data.*

Table 4. *Average annual groundwater level (unit: m).*

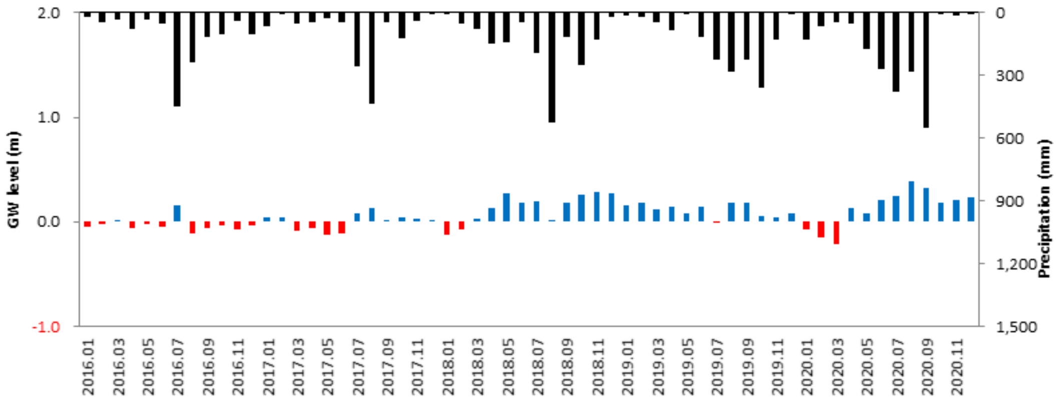
	Jan.	Fab.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
GG	6.08	6.15	6.13	6.04	5.82	5.76	5.54	5.38	5.42	5.68	5.97	5.94
GW	5.03	5.12	5.07	4.99	4.74	4.70	4.50	4.40	4.47	4.73	4.99	5.11
CB	5.81	5.68	5.66	5.61	5.68	5.72	5.43	5.34	5.34	5.45	5.46	5.46
CN	4.06	4.02	3.96	3.84	3.82	3.86	3.54	3.44	3.43	3.67	4.28	4.31
JB	6.04	6.03	5.95	5.94	5.90	6.00	5.83	5.74	5.82	5.87	5.91	5.92
JN	5.63	5.76	5.58	5.33	5.44	4.82	5.29	5.37	5.28	5.28	4.91	4.72
GB	4.77	4.87	4.78	4.69	4.94	5.13	4.87	4.95	4.60	4.85	4.98	4.96
GN	6.84	6.92	6.27	5.00	4.78	4.93	4.90	4.65	4.58	4.66	4.79	5.41

4.2. Groundwater Level Change Compared to Annual Average Groundwater Level

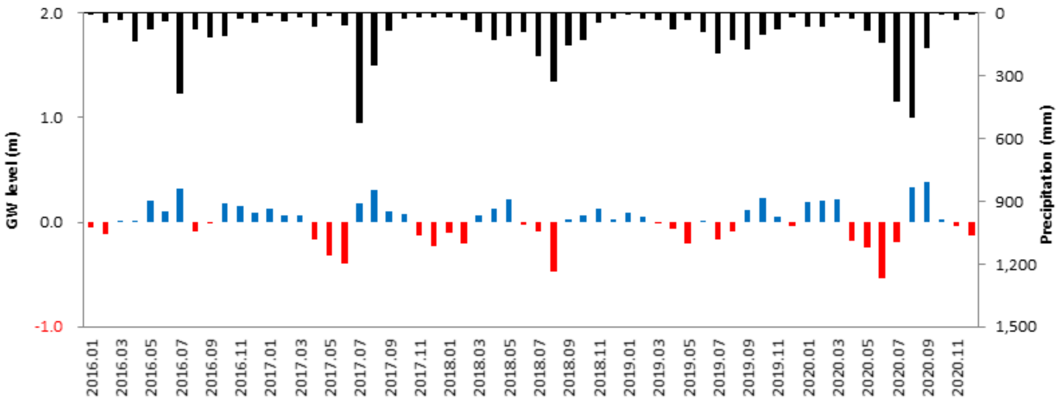
The increase and decrease in the groundwater level over the past 5 years is the value obtained by subtracting the average monthly water level from the average monthly water level. Changes in the groundwater level by region can be grasped at a glance. GG, CN, JN, GB, and GN suffered extreme drought in 2016, 2017, and 2018. Therefore, analyzing the change in the groundwater level compared to the normal period can show the local groundwater level and drought better than the SGI application method using the existing single well observation data that does not adequately represent the effect of use interference and the local groundwater level. It is evaluated that there is a representativeness that exists, so it is judged that it can prepare for future water demand management and agricultural drought (Figure 9).



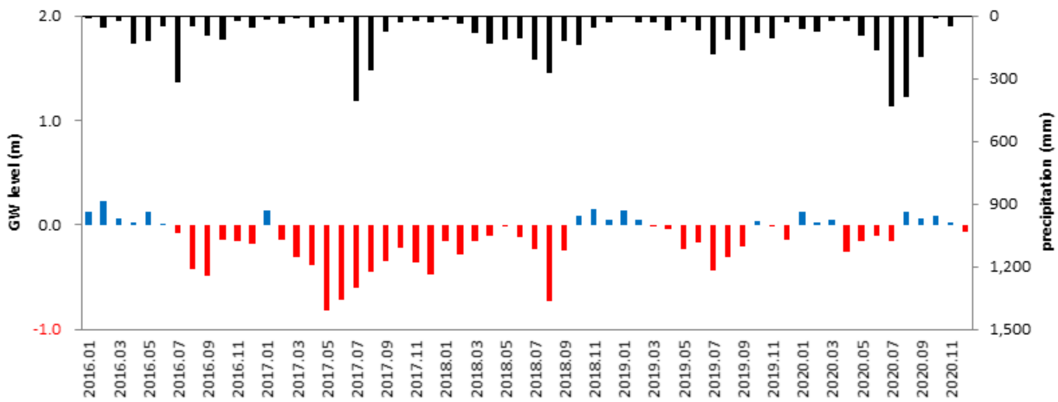
(a) Gyeonggi (GG)



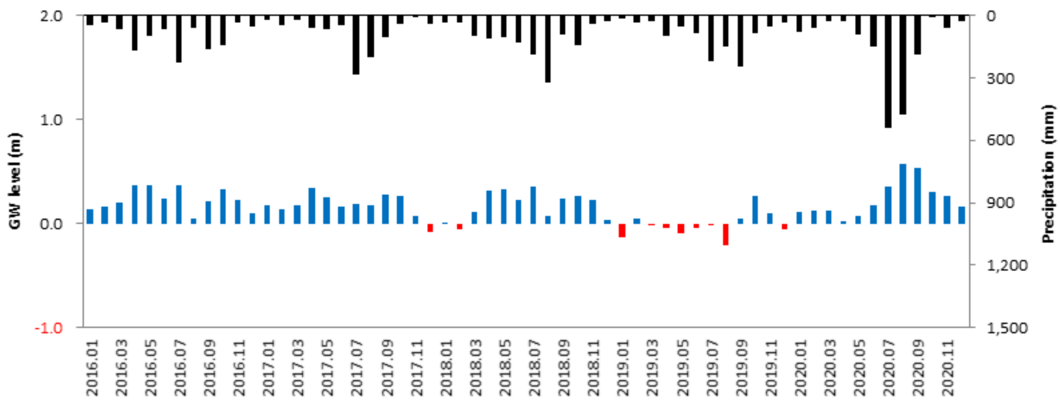
(b) Gangwon (GW)



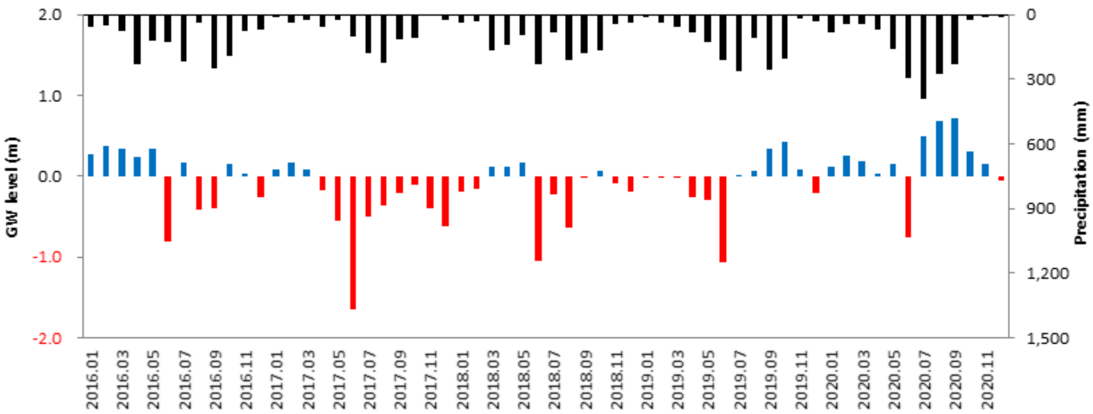
(c) Chungbuk (CB)



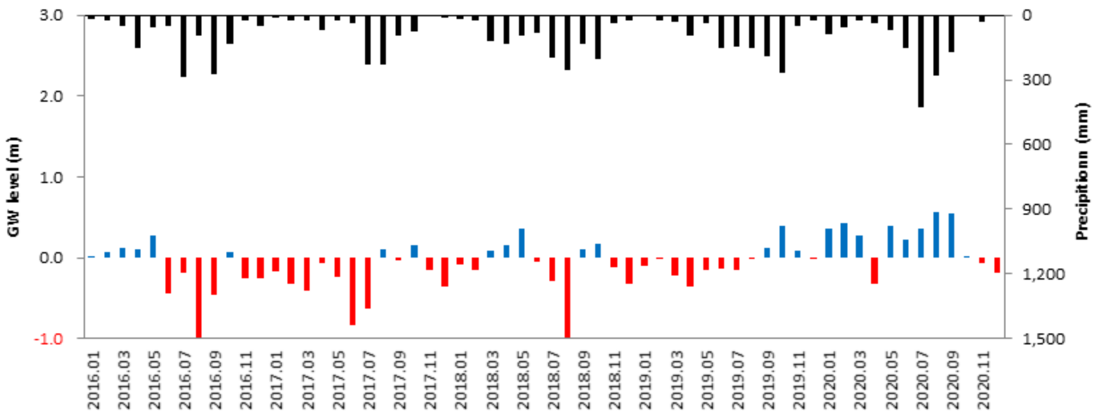
(d) Chungnam (CN)



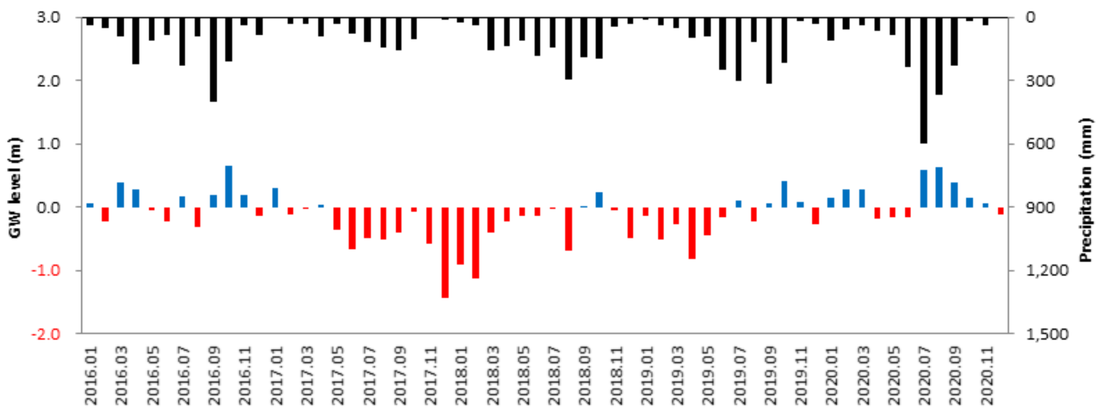
(e) Jeonbuk (JB)



(f) Jeonnam (JN)



(g) Gyeongbuk (GB)



(h) Gyeongnam (GN)

Figure 9. *Comparison of groundwater level change and precipitation graph.*

Table 5. *Groundwater level change compared to the average annual groundwater level during the last 5 years.*

	Jan.	Fab.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
Average	0.05	0.01	0.06	0.00	0.01	-0.06	0.02	-0.06	0.08	0.17	0.03	-0.12
GG	-0.09	-0.12	-0.05	-0.06	-0.04	-0.08	-0.08	-0.02	-0.09	-0.04	-0.11	-0.20
GW	-0.01	-0.01	-0.03	0.06	0.06	0.08	0.13	0.12	0.13	0.10	0.04	0.07
CB	0.05	0.00	0.07	-0.05	-0.07	-0.17	0.01	0.00	0.12	0.11	0.03	-0.05
CN	0.07	-0.02	-0.07	-0.16	-0.22	-0.22	-0.30	-0.36	-0.25	-0.03	0.01	-0.09
JB	0.06	0.08	0.12	0.20	0.18	0.15	0.25	0.14	0.26	0.29	0.18	0.04
JN	0.41	0.47	0.48	0.31	0.27	0.31	0.26	0.18	0.39	0.48	0.23	0.01
GB	0.00	0.00	-0.03	-0.10	0.13	-0.25	-0.18	-0.35	0.05	0.16	-0.10	-0.23
GN	-0.11	-0.34	0.00	-0.18	-0.22	-0.27	0.07	-0.22	0.05	0.27	-0.06	-0.49

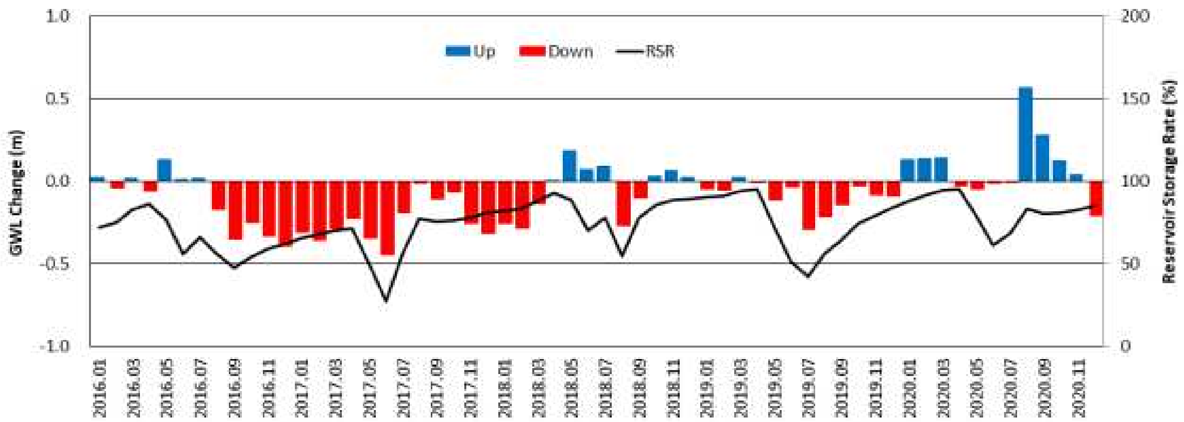
4.3. Correlation Analysis of GW Level Change and Reservoir Storage Rate

In the past, Song et al analyzed the correlation between the groundwater level time series data of a single observation well and the water retention rate of a single reservoir, and showed a low correlation in the correlation between the groundwater level and the reservoir water yield [15]. Comparing the data from all groundwater level observation holes in the region and the water storage rate of the reservoir, it was found to be as high as 0.8% to 58.9%. From 2016 to early 2018, GG, CN, JN, GB and GN showed a relatively high correlation of 48.5 to 58.9%, and in GW, CB, JB, and GN, where there was relatively heavy rainfall, 0.8 to 38.7% showed a low correlation. In the case of drought, the use of groundwater increases and the groundwater level is lowered, but the reservoir is discharged at a time when the water retention rate is the most effective and the sluice gate is not easily opened to supply water. In addition, even when it rains, the groundwater level rises, but there are many cases in which reservoirs open their sluice gates before rainfall to prevent flooding or do not open the sluice gates until the full water level, so a general correlation does not appear [14].

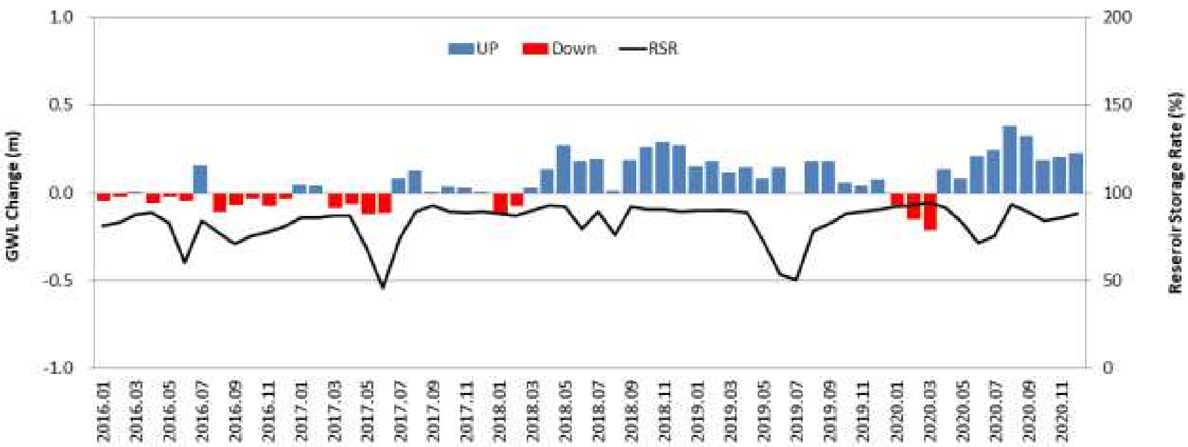
Nevertheless, when plotting the graph with the increase and decrease of the current groundwater level compared to the normal water level, the low yield rate is very similar (Figure 10).

Table 6. *Correlation of groundwater level change and reservoir storage rate.*

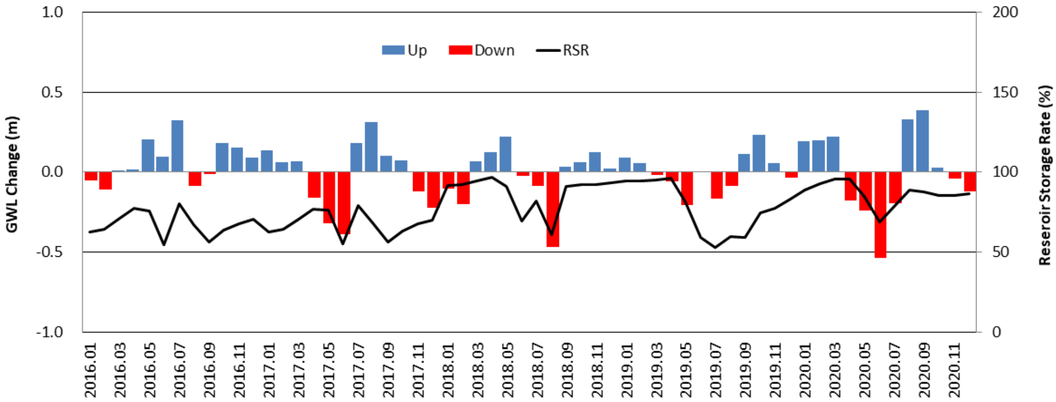
Province	Average groundwater level change (m)	Average agricultural reservoir storage rate	Correlation Coefficient
GG	0.02	74.3%	55.9%
GW	-0.02	83.3%	18.8%
CB	0.04	77.2%	20.9%
CN	-0.01	76.2%	54.9%
JB	0.00	73.9%	0.8%
JN	-0.06	69.7%	58.9%
GB	0.02	79.1%	48.5%
GN	-0.06	78.9%	55.0%



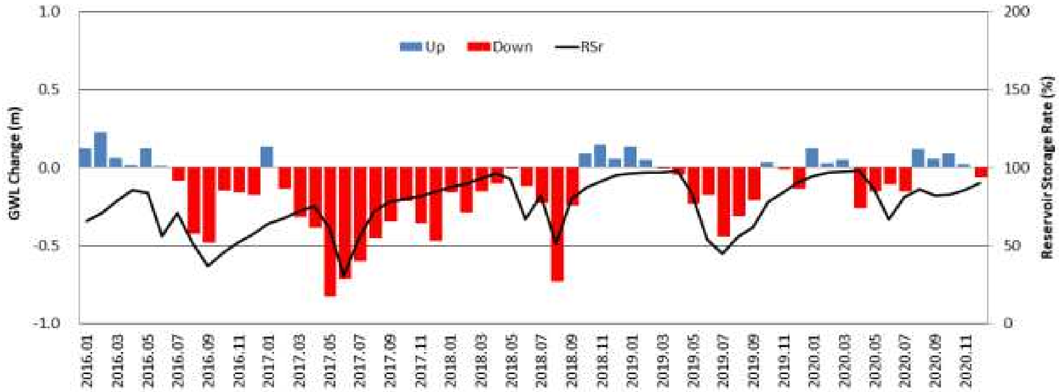
(a) Gyeonggi (GG)



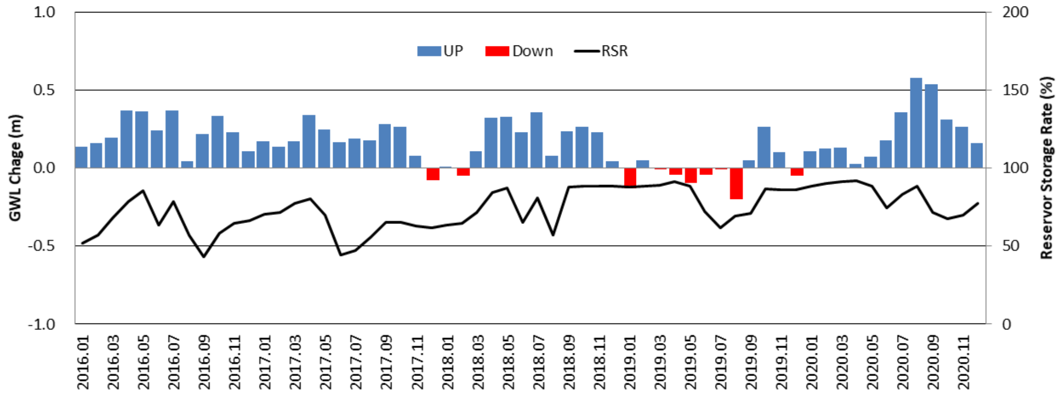
(b) Gangwon (GW)



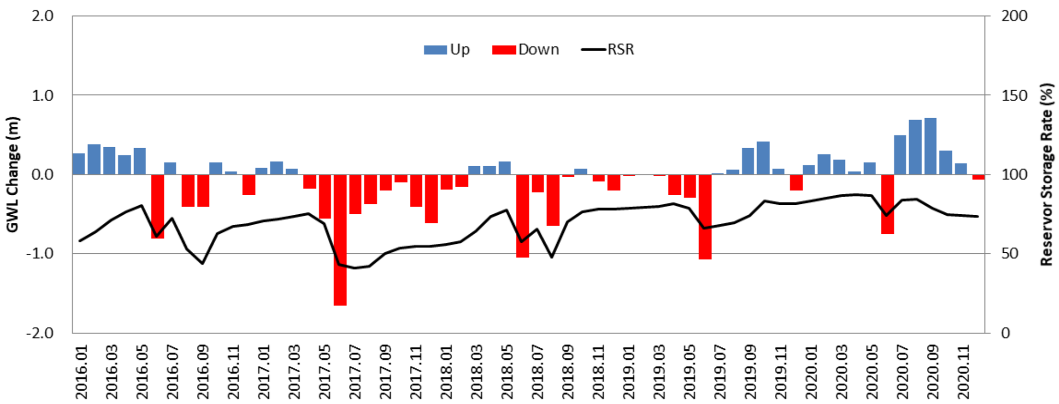
(c) Chungbuk (CB)



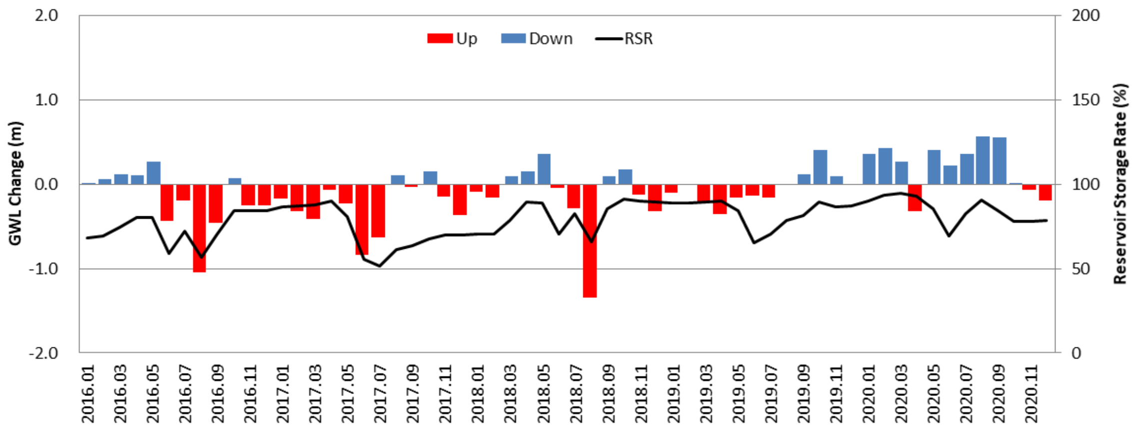
(d) Chungnam (CN)



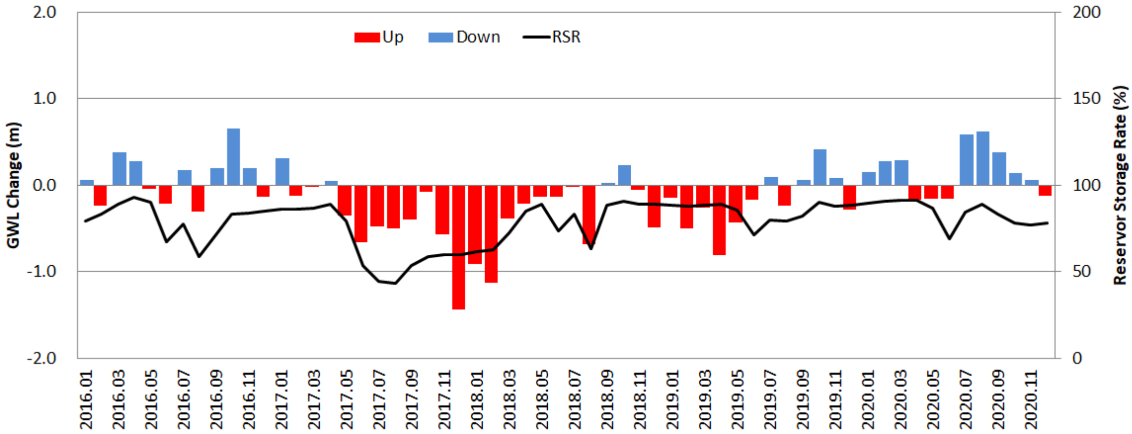
(e) Jeonbuk (JB)



(f) Jeonnam (JN)



(g) Gyeongbuk (GB)



(h) Gyeongnam (GN)

Figure 10. *Comparison of GW Level Change and Agricultural RS Rate graph.*

4.4. Frequency Analysis of GW Level Change and Classification of Drought Grade

As a result of the frequency analysis, in the case of GG, where drought was severe in 2016 and 2017, values greater than –0.25 m were normal (Near Normal), the interval of -0.32 to -0.25 m was moderate drought, and the interval of -0.36 to -0.32 m. In the case of severe drought, the section smaller than -0.36 m was classified as extreme drought. Also, in the case of CN, if it is greater than -0.28 m, it is normal, -0.43~-0.28 m is normal drought, -0.58~-0.43 m is severe drought, and extreme drought is less than -0.58 m. And GB was classified as normal when it was greater than 0.29, moderate drought in the -0.60~-0.29 m section, severe drought in the -0.68~-0.60 m section, and extreme drought less than -0.68 m (Table 7), (Figure 11). These values need to be recalculated periodically on a monthly, quarterly, or semi-annual basis.

As such, the range of groundwater level increase and decrease was wide in regions where there was severe drought, and the range of increase and decrease in the groundwater level was narrow in GW, CB, and JB regions where there was no drought or abundant rainfall (Table 8), (Table 9).

Table 7. *Agricultural drought classification by frequency analysis.*

	Near Normal	Moderate drought	Severe drought	Extreme drought
GG	> -0.25	-0.32~-0.25	-0.36~-0.32	-0.36 >
GW	> -0.04	-0.08~-0.04	-0.12~-0.08	-0.12 >
CB	> -0.11	-0.20~-0.11	-0.31~-0.11	-0.31 >
CN	> -0.28	-0.43~-0.28	-0.58~-0.43	-0.58 >
JB	> 0.05	-0.02~-0.05	-0.05~-0.07	-0.07 >
JN	> 0.12	-0.04~-0.12	-0.19~-0.04	-0.19 >
GB	> -0.29	-0.60~-0.29	-0.68~-0.60	-0.68 >
GN	> -0.34	-0.50~0.34	-0.78~-0.50	-0.78 >

Table 8. *GW level change relative to average annual groundwater level by province (unit: m).*

Month	AVE.	GG	GW	CB	CN	JB	JN	GB	GN
2016.01	0.00	0.03	-0.05	-0.05	0.12	0.14	0.60	-0.70	0.05
2016.02	0.03	-0.05	-0.02	-0.11	0.23	0.16	0.72	-0.71	-0.23
2016.03	0.06	0.02	0.01	0.01	0.06	0.20	0.70	-0.68	0.38
2016.04	0.05	-0.06	-0.05	0.02	0.02	0.37	0.61	-0.67	0.27
2016.05	0.19	0.14	-0.02	0.20	0.12	0.36	0.72	-0.10	-0.04
2016.06	0.04	0.02	-0.05	0.10	0.01	0.24	0.64	-0.65	-0.22
2016.07	-0.08	0.02	0.16	0.33	-0.08	0.37	0.51	-0.35	0.17
2016.08	-0.48	-0.17	-0.11	-0.09	-0.43	0.05	-0.01	-1.14	-0.31
2016.09	-0.37	-0.35	-0.07	-0.01	-0.48	0.22	-0.05	-0.53	0.19
2016.10	-0.08	-0.25	-0.03	0.18	-0.15	0.34	0.51	0.28	0.65
2016.11	-0.20	-0.36	-0.08	0.15	-0.16	0.23	0.33	0.29	0.19
2016.12	-0.09	-0.44	-0.03	0.09	-0.18	0.10	0.12	0.40	-0.14
2017.01	0.07	-0.31	0.05	0.13	0.13	0.17	0.56	-0.42	0.31
2017.02	-0.01	-0.36	0.04	0.06	-0.14	0.14	0.62	-0.51	-0.12
2017.03	-0.05	-0.29	-0.08	0.07	-0.32	0.17	0.54	-0.65	-0.02
2017.04	-0.02	-0.23	-0.06	-0.16	-0.39	0.34	0.24	-0.32	0.05
2017.05	-0.18	-0.35	-0.12	-0.32	-0.82	0.25	-0.16	-0.18	-0.36
2017.06	-0.29	-0.45	-0.12	-0.39	-0.72	0.17	-0.23	-0.62	-0.66
2017.07	-0.13	-0.19	0.08	0.18	-0.60	0.19	-0.20	-0.41	-0.48
2017.08	0.06	-0.02	0.13	0.31	-0.45	0.18	-0.04	0.28	-0.50
2017.09	0.04	-0.11	0.01	0.10	-0.35	0.28	0.11	0.23	-0.40
2017.10	0.14	-0.07	0.04	0.07	-0.22	0.26	0.21	0.51	-0.08
2017.11	-0.05	-0.32	0.03	-0.12	-0.36	0.08	-0.09	0.29	-0.57
2017.12	-0.20	-0.41	0.01	-0.22	-0.47	-0.08	-0.35	0.14	-1.44
2018.01	-0.07	-0.26	-0.12	-0.10	-0.16	0.01	0.18	-0.18	-0.91
2018.02	-0.12	-0.29	-0.08	-0.20	-0.29	-0.05	0.18	-0.22	-1.12
2018.03	0.09	-0.14	0.03	0.07	-0.15	0.11	0.42	0.01	-0.39
2018.04	0.21	0.01	0.14	0.13	-0.10	0.32	0.39	0.14	-0.22
2018.05	0.35	0.19	0.27	0.22	0.00	0.33	0.48	0.59	-0.13
2018.06	0.22	0.08	0.18	-0.02	-0.12	0.23	0.31	0.43	-0.14
2018.07	0.18	0.09	0.19	-0.09	-0.23	0.36	0.09	0.38	-0.02
2018.08	-0.28	-0.27	0.01	-0.47	-0.73	0.08	-0.30	-0.60	-0.69
2018.09	0.21	-0.11	0.18	0.03	-0.24	0.24	0.30	0.85	0.02
2018.10	0.36	0.03	0.26	0.06	0.09	0.26	0.38	1.01	0.23
2018.11	0.36	0.05	0.29	0.13	0.15	0.23	0.16	1.14	-0.06
2018.12	0.26	0.02	0.27	0.02	0.05	0.04	0.04	0.90	-0.49
2019.01	0.14	-0.05	0.15	0.09	0.14	-0.13	0.29	0.00	-0.14
2019.02	0.14	-0.05	0.18	0.05	0.05	0.05	0.26	0.06	-0.50
2019.03	0.10	0.03	0.11	-0.02	0.00	-0.01	0.26	-0.09	-0.26
2019.04	0.01	0.00	0.14	-0.06	-0.05	-0.04	0.02	-0.15	-0.81
2019.05	0.01	-0.12	0.08	-0.21	-0.23	-0.10	-0.08	0.39	-0.44
2019.06	0.16	-0.04	0.15	0.00	-0.17	-0.05	0.25	0.53	-0.17
2019.07	0.07	-0.30	-0.01	-0.17	-0.44	-0.01	0.20	0.61	0.09
2019.08	0.13	-0.21	0.18	-0.09	-0.31	-0.20	0.29	0.81	-0.23
2019.09	0.28	-0.14	0.18	0.11	-0.21	0.05	0.56	0.93	0.06
2019.10	0.43	-0.03	0.06	0.23	0.04	0.26	0.67	1.27	0.41
2019.11	0.31	-0.04	0.04	0.05	-0.01	0.10	0.35	1.20	0.08
2019.12	0.19	-0.03	0.08	-0.03	-0.14	-0.05	0.12	0.73	-0.28
2020.01	0.28	0.14	-0.07	0.20	0.12	0.11	0.44	0.38	0.15
2020.02	0.31	0.14	-0.15	0.20	0.03	0.13	0.57	0.45	0.28
2020.03	0.25	0.15	-0.22	0.22	0.05	0.13	0.50	0.30	0.29
2020.04	0.06	-0.03	0.13	-0.18	-0.26	0.02	0.31	-0.18	-0.17
2020.05	0.21	-0.05	0.08	-0.24	-0.15	0.07	0.40	0.95	-0.15
2020.06	0.22	-0.01	0.21	-0.54	-0.11	0.18	0.57	0.84	-0.16
2020.07	0.36	-0.01	0.25	-0.19	-0.16	0.36	0.70	0.97	0.58
2020.08	0.67	0.57	0.38	0.33	0.12	0.58	0.96	1.18	0.62
2020.09	0.59	0.28	0.32	0.39	0.06	0.54	1.00	1.15	0.38
2020.10	0.27	0.13	0.19	0.03	0.09	0.31	0.62	0.63	0.14
2020.11	0.32	0.23	0.20	-0.04	0.02	0.26	0.48	0.85	0.06
2020.12	0.17	0.03	0.23	-0.12	-0.06	0.16	0.27	0.38	-0.12

Table 9. *Classification of agricultural drought level using groundwater level change.*

	GG	KW	CB	CN	JB	JN	GB	GN
2016.01		M. Drought						
2016.02								
2016.03								
2016.04		M. Drought						
2016.05								
2016.06		M. Drought				E. Drought	M. Drought	
2016.07								
2016.08		S. Drought		M. Drought		E. Drought	E. Drought	
2016.09	S. Drought	M. Drought		S. Drought		E. Drought	M. Drought	
2016.10	M. Drought							
2016.11	S. Drought							
2016.12	E. Drought					E. Drought		
2017.01	M. Drought							
2017.02	M. Drought						M. Drought	
2017.03	M. Drought			M. Drought			M. Drought	
2017.04				M. Drought				
2017.05	M. Drought		M. Drought	M. Drought		M. Drought		M. Drought
2017.06	M. Drought		M. Drought	M. Drought		M. Drought	M. Drought	S. Drought
2017.07				M. Drought		M. Drought	M. Drought	M. Drought
2017.08				M. Drought		M. Drought		S. Drought
2017.09				M. Drought				M. Drought
2017.10								
2017.11	M. Drought			M. Drought		M. Drought		S. Drought
2017.12	M. Drought			M. Drought		M. Drought	M. Drought	E. Drought
2018.01	M. Drought							E. Drought
2018.02	M. Drought			M. Drought				E. Drought
2018.03								M. Drought
2018.04								
2018.05								
2018.06						M. Drought		
2018.07							M. Drought	
2018.08	M. Drought		M. Drought	M. Drought		M. Drought	M. Drought	S. Drought
2018.09								
2018.10								
2018.11								
2018.12							M. Drought	M. Drought
2019.01								
2019.02				M. Drought				
2019.03								
2019.04								
2019.05								
2019.06								
2019.07	M. Drought							
2019.08								
2019.09								
2019.10								
2019.11								
2019.12								
2020.01								
2020.02								
2020.03								
2020.04				M. Drought			M. Drought	
2020.05								
2020.06			M. Drought			M. Drought		
2020.07								
2020.08								
2020.09								
2020.10								
2020.11								
2020.12								

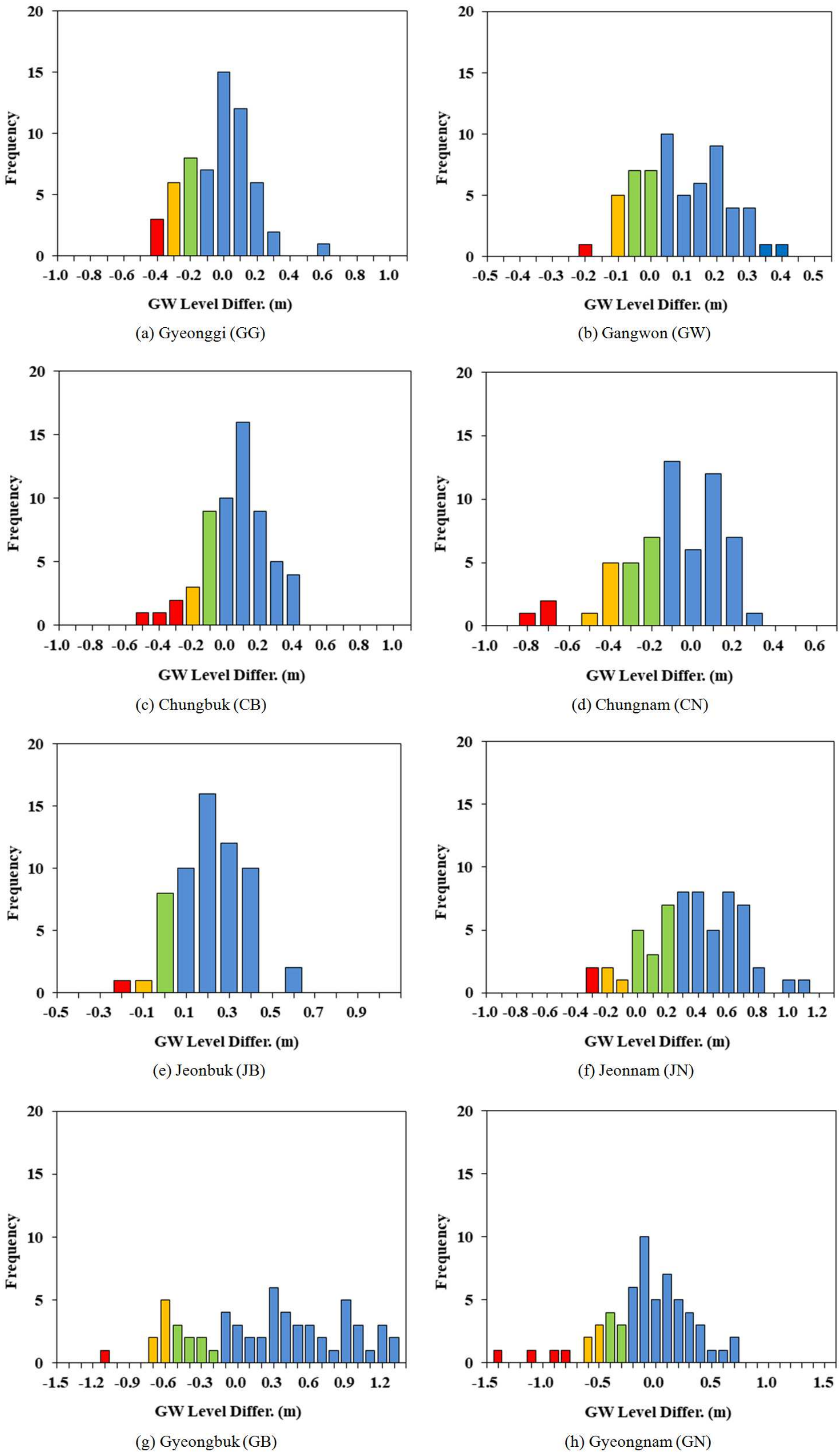


Figure 11. *Frequency analysis of groundwater level difference.*

When the range of groundwater level increase and decrease through frequency analysis was calculated and percentiles were obtained to indicate the agricultural drought grade, it was found that drought occurred mainly in GG, CN, JN, GB, and GN. In the case of GG, drought occurred from September 2016 to June 2017, and from the end of 2017 to February 2018. In CN, a severe drought occurred in August and September 2016, and then in 2017. From March to February 2018, there was a continuous drought. Also, in the case of JN, although intermittent, severe drought appeared from June to December 2016, and a moderate drought occurred from May to December 2017. GB has been experiencing intermittent drought since the extreme drought in August 2016. In the case of GN, the drought occurred continuously from May 2017 to March 2018. In particular, a severe drought occurred in June and August 2017. Figure 11 is a graph showing the increase and decrease in the groundwater level by region for the last 5 years (2016-2020) with the maximum and minimum values. It is easy to check which area has the largest increase or decrease in the groundwater level (Figure 12).

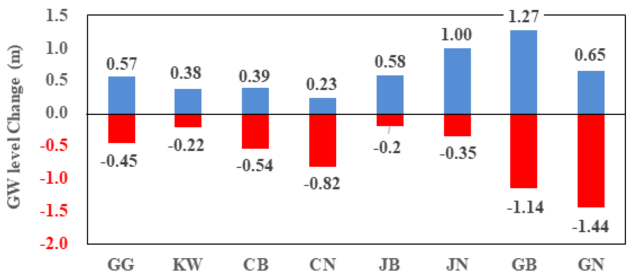


Figure 12. *Comparison of groundwater level changes of province.*

5. Conclusions

When a drought occurs, the groundwater level is also lowered, so it can be seen that a change in the groundwater level can represent a drought. Like precipitation, groundwater level changes also have a high correlation with drought, so many researchers use SGI to which the SPI method is applied to evaluate the severity of drought and predict trends.

However, in order to properly understand the correlation with drought, it is necessary to analyze the groundwater level fluctuations by reflecting the interference caused by the use of groundwater. Therefore, agricultural drought stages were classified using long-term groundwater level observation data including interference data from groundwater use.

To analyze the groundwater level fluctuation pattern in this study, the average monthly groundwater level value was obtained. The increase or decrease of the groundwater level over the past 5 years was compared with the average groundwater level obtained in this way. As a result, it confirmed that the average groundwater level reduction data appeared very similar to the drought occurrence period. In addition, as a result of analyzing the correlation between groundwater level increase and the water storage rate of 3,423 agricultural reservoirs, it was found that the correlation was more than 56% in the natural state.

However, the long-term average groundwater level patterns it is difficult to represent the drought of watershed by applying the relationship between SPI and SGI by designating one representative monitoring well for surrounding interference and frequently changing groundwater level.

Consequently, considering that the groundwater level responds later than the surface water to weather change, it is possible to apply the current groundwater level compared to the normal level to agricultural drought and expected to use as a forecast tool for the future agricultural drought.

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