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The scale of typhoon RUSA

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Abstract

In August 2002, Typhoon RUSA hit Korea with severe gale and storm, causing extensive damage throughout the whole country and especially in the Gangneung area. Even on a single day, Typhoon RUSA recorded up to 879.5 mm of rainfall in the Gangneung area. Quantitative and qualitative analyses of the scale of Typhoon RUSA are performed in this study. Most of the inland affected by RUSA in the Korean Peninsula recorded heavy rainfall, equivalent to a return period of more than 200 years. Especially, rainfall of 24 h duration exceeded the maxima observed so far. Although areal rainfall showed a rapidly decreasing trend with increasing area, it reached 96 percent of the existing PMP within a 2000 km^2 area and recorded the maximum observed value of Korea according to a DAD analysis of rainfall. Re-estimated PMP values obtained from a hydro-meteorological approach compared with existing PMP estimates revealed a discrepancy between the two values, which showed that re-estimated PMP values of 12 to 24 h duration within 2000 km^2 exceeded the existing PMP estimates of Korea. Therefore, modification of the existing PMP is required, which is used as a design hydrological variable of hydraulic structure.

1 Introduction

There have been a lot of natural disasters which have hit Korea heavily during the last years of the 20th century. Some of these natural storms and flood disasters include: Typhoon JANIS in 1995, heavy rainfalls in 1996 and 1998, typhoon YANNI in 1998, a heavy storm in 1999, typhoon PRAPIRON in 2000 and typhoon RUSA in 2002. When South Korea was hit by heavy rainfall in 1999, it was recorded to be the most devastating natural disasters to hit Korea throughout the entire hydrological history at that time. It affected the lives of many along with casualties and an enormous amount of damage totaling up to nearly 1 billion USD. However, when RUSA hit South Korea, it brought almost five times more (5.5 billion USD) damage and much more casualties than that of the heavy rainfall in 1999.

Typhoon RUSA passed through the Korean Peninsula and brought a tremendous amount of damage with gale and storm to the country. Compared to other parts of Korea, the Gangeung area recorded the largest amount of damage. Daily rainfall in Gangneung, during this period, was up to 879.5 mm and this was equivalent to 62 percent of the average annual rainfall (1401.9 mm) in this particular area. This record exceeded by more than 300 mm the record in Jangheung (547.4 mm) on 2 September 1981, which was recorded to be the largest rainfall in Korean History. This devastating storm went to affect other areas such as the Yeoungdong region (eastern part of Taebaek Mountain), which wreaked havoc in major cities such as Gangneung, Samcheok, Sokcho and Yangyang.

This paper evaluates the formation of heavy rainfall in terms of the mechanism of occurrence and decay with time and space. This research will also attempt to investigate the scale of Typhoon RUSA using quantitative and qualitative analysis. Due to the fact that the main issue at hand is the magnitude of rainfall by duration and area, the evaluation of the scale of Typhoon RUSA will depend on the point probable rainfall and possible maximum precipitation.

2 The origin of Typhoon RUSA

Typhoon RUSA originated in the location which apart 1800 km from the east-northeast of Guam at 09:00 a.m. on 23 August 2002. Her central atmospheric pressure was 950 hPa and the central wind velocity within the storm was 36 m per second. Sporadically, she maintained her magnitude as she approached and hit the Goheung peninsula located in the Jeonnam province of Korea at 03:00 PM on 31 August. A typhoon which develops from vapor of high water temperatures of the Pacific Tropics gradually weakens when it travels north due to the difference in temperature. It was anticipated that RUSA would weaken as she reached the Japanese sea; however, she maintained her power. Furthermore, typhoons generally loose power when they arrive inland because

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of many obstacles, such as mountains. However, RUSA sustained maximum intensity and power as she reached Korea and devastated the whole nation for quite some time.

The main factor of unabated power was that the temperature of the southern sea was higher than that of average. This allowed RUSA to take energy continuously from the sea. The temperature of the southern sea was 27~29 C and generated vapor which helped RUSA maintain her power. Additionally, the prevailing westerly and the upper air above the North Pacific, which lay from the east to the west in Korean Peninsula, was exceptionally weak. These phenomena seemed to block the movement of velocity and restrict changes in direction of the typhoon. Consequently, she penetrated the Korean Peninsula with powerful winds of maximum speeds at 30~50 m per second and torrential rainfalls reaching up to 871 mm on a daily basis. According to the analysis, low and humid easterly wind blew to Yeongdong as the typhoon approached the north. Yeongdon is in the region of Gangwon province, located near the edge of the North Pacific, which meant that a zone of high atmospheric humidity would surround Gangneung. In this worst-case scenario, the cold atmosphere at an altitude of 1.5 km and the hot atmosphere of the tropical cyclone joined at the upper atmosphere of Gangeung and created a storm. Additionally, humid northeast current air rose from Taebaek Mountain and generated a severe storm around the Gangwon province, which includes areas such as Gangneung and Sokcho. Conversely, Yeongseo region(western part of Taebaek Mountain) had relatively less precipitation with air going down along the mountain.

3 The direction of the typhoon

3.1 The path of the Typhoon and spatial distribution of rainfall

Typhoon RUSA slowly approached to the north from approximately 330 kilometers off the south-southeast of Jeju Island at 05:00 p.m. on 30 August. She caused torrential rainfall on Jeju Island and the southern part of Korea with the approaching helicoids rain cloud distributed on the outer ring of the typhoon (Fig. 1a). She expanded towards the north, and 170 kilometers off the south-southeast of Jeju Island. She also extended to most of the inland and sea, except central and southwestern part of Korean Peninsula (Fig. 1b). Henceforth, the storm passed near the Jeju Island Sea around noon (Fig. 1c), and at 06:00 p.m., it reached the south coast of the Goheung Peninsula of Jeonnam province, causing heavy rainfall. There were also severe rain and wind at the mountainous areas of the southern part and Yeongdong of Gangwon province (Fig. 1d). She passed through Muju of Jeonbuk province at 01:00 a.m. on 1 September. Meanwhile, the storm was getting weaker at the southern part and on Jeju Island, which was located at the backside of the typhoon during that time. However, torrential rainfall in the mid-west area moved to the front side of the typhoon. Specifically, the severe rainstorm had continued to the Yeoungdong area of the Gangwon province (Fig. 1e). Since then, typhoon RUSA, the 15th of the season, lost her power as she moved from the north-northeast to the northeast and passed through Gangneung-Donghae as shown in (Fig. 1f). The Path of the typhoon is shown in Fig. 2.

Figure 3 shows the spatial distribution of rainfall a three hourly intervals from midnight of 31 August to 06:00 a.m. on 1 September. As presented in the figure, Typhoon RUSA passed from the southeastern part such as Jeju Island and Goheung Peninsula and moved toward the Midwest and the Northeast, and eventually lost her power. Under the influence of the typhoon, an inflow of moist air from the east, and the topographical factor, Taebaek Mountain, there was more precipitation than in the center of the typhoon in Yeoungdong area from 31 August to 1 September. In detail, the center of cumulative rainfall was in the southwestern part of the country such as Jeju Island, Daeheuksan Island and Jin Island from 06:00 p.m. to midnight on 30 August. The storm expanded towards the south coast from midnight to 06:00 a.m. on 31 August. However, the center of rainfall was in the Samcheok area and rainfall duration in the Singi-Myeon district was 107.0 mm and 95.0 mm in Miro-Myeon district (Table 1).

Typhoon RUSA expanded her power to Jeonnam and Gyeoungnam province from 06:00 a.m. to 12:00 p.m. on 31 August. The center of rainfall moved slightly over to Gangneung, and accumulated to about 237.5 mm of rainfall in Gangneung and 180 mm in Daegwallyeong. When she passed Jeju island, the south coast of Goheung Peninsula of Jeonnam province, from 12 p.m. to 6 p.m. on August 31, rainfall was concentrated in the south and Yeoungdong, but relatively small amount of rainfall occurred in Chungnam, Chungbuk and Gyeonggi province, which were located on the west side of Typhoon. The center of cumulated precipitation was at the Ssanggye area and Jungsanri area of Sumjin River Basin with 261 mm and 252.5 mm of rainfall, respectively. Afterwards, the typhoon was heading towards the northeast, thus the south coast was free from typhoon after midnight on 31 August. However, heavy rainfall of typhoon and storm due to the northeast air created more than 50 mm of rainfall per an hour for 5 h in the Yeoungdong area. At that moment, the maximum precipitation of 5 h duration was 365.5 mm; 6 h duration was 397.5 mm in Gangneung and 368 mm in Seo-Myeon in Yangyang County. From midnight to 6 a.m. on 1 September, the power of typhoon was getting weaker and passed away to the northeast through Gangneung-Donghae. Meanwhile, the center of rainfall moved slightly to the north and recorded up to 139 mm in Yangyang and 119 mm in Sokcho. Figure 3 and Table 1 show the characteristics of the storm along the path of the typhoon, and Fig. 4 and Table 2 present spatial distributions and maximum value of rainfall according to the rainfall durations. In case of 6 h duration, maximum rainfall was 403 mm in Yangyang from 8 p.m. on 31 August to 2 a.m.on 1 September. It was Gangneung that had maximum rainfall for 12 h to 48 h. The period and maximum rainfall by duration was 576 mm for 12 h duration from 12 a.m. to 12 p.m. on 31 August. 880 mm for the 24 h duration from 1 a.m. on 31 August to 1 a.m. on September. And as for the 48 h duration from 5 a.m. on 30 August to 5 a.m. on September, 897.5 mm was recorded as maximum rainfall.

3.2 Time distributions of rainfall

Figure 5 through Fig. 8 show the time distribution of rainfall based on the area of heavy rainfall by the 15th typhoon RUSA. The figures present a representative time distribution and cumulative rainfall of the observation stations; Gimcheon (Fig. 5), Samcheok and Donghae in the south of Gangneung (Fig. 6), Gangneung (Fig. 7), Yangyang and

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Sokcho in the north of Gangneung (Fig. 8).

In case of Gangneung (Fig. 7), the results are similar to the time distribution of rainfall between Gangneung and Daegwallyeong before 6 p.m. on 31 August, but there is a large difference after that period. This happens exactly at the neighboring observation stations such as Miro-Myeon and Donghae (Fig. 6), and Yangyang County and Sokcho (Fig. 8). This means that there are large rainfall deviations even in the Yeoungdong area, which had much rainfall from RUSA.

In terms of the temporal distribution of rainfall, the peak values at Chupungnyeong and Gimcheon station are lower than those of the other stations, and the time to peak and the duration of rainfall are much shorter than those at Miro-Myeon and Donghae. The time to peak and the duration of rainfall at Miro-Myeon and Donghae are shorter than those at Gangneung and Daegwallyeong. The time to peak and the duration of rainfall are longest at Yangyang and Sokcho. This order is in accordance with the route of maximum rainfall of each duration and the path of the typhoon.

4 The Magnitude and scale of typhoon RUSA

4.1 Maximum rainfall by locality

Among the 8 observation stations of Fig. 5, one station that has the largest rainfall is chosen. Probable rainfall and observed rainfall by duration is presented for this station in Table 3. Except for the peak of Chupungnyeong, which shows a 5-year return period for 1 h duration, more than 200 year return periods have been observed at four stations. In other words, it is hard to evaluate the scale of heavy rainfall for each station by probable rainfall.

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4.2 DAD analysis

The rainfall data from 850 stations have been collected; 508 stations of KMA[1] and AWS, 294 stations of MOCT[2] and KOWACO[3] and 18 stations of MOGAHA[4]. A station was excluded if there were missing data or if the deviations from other observation stations were too large. A station would also be excluded if it had a different distribution of cumulative rainfall compared to neighboring observation stations. Such examples can be seen in Fig. 5 to Fig. 8. In the final analysis, 73 data from KMA, 239 from AWS, 266 from MOCT and KOWACO and 13 from MOGAHA were used. Due to the severe damage caused by RUSA, there were few or no T/M rainfall measurement stations for MOCT and KOWACO in Gangneung. The data from KMA were missing except for the Gangneung and Daegwallyeong stations, after 7 p.m. of 31 August when there was severe rainfall. To compensate for the missing data, the data of MOGAHA from 18 additional stations in Donghae/Samcheok and Yangyang County were collected, and data from 13 out of the 18 stations were used. However, due to the missing data of Gangneung and Ganseong County, it was not possible to use the data directly, thus it was not possible to find out how much of rain had concentrated on a certain size of land. The total number of data for established DAD analysis procedure(World Meteorological Organization, 1969) were 591, excluding 229 due to missing data and outliers. The analysis was based on the DAD analysis program, considering rainfall movement, which was already developed (MOCT 2000a). The duration period and area of analysis was divided into ten categories of 1, 2, 4, 6, 8, 12, 18, 24, 48, 72 h and 25, 50, 100, 200, 500, 1000, 2000, 5000, 10 000, 20 000 km^2. Additionally, the representative area of point rainfall was limited to 1 km^2, because the rainfall by RUSA tended to concentrate in a small area. The result of the DAD analysis shown in Fig. 9 and Fig. 10

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represents comparisons with PMP value of the Gangneung area with previous studies (MOCT, 2000b).

With the limitation of 1 km^2 for the representative area of point rainfall, the result of the DAD analysis (solid line) of the heavy rainstorm by RUSA was smaller than the PMP (dotted line) from the PMP diagram, and it was close to the PMP for 24 h duration, but not more than that value (Table 4).

4.3 Evaluation of the magnitude and scale of the Typhoon RUSA

To evaluate the magnitude and scale of rainfall of typhoon RUSA, comparisons were made with the DAD analysis result of 132 other heavy rainstorms which occurred during 1969 to 1999 with daily precipitation levels that exceeded 150 mm. Table 5 shows the order of magnitude of the storm of RUSA with duration and area from the DAD analysis results of the 132 heavy rainstorms. As shown in the table, the rainstorm by RUSA ranked first to fourth for an area of 2000 km^2 and ranked at the top for an area of 1000 km^2 for 24 h duration. Thus the heavy rainfall of this typhoon was concentrated on a relatively small area.

According to the DAD analysis results shown in the Table 5, little movement and geographical concentration of rain caused a large amount of precipitation in terms of its size and scale. It may be possible that the application of maximum rainfall might affect the design guideline of dam and nuclear- power stations in Korea. Therefore, it is necessary to reevaluate the PMP of this rainfall using established procedure (World Meteorological Organization, 1986). A 1000 mb maximum dew station has to be selected out of the dew stations of Daegwallyeong on August 30 to estimate the PMP of this rainfall in the Gangneung area. Likewise, the average altitude of Gangneung and Donghae has been used as representing 1000 mb average altitude to consider average altitude of the heavy rainfall area. The moisture maximization ratio of heavy rainfall is approximately 1.29 for this typhoon (Table 6).

Based on the multiplication of the DAD results of heavy rainfall of RUSA (Table 4) with the moisture maximization ratio (Table 6), PMP has been estimated and compared with the existing PMP, which is extracted from the PMP diagram in Table 7. In case of a 6 h duration, the PMP from the PMP diagram was larger than the estimated PMP of this heavy rainfall, but the estimated PMP was higher if we extended duration up to 12∼48 h within a smaller area. In particular, for 24 h duration, the estimated PMP exceeds the existing PMP within 2000 km^2, and exceeds the existing PMP for 12 and 24 h durations within 200 km^2. As noted earlier, the heavy rainfall of this typhoon shows large size and scale for the 24 h duration, and exceeded PMP within a smaller area for approximately 12 to 48 h durations.

5 Conclusions

In Yeongdong, Gangwon province, an extreme storm was recorded by moisture supply from typhoon RUSA on 31 August and additional geographical reasons. Rainfall data have been analyzed to understand the characteristics, and magnitude and scale of the heavy rainstorm of the typhoon from 30 August to 1 September. The results are as follows;

1. Low and high humid east wind continuously supplied much moisture into Yeongdong, Gangwon province, and frontal precipitation was created by cold air in this area joining the warm air of typhoon RUSA. Additionally, the northeastern air containing much moisture was lifted by Taebaek Mountain and brought a large amount of precipitation in Yeongdong, Gangwon province.

2. In Yeongdong, Gangwon province, local precipitation of the event exceeded a return period of 200-years. This rainfall does not exceed existing PMP values (MOCT, 2000b), but the magnitude and scale of rainfall was ranked first through fourth for smaller areas. Most importantly, it is the highest observed rainfall for areas smaller than 1000 km^2 during a 24 h duration.

3. The PMP moisture maximization ratio of rainfall is approximately 1.29 for this typhoon, and the estimated PMP exceeds the PMP diagram within 2000 km^2.

Additionally, these values exceed the PMP diagram for 12 and 24 h durations within 200 km^2. These results indicate that the PMP can increase within small area, if storm movement is considered.

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References

World Meteorological Organization: Manual for Depth-Area-Duration Analysis of Storm Precipitation, WMO No. 237, Technical Paper 129, 130p., Geneva, Switzerland, 1969.

World Meteorological Organization: Manual for Estimation of Probable Maximum Precipitation, Second Edition, Operational Hydrology Report No. 1(WMO No. 332),190p., Geneva, Switzerland, 1986.

Ministry of Construction & Transportation, Main Storms in Korea, Report of Water Resources Management Techniques Research in 1999, Vol. 2, separate Vol. 1, KICT, 289p., 2000a.

Ministry of Construction & Transportation: Estimation of Probable Maximum Precipitation in Korea, Report of Water Resources Management Techniques Research in 1999, Vol. 2, KICT, 440p., 2000b.

Ministry of Construction & Transportation: Creation of Probability Rainfall Map in Korea, Report of Water Resources Management Techniques Research in 1999, Vol. 1, KICT, 330p., 2000c.

Table 1. The center of rainfall of 6 h duration.

Strom Duration	1st Station	Rainfall (mm)	2nd Station	Rainfall (mm)
06:00 a.m. 30 Aug. – 12:00 p.m. 30 Aug.	Jeju	41.0	Daeheuksan Island	23.5
00:00 a.m. 31 Aug. – 06:00 a.m. 31 Aug.	Singi-Myeon	107.0	Miro-Myeon	95.0
06:00 a.m. 31 Aug. – 12:00 p.m. 31 Aug.	Gangneung	237.5	Daegwallyeong	180.0
12:00 a.m. 31 Aug. – 06:00 a.m. 31 Aug.	Ssanggye	261.0	Jungsanri	252.5
06:00 p.m. 31 Aug. – 12:00 p.m. 31 Aug.	Gangneung	397.5	Seo-Myeon	368.0
00:00 a.m. 1 Sep. – 06:00 a.m. 1 Sep.	Yangyang	139.0	Sokcho	119.0

Table 2. The center of maximum rainfall according to the duration.

Strom Duration	1st Station	Rainfall (mm)	2nd Station	Rainfall (mm)
6-hr Duration 8 p.m. 31 Aug. –	Yangyang	403.0	Gangneung	274.5
12-hr Duration 12 a.m 31 Aug. –	Gangneung	576.0	Miro-Myeon	529.0
24-hr Duration 1 a.m. 31 Aug. –	Gangneung	880.0	Daegwallyeong	739.0
48-hr Duration 5 a.m 30 Aug. –	Gangneung	897.5	Daegwallyeong	758.8

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Table 3. Comparison of rainfall frequencies by locality.

Station	Division	Duration (hr)				
		1	6	12	24	48
Chupungnyeong	Frequency	<5- yr	>200- yr	>200- yr	>200- yr	>200- yr
	Rainfall (mm)	32.5	170.0	252.5	280.0	287.0
Miro-Myeon	Frequency	>200- yr	>200- yr	>200- yr	>200- yr	>200- yr
	Rainfall (mm)	100.0	386.0	537.0	739.0	742.0
Gangneung	Frequency	>200-yr	>200-yr	> 200–yr	>200-yr	>200- yr
	Rainfall (mm)	98.0	399.5	576.0	880.0	897.5
Yangyang	Frequency	> 200-yr	> 200-yr	> 200-yr	> 200-yr	> 200- yr
	Rainfall (mm)	83.0	403.0	560.0	664.0	679.0

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Table 4. Comparison between rainfall from the DAD analysis and PMP.

Area (km^2)	Division	Duration (hr) 6	12	24	48
25	RUSA-DAD*	342	505	771	790
	PMP	490	646	840	990
100	RUSA-DAD*	315	470	718	738
	PMP	445	585	765	925
200	RUSA-DAD*	302	446	676	697
	PMP	425	560	725	900
1000	RUSA-DAD*	255	377	570	588
	PMP	385	510	645	845
2000	RUSA-DAD*	220	340	504	520
	PMP	360	485	610	810

* Indicates the result of DAD analysis of the RUSA storm.

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Table 5. The order of magnitude of heavy rainfall by RUSA.

Area (km^2)	Duration (hr) 6	12	24	48
25	2	2	1	2
100	2	2	1	2
200	2	2	1	2
1000	2	3	1	4
2000	2	3	2	4

Table 6. Moisture maximization ratio of heavy rainfall for RUSA.

Mean Elevation	Representative Dew Point at 1000 hPa (˚C)	Representative Precipitable Water at MSL (mm)	Representative Precipitable Water at Mean Elevation (mm)	Maximum Dew Point at 1000 hPa (˚C)	Maximum Precipitable Water at MSL (mm)	Maximum Precipitable Water at Mean Elevation (mm)	Ratio of Moisture Maximization
30.00	23.00	68.00	0.6	25.98	87.86	0.60	1.29

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Table 7. Comparison between estimated PMP of heavy rainfall of RUSA and existing PMP in Gangneung (Unit: mm).

Area (km^2)	Division	Duration (hr) 6	12	24	48
25	RUSA-PMP*	441	651	995	1019
	PMP	490	645	840	990
100	RUSA-PMP*	406	606	926	952
	PMP	445	585	765	925
200	RUSA-PMP*	390	575	872	899
	PMP	425	560	725	900
1000	RUSA-PMP*	329	486	735	759
	PMP	385	510	645	845
2000	RUSA-PMP*	284	439	650	671
	PMP	360	485	610	810

* Indicates re-estimated PMP of the RUSA storm.

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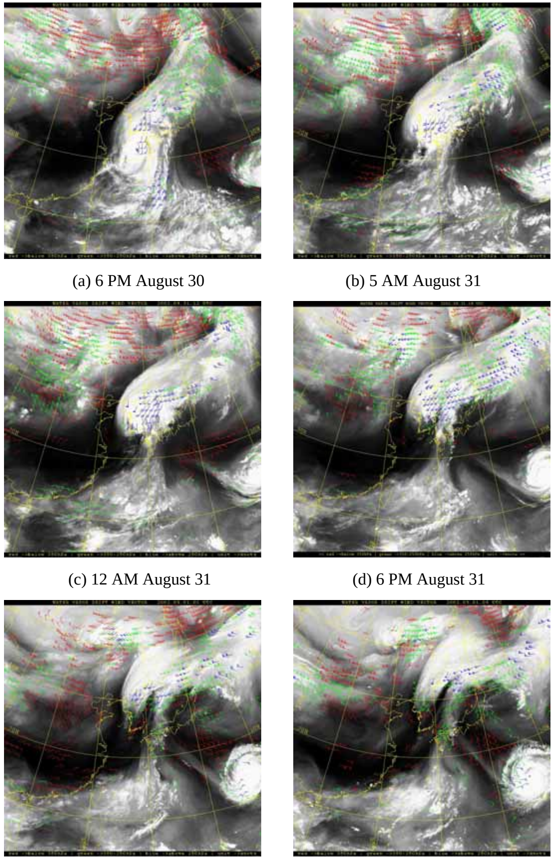

Fig. 1. A GMS satellite image and moisture vector (data: Korea Meteorological Administration) **(a)** 6 p.m. 30 August **(b)** 5 a.m. 31 August **(c)** 12 a.m. 31 August **(d)** 6 p.m. 31 August **(e)** 1 a.m. 1 September **(f)** 6 a.m. 1 September.

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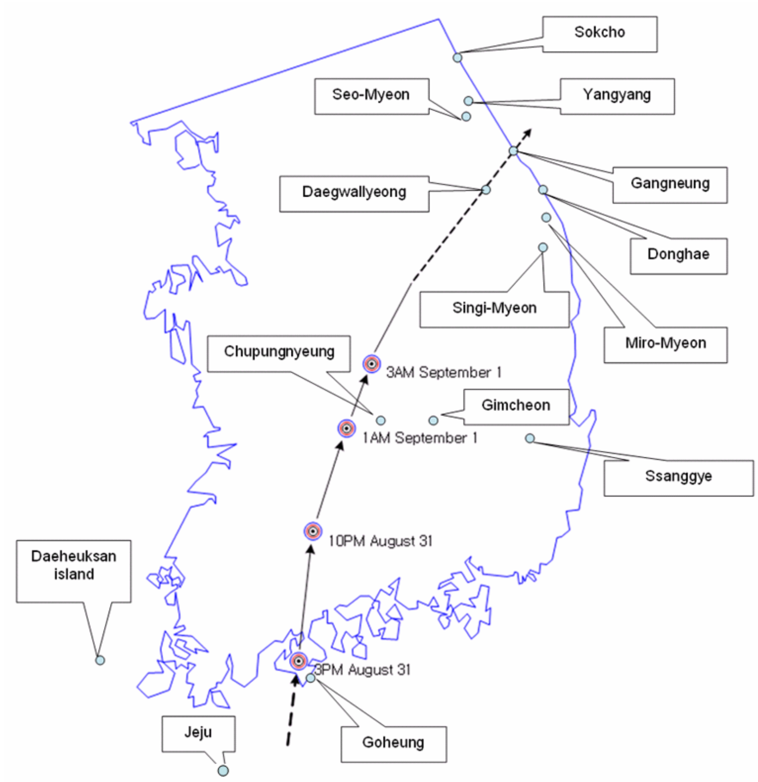

Fig. 2. Path of typhoon in South Korea.

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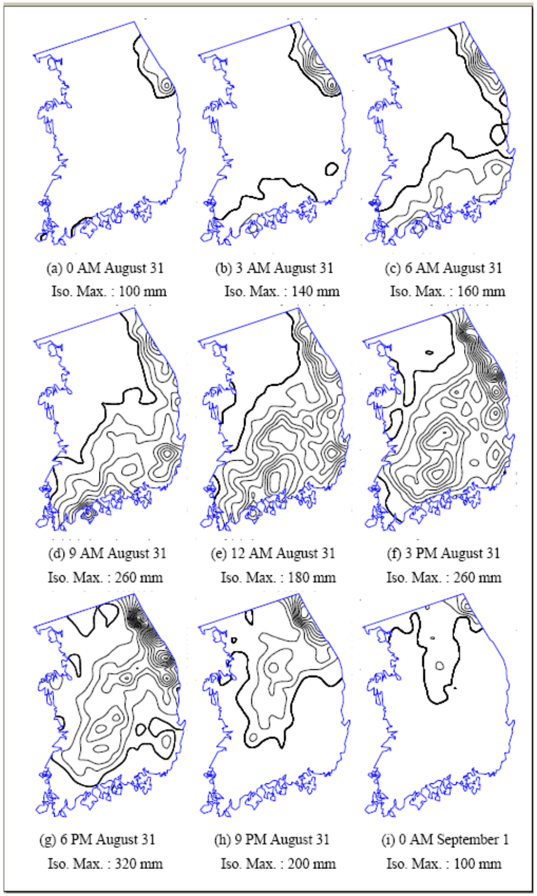

Fig. 3. The spatial distribution of rainfall of 6 h duration. (Iso. Interval: 20 mm) **(a)** 0 a.m. 31 August–**(b)** 3 a.m. 31 August –**(c)** 6 a.m. 31 August–**(d)** 9 a.m 31 August–**(e)** 12 a.m 31 August–**(f)** 3 p.m. 31 August–**(g)** 6 p.m. 31 August–**(h)** 9 p.m. 31 August–**(i)** 12 p.m. 1 September–.

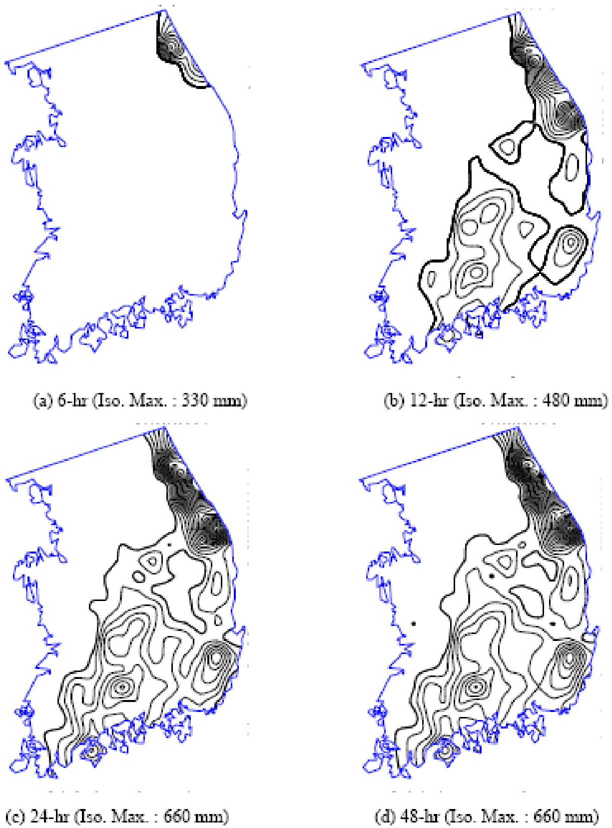

Fig. 4. The spatial distribution of maximum rainfall by duration (Iso. Interval: 30 mm). **(a)** 6-hr **(b)** 12-hr **(c)** 24-hr **(d)** 48-hr.

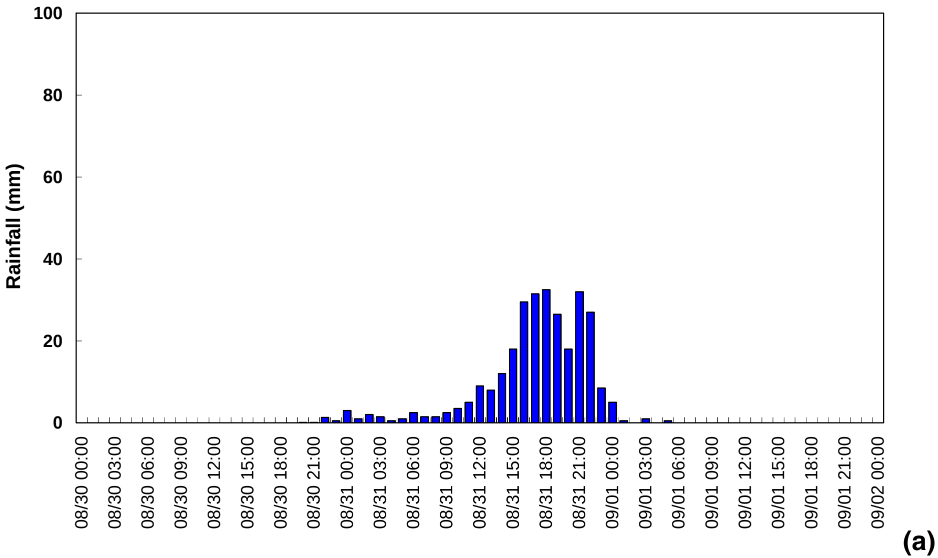

Fig. 5. Time distribution of rainfall in Gimcheon area **(a)** Chupungnyeong.

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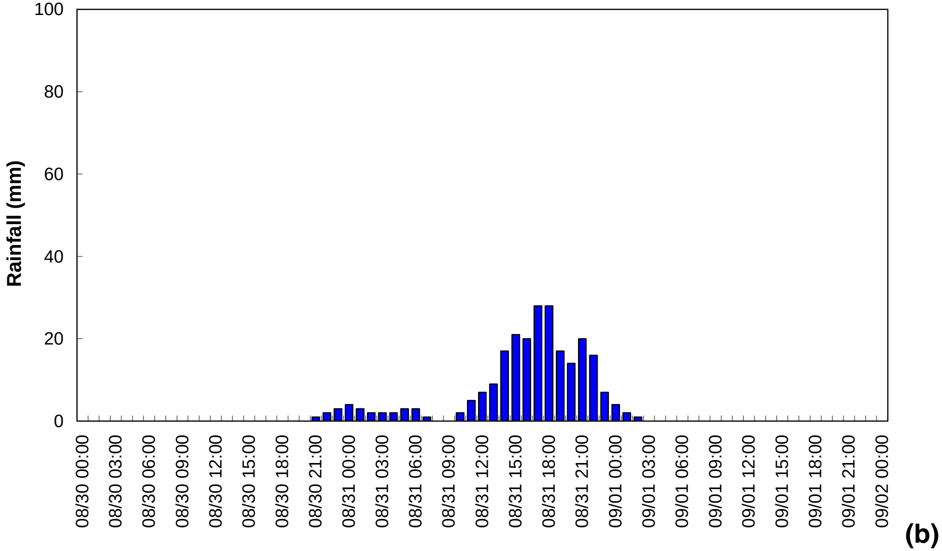

Fig. 5. Time distribution of rainfall in Gimcheon area **(b)** Gimcheon.

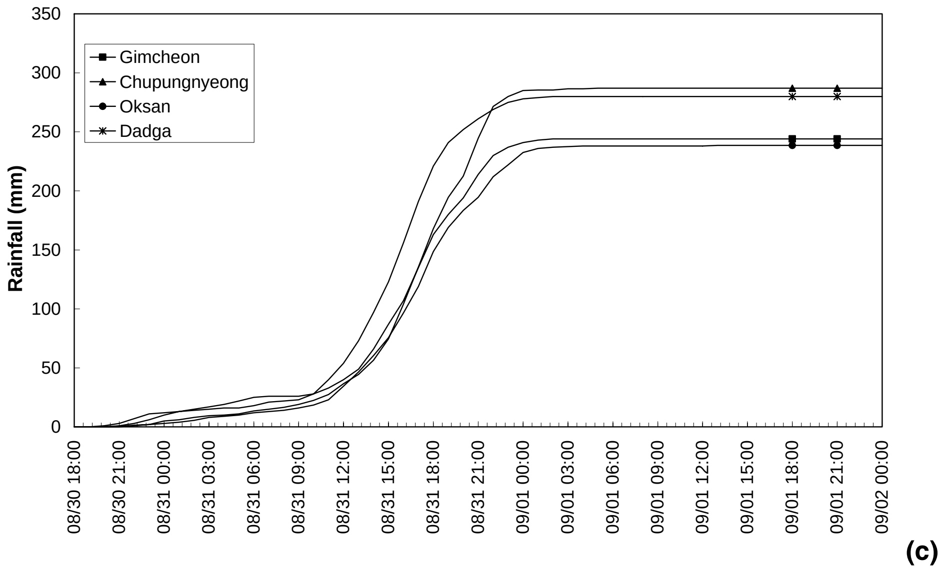

Fig. 5. Time distribution of rainfall in Gimcheon area **(c)** Cumulative rainfall.

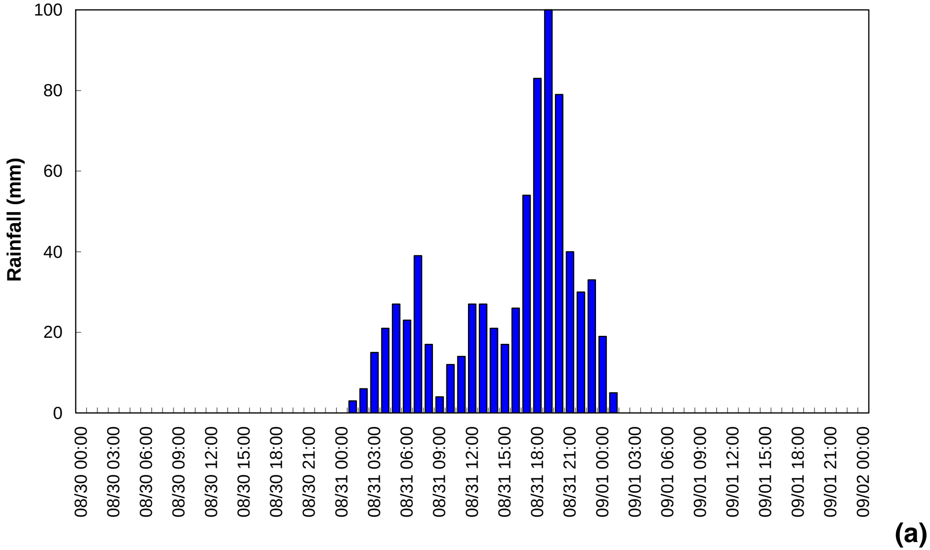

Fig. 6. Time distribution of rainfall in the Donghae/Samcheok area **(a)** Miro-Myeon.

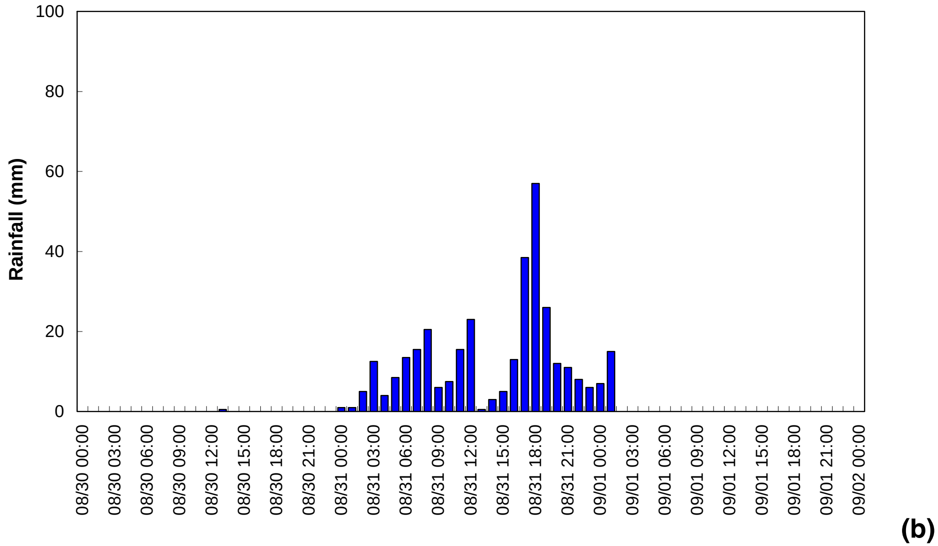

Fig. 6. Time distribution of rainfall in the Donghae/Samcheok area **(b)** Donghae.

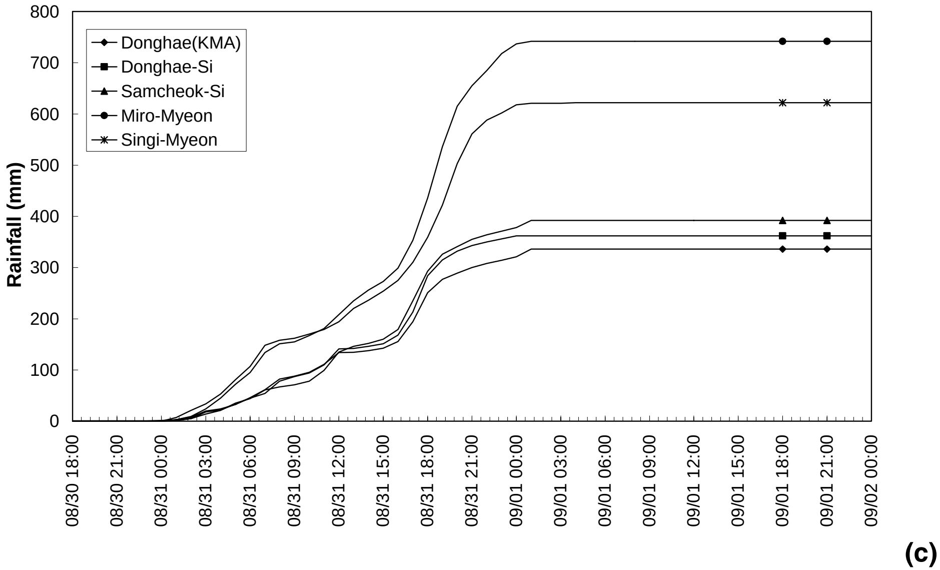

Fig. 6. Time distribution of rainfall in the Donghae/Samcheok area **(c)** Cumulative rainfall.

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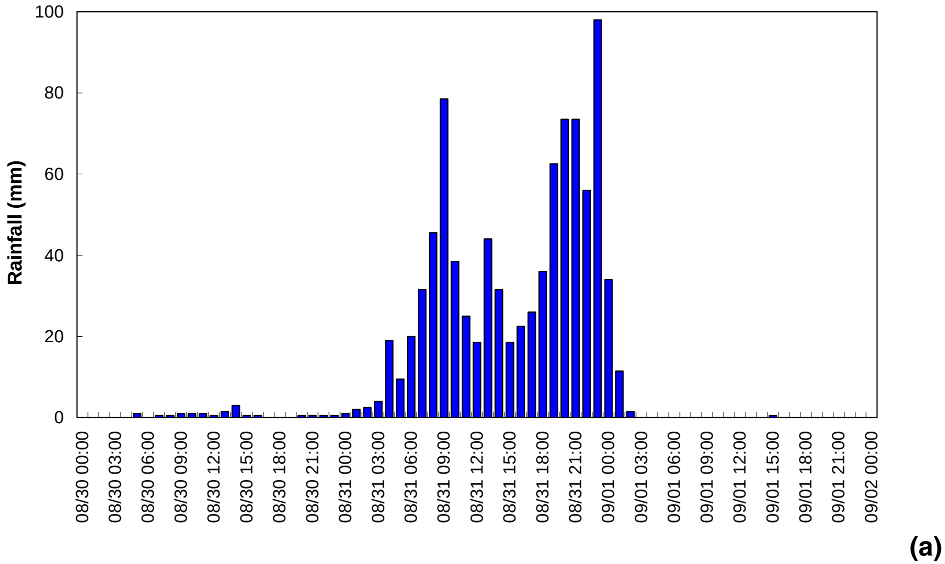

Fig. 7. Time distribution of rainfall in the Gangneung area **(a)** Gangneung.

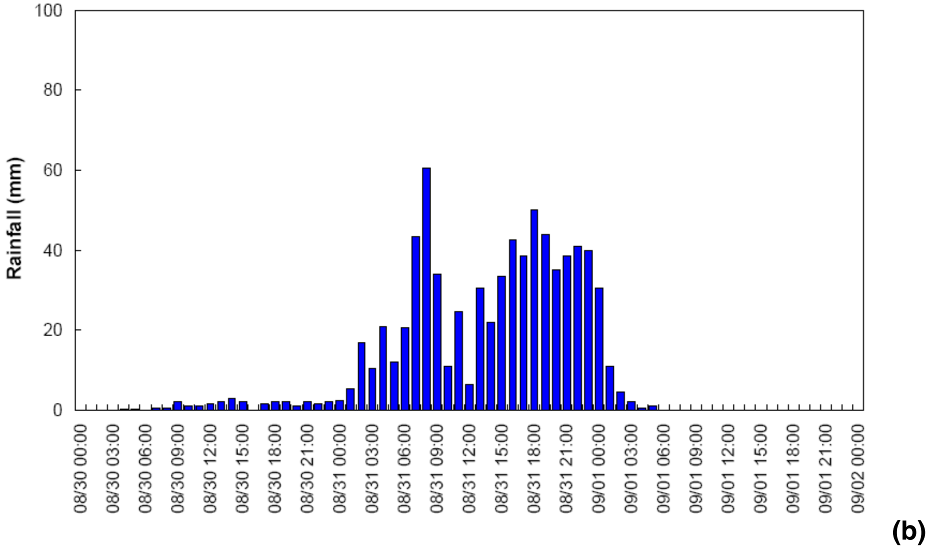

Fig. 7. Time distribution of rainfall in the Gangneung area **(b)** Daegwallyeong.

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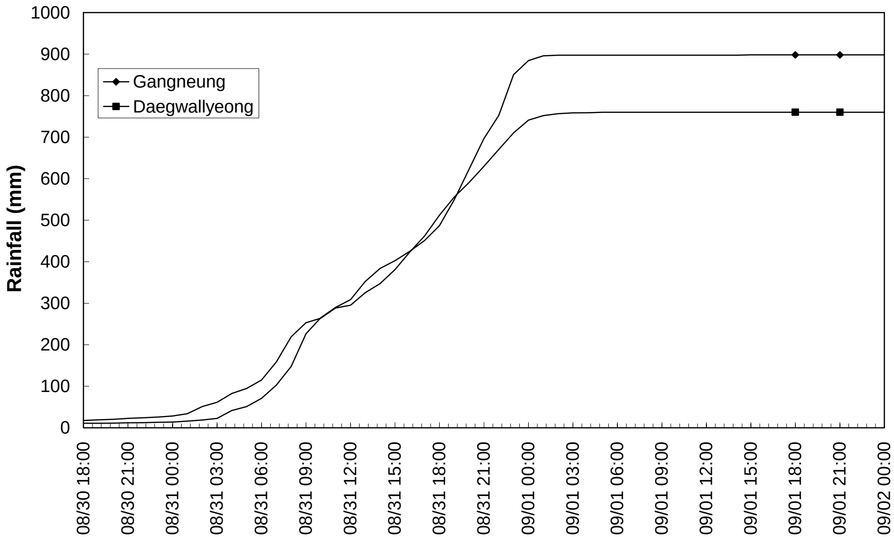

(c)

Fig. 7. Time distribution of rainfall in the Gangneung area **(c)** Cumulative rainfall.

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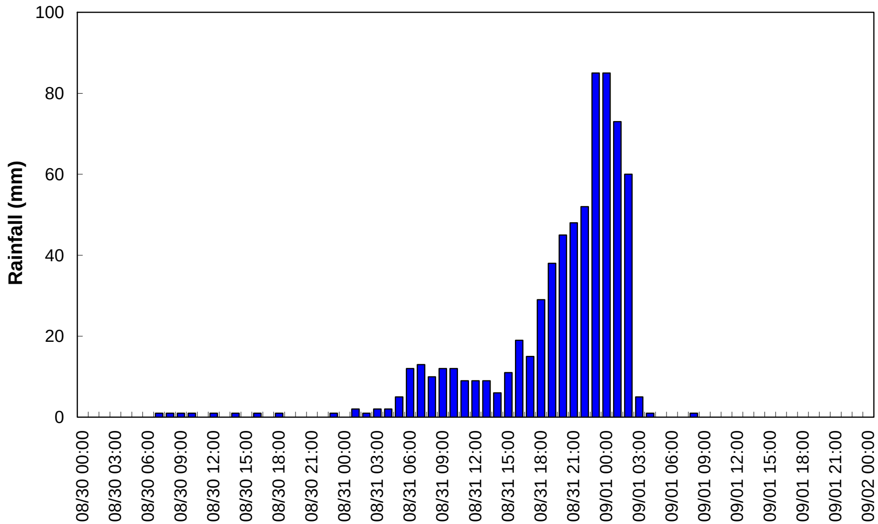

(a)

Fig. 8. Time distribution of rainfall in the Yangyang/Sokcho area **(a)** Yangyang.

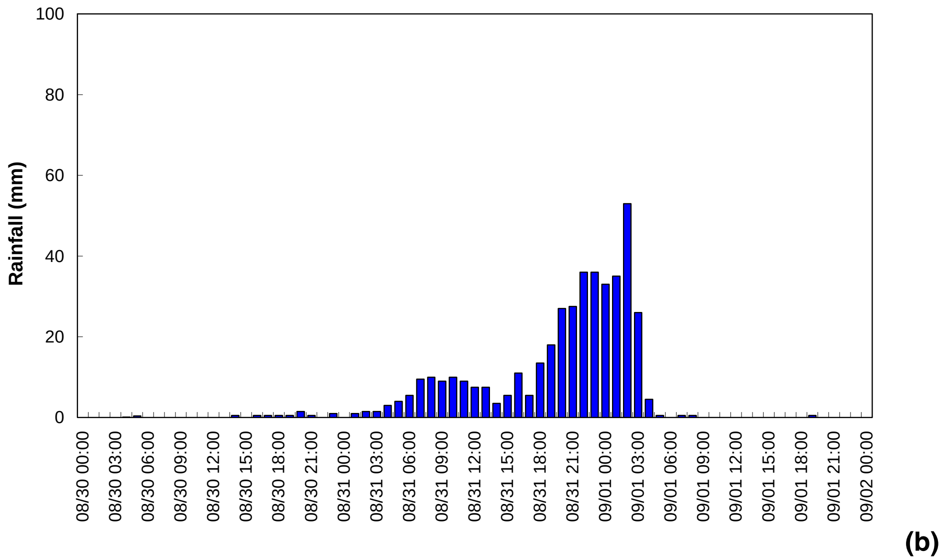

Fig. 8. Time distribution of rainfall in the Yangyang/Sokcho area **(b)** Sokcho.

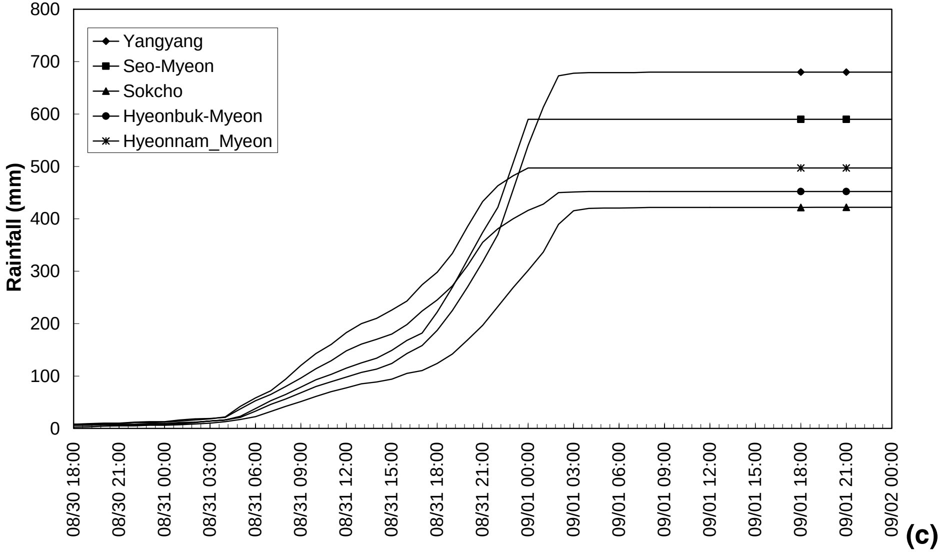

Fig. 8. Time distribution of rainfall in the Yangyang/Sokcho area **(c)** Cumulative rainfall.

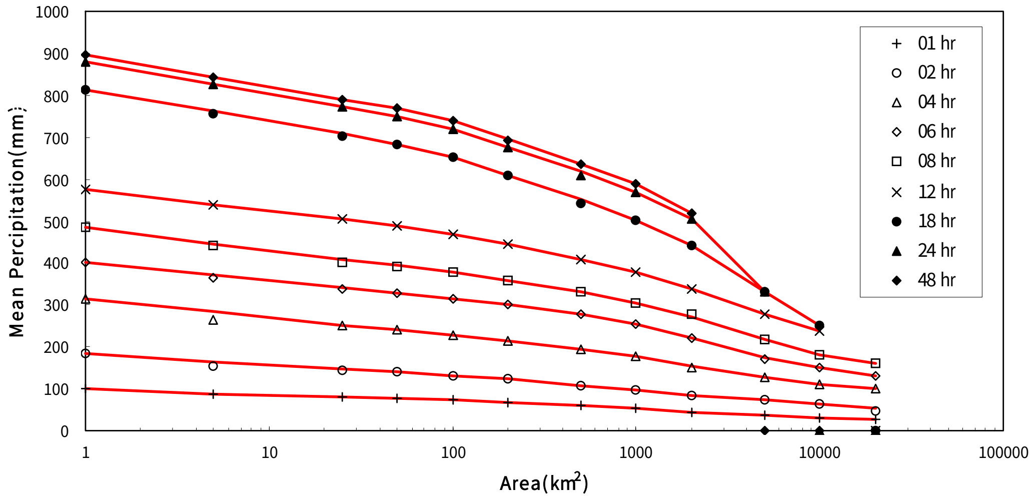

Fig. 9. DAD analysis result of the rainfall of RUSA.

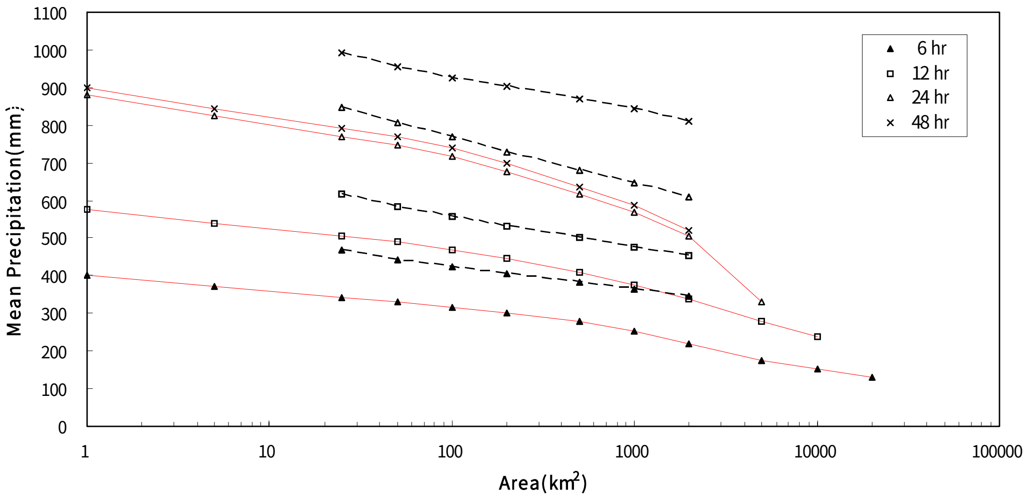

Fig. 10. Comparison between PMP of Gangneung and rainfall from the DAD analysis.

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