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ANALYSIS OF LONG-TERM CHANGE IN THE DEGREE OF TIME-CONCENTRATION OF RAINFALL IN JAPAN

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ABSTRACT

It has been suggested that torrential rainfall is likely to become more frequent due to the increasing severity of extreme weather events associated with climate change (IPCC, 2014).And the Japan Meteorological Agency (JMA) (2016)reported that the number of annual occurrences of short-term intense rainfall (for example, exceeding 50 mm/h) have increased in recent years.In Japan Automated Meteorological Data Acquisition System (hereafter AMeDAS; Meteorological Agency, Japan) started routine measurements of fundamental meteorological elements, including precipitation, from 1974 at approximately 1,300 observation stations throughout Japan. This report quantifies time-concentration of rainfall from hourly rainfall data collected by AMeDAS over 42 years in five areas of Japan, and analyzes the long-term changes. We collected hourly precipitation record from 80 stations that have more than a whole 40 years of record. Then we divided the record by a period without precipitation lasting at least 24 hours; and the divided precipitation series was defined as 'rainfall event'. We evaluated temporal intensities of each event by Sherman equation: $r_t = \frac{\mathrm{a}}{t^{\mathrm{c}}}$, where$r_t$: maximum *t*-hour rainfall intensity $(= R_t/t)$, R_t:maximum t-hour rainfall, and a, c:empirical coefficients $(\mathrm{a} = r_1)$. The coefficient *c* indicates the time-concentration of rainfall and can be easily understood by two extremes. If event rainfall fell in 1 hour within the event, c=1, while if event rainfall fell uniformly within 24 hours with $t = 24$ hours, c=0. Overall, this study revealed that the increasing trend of rainfall intensity even for the same 24-hour cumulative rainfall in part of Japan that could influence the regional water management.

Keywords: Rainfall characteristics, Time-concentration of rainfall, Automated Meteorological Data Acquisition System

1. INTRODUCTION

It has been suggested that torrential rainfall is likely to become more frequent due to the increasing severity of extreme weather events associated with climate change (IPCC, 2014), and there is concern about increasing flood damage. Recently, Japan has experienced flood damage almost every year, and some of this damage has occurred in the same areas year after year. It has been pointed out that, damage is increasing due to the spatial concentration of rainfall, flood damage will be magnified by an increase in the time-concentration (Ozaki et al., 2014). The Japan Meteorological Agency (JMA) (2016) reported that the number of annual occurrences of short-term intense rainfall (for example, exceeding 50 mm/h) has increased in recent years, but there are few studies that examine this trend from the perspective of time- concentration of each rainfall event. Matsuda et al. (2001) found that probable 1-hour rainfall can be estimated by normal transformation using time-concentration of rainfall, and the probability distribution of annual maximum rainfall at individual observation stations can be estimated easily using the proposed coefficient of the normal transformation equation. However, their analysis covered a period up to 1998, and recent time-concentrations have not been evaluated. Therefore, this report

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quantifies time-concentration of rainfall from hourly rainfall data collected by AMeDAS over 42 years in five areas of Japan, in accordance with Matsuda et al. (2001), and analyzes the long-term changes.

2. METHODS

2.1 Selection of Target Areas

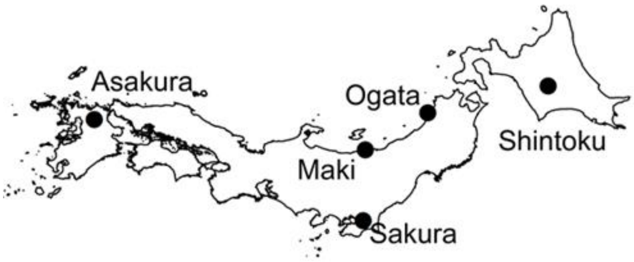


Figure 1. AMeDAS observation stations used

In Japan, JMA has established a regional meteorological observation system called AMeDAS (Automated Meteorological Data Acquisition System). AMeDAS currently measures the amount of precipitation at approximately 1,300 observation stations (at approximately 17 km intervals) throughout Japan. At approximately 840 of these stations (at approximately 21 km intervals), wind direction, wind speed, air temperature, and daylight hours are also measured, and snow depth is measured at approximately 320 stations in snowy regions.

In the AMeDAS precipitation measurements, snow, hail, etc. is melted to become liquid water and measured together with rain. Currently, precipitation is measured by tipping bucket rain gauges in 0.5 mm units, and the results are summarized as 10-minute precipitation, 1-hour precipitation, daily precipitation, etc.

In this report, the term “rainfall” is used to mean precipitation including snow and hail. Using the hourly rainfall data from AMeDAS between 1976 and 2017, the long-term changes in time-concentration of rainfall were analyzed.

We selected five areas as the target areas. These were areas that had recently suffered disasters caused by torrential rain (Tokachi and southern Kamikawa in Hokkaido, 2016; northern Kyushu, 2017), and low-lying areas where governmental land improvement projects (large-scale drainage improvement and land reclamation projects) had been implemented and drainage had become an issue during heavy rains. We selected AMeDAS observation stations at Shintoku, Ogata, Sakura, Maki, and Asakura as stations representative of each area (Figure 1). Also, because changes over time observed at each observation station may indicate trends that differ from adjacent observations stations, the local consistency of the trends was verified by performing the same analysis using data from AMeDAS observation stations surrounding each station: 23 stations around Shintoku, 25 stations around Ogata, 5 stations around Sakura, 10 stations around Maki, and 12 stations around Asakura were added, resulting in data from a total of 80 AMeDAS observation stations being analyzed.

2.2 Extraction of Rainfall Events and Data

JMA (2017) calls hourly rainfall exceeding 20 mm but less than 30 mm “heavy rain;” exceeding 30 mm but less than 50 mm “intense rain;” exceeding 50 mm but less than 80 mm “extremely intense rain;” and exceeding 80 mm “violent rain.” Also, as an approximate guide to the total amount and intensity of rain that will initiate a disaster, if approximately 10% of the rain expected to fall in one year falls all at once, it is considered to constitute a disaster (National Research Institute for Earth Science and Disaster Prevention, 2006). This guideline rainfall is approximately 100 mm in Hokkaido, and 200–300 mm on the Pacific Coast of western Japan, and major downpours occur frequently along the southern Pacific coast, with daily rainfall exceeding 100 mm on two to three days per year (National Research Institute for Earth Science and Disaster Prevention, 2006).

Therefore, this analysis was performed using 24-hour rainfall and 1-hour rainfall. First, rainfall events demarcated by more than 24 hours without rain were extracted from the collected hourly rainfall data. From each extracted rainfall event, the time of maximum 24-hour accumulated rainfall was identified, and the amount of rainfall during that period was extracted as the maximum 24-hour rainfall R_{24}, while the hourly rainfall with the maximum hourly rainfall intensity during that period was extracted as the maximum 1-hour rainfall R_1.

2.3 Indices of Time-Concentration of Rainfall and their Statistical Evaluation

The Sherman equation given in Equation (1) has been used as one relational equation of maximum *t*-hour rainfall intensity and rainfall duration *t* (Tanaka and Kadoya, 1979).

$$r_t = \frac{a}{t^{c}} \qquad (1).$$

Wherer_t: maximum *t*-hour rainfall intensity ($= R_t/t$), R_t: maximum *t*-hour rainfall, and a, c: coefficients ($a = r_1$). When R_t is fixed, c=1 means that $R_1 = R_t$, i.e. the total rainfall was concentrated in one unit of time; whereas, c=0 means that $r_1 = r_t$, i.e. the rain fell with uniform intensity in all units of time during the period (Matsuda et al., 2001). Therefore, coefficient c from Equation 1 was used as a relative index and R_1 was used as an absolute index for quantifying time-concentration of rainfall.
Coefficient c was calculated for each extracted rainfall event using Equation (1) with $t = 24$ hours, and the change at each site was analyzed by dividing the events into two periods: 1976–1996 (hereafter, early period) and 1997–2017 (hereafter, late period).

Transforming Equation (1) gives:

$$c = \frac{\log_{10}(r_1/r_{24})}{\log_{10} 24} = \frac{\log_{10}(R_1 \cdot 24)}{\log_{10} 24} - \frac{1}{\log_{10} 24} \cdot \log_{10}(R_{24}) \qquad (2)$$

Table 1. ξ and return period N

N (years)	ξ
2	0.0000
10	0.9062
20	1.1630
50	1.4520
100	1.6450
200	1.8215
500	2.0350
1000	2.1850

This shows that when R_1 is constant, as R_{24} becomes larger, c becomes smaller. In other words, the case in which c is close to 1 and rainfall is concentrated in a short time period is common when R_{24} is relatively small but disappears as R_{24} becomes larger.

Coefficient c is characterized by a lower limit of 0 and an upper limit of 1, and therefore c was transformed into a normal variable using the Slade Type III expression for normal transformation (Iwai and Ishiguro, 1970), which allows upper and lower limits. Specifically, the below coefficients α, g, c_0 of the estimation equation for probable 1-hour rainfall were found using AMeDASrainfall amounts for all of Japan for 23 years from 1976 to 1998, and using those coefficients, the value of c was normalized to ξ.

$$\xi = \alpha \log_{10}\left(\frac{c(g-c_0)}{c_0(g-c)}\right)$$
$$\alpha = 0.8646\log_{10}(R_{24}) + 1.6273$$
$$g = -0.1277\log_{10}(R_{24}) + 1.5706$$
$$c_0 = -0.178\log_{10}(R_{24}) + 0.812$$

Then, the 1/N exceedance probability was found from the relationship between the normalized index ξ and the return period N (Table 1) (Iwai and Ishiguro, 1970). Here, events with a large N-value are events with a low frequency in terms oftime-concentration c.

2.4 Analysis of Changes During the Evaluation Period

When the relationship between R_{24} and R_1 for all rainfall events during the evaluation period at an observation station is displayed, the data is distributed between the lines c=1 and c=0, as in Figure 2. The influence of the small rainfall events that occur frequently (bottom-left area of Figure 2) would dominate if the change in all rainfall events were evaluated, and so this influence must be removed. Also, the kind of rainfall that causes disasters generally occurs when R_{24} and R_1 are large. Therefore, changes during the evaluation period were analyzed by extracting rainfall events using the following methods.

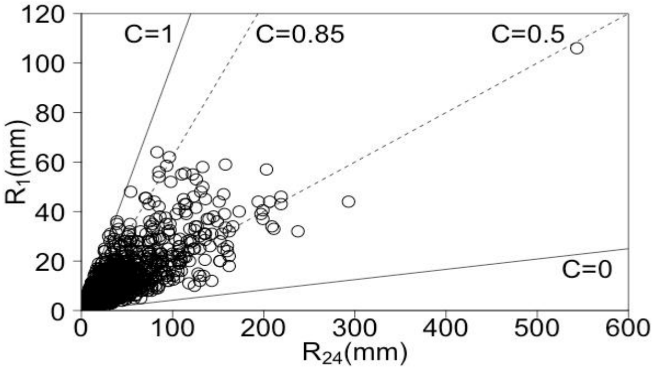


Figure 2. Relationship between$\boldsymbol{R_{24}}$ and$\boldsymbol{R_1}$ at Asakura observation station (all data plots)

(1) Extraction by top ten R_{24} and R_1 (ranking extraction method)

The rainfall events with the top ten highest values of R_{24} and R_1 are extracted respectively from the entire observation period at each observation station. In this case, the same events can be ranked as top 10for both R_{24} and R_1, or a few event scan be ranked in the same order, thus the number of data extract will not necessarily be 20.

(2) Extraction by exceedance probability of c (probability extraction method)

Rainfall events for which the exceedance probability of c is 1/50 or below are extracted from the entire observation period at each observation station.

3. RESULTS AND DISCUSSION

3.1 Trends in Rainfall Event Frequency

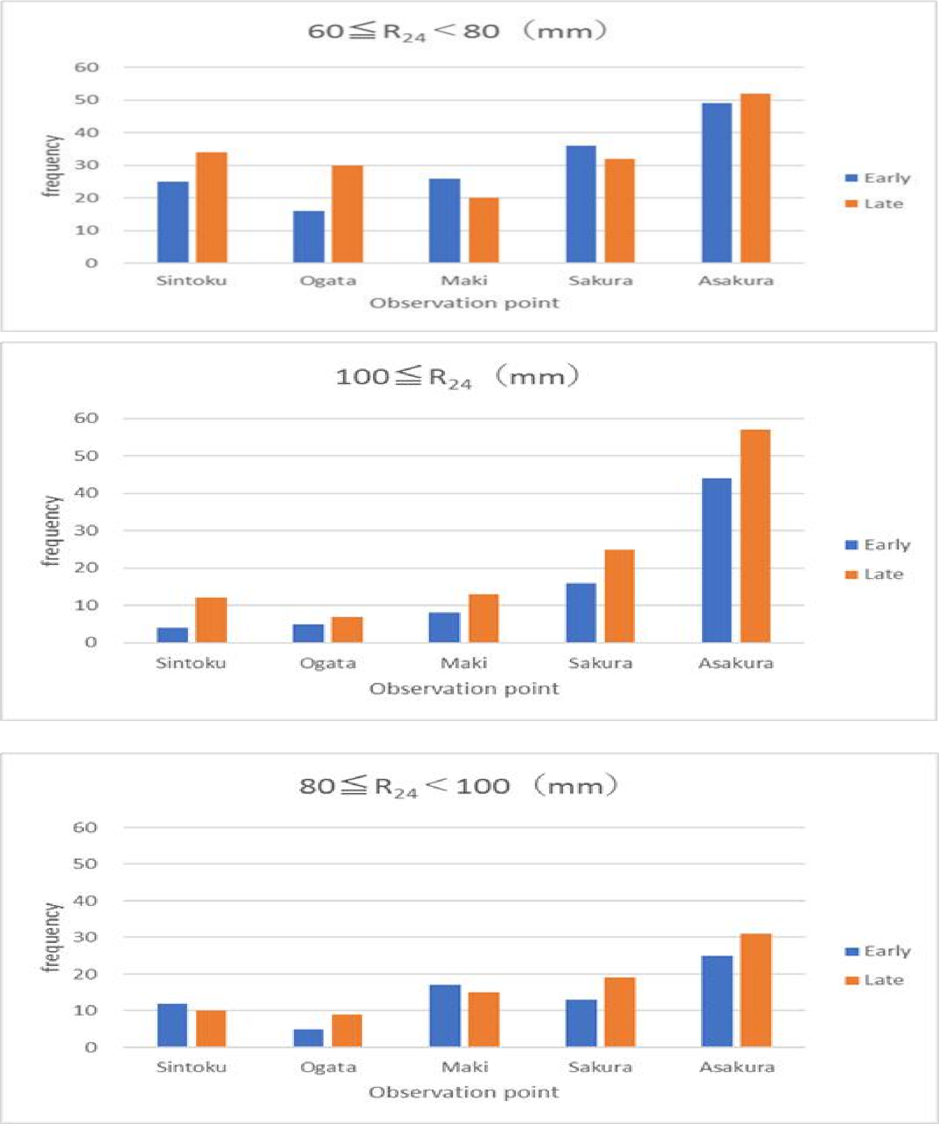


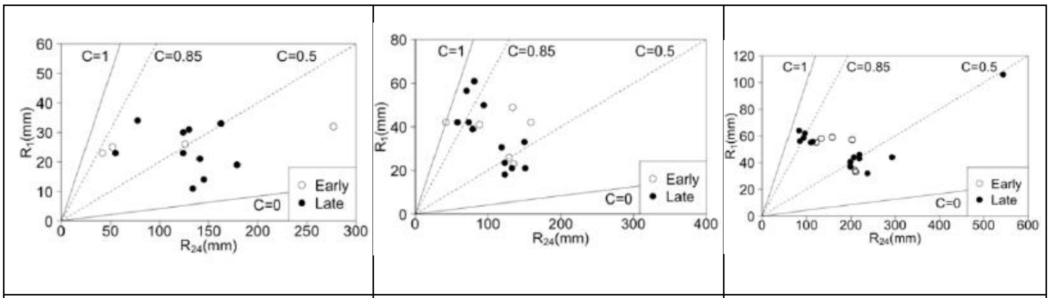
Figure 3. Changes in number of rainfall events

Table 2. Situation regarding observation of $R_{24} \geq 100$mm (from early to late period)

Obs. point	Incr.	Equal	Decr.	Total
Shintoku	23	1		24
Ogata	22		4	26
Sakura	6			6
Maki	10		1	11
Asakura	11	1	1	13
Total	72	2	6	80
（the number of observated rainfall）				

Dividing R_{24} into three classes according to rainfall (60–80 mm, 80–100 mm, greater than 100 mm) for each representative observation station in the five target areas, Figure 3 shows the changes in the number of rainfall events during the evaluation period for each class. The figure shows that the number of rainfall events with a value of R_{24} greater than 100 mm increased at all of the observation stations (Shintoku: increased from 4(early) to 12 (late)events, Ogata: from 5 to 7 events, Maki: from 8 to 13 events, Sakura: from 16 to 25 events, and Asakura: from 44 to 57 events). The differences observed in the classes with R_{24} of moderate size (60–80 mm and 80–100 mm) are not as striking as in the "greater than 100 mm" class, but the number of rainfall eventsincreased in both classes at Ogata and Asakura. he situation regarding observation of rainfall events with R_{24} greater than 100 mm at allthe observation stations. The number of observations increased at 72 of the 80 observation stations, remained the same at 2 observation stations, and decreased at 6observation stations. The stations where observations increased account for 90% of the total, and even at the stations were observations decreased, the decreases were not pronounced, and there for the overall trend can be increasing. This result means that the data at each observation station is consistent with the increasing trend in heavy rainfall events in the Japan region reported in the Climate Change Monitoring Report (JMA, 2016) as “the annual number of days with daily rainfall of 100 mm or more has increased in 116 years from 1901 to 2016.”

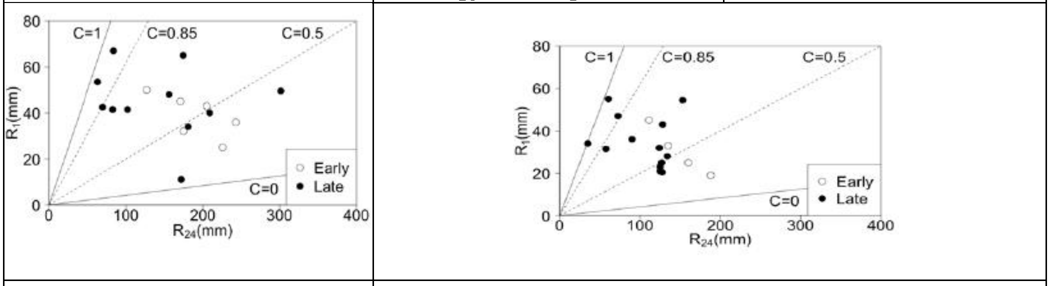
3.2 Changes in R_{24} and R_1 Using the Ranking Extraction Method



(A) Shintoku: Early 4, Late 10
R_{24}≥124.0, R_1≥23.0)

(B) Ogata: Early 6, Late 12（
R_{24}≥118.5, R_1≥39.0）

(C) Sakura: Early 6, Late 11
（R_{24}≥171.0, R_1≥41.5）



(D) Maki: Early 4, Late 13
（R_{24}≥125.0, R_1≥31.5）

(E) Asakura: Early 6, Late 14
（R_{24}≥199.0, R_1≥55.0）

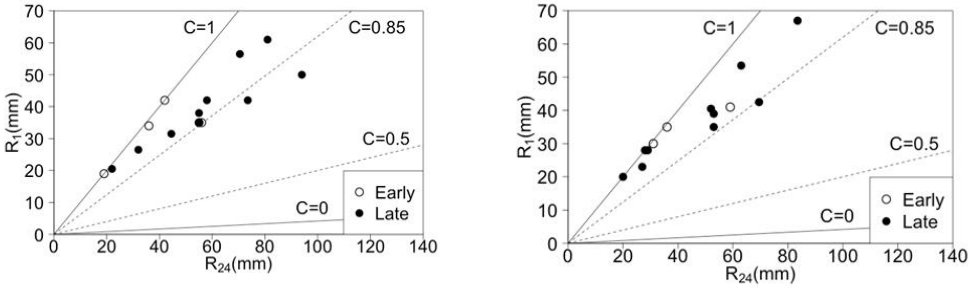
Figure 4. Relationship betweenR_{24}andR_1at representative observation stations (ranking extraction method)

The rainfall events with the top ten highest values of R_{24} and R_1 respectively were extracted at each observation station, and Figure 4 shows the relationship between R_{24} and R_1.

The number of rainfall events increased in the late period compared to the early period at all the observation stations (Shintoku: increased from 4 (early) to 10 (late) events, Ogata: from 6 to 12 events, Sakura: from 6 to 11 events, Maki: from 4 to 13 events, and Asakura: from 6 to 14 events). It is also notable that, at all the observation stations except for Shintoku, late period events accounted for most of the c-values between 0.85 and 1 among the R_1 top ten. Meanwhile, about the R_{24} top ten, the c-values were less than 0.85 at all the observation stations. At Shintoku and Asakura, most of the c-values were below 0.5, and there were more events in the late period than the early period. In contrast, at Ogata, Sakura, and Maki, the c-values were widely distributed on either side of the 0.5 line, and except at Maki, the difference between the number of events in the early and late periods was not as striking as at Shintoku and Asakura.

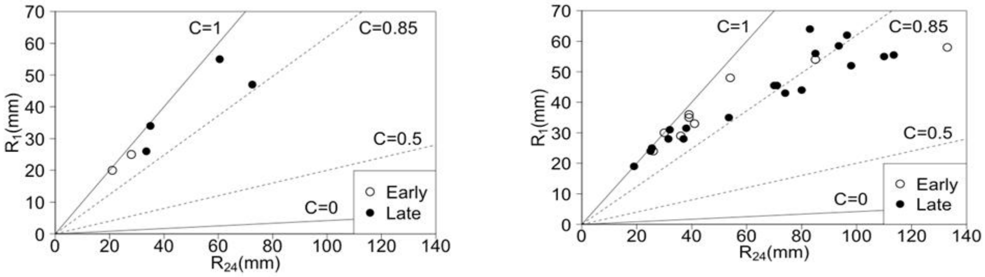
3.3 Changes in R_{24} and R_1 Using the Probability Extraction Method

Next, rainfall events for which the exceedance probability of c was less than 1/50 at each observation station were extracted, and Figure 5 shows the relationship between R_{24} and R_1.



(a) Ogata: Early 5, Late 10

(b) Sakura: Early 3, Late 10



(c) Maki: Early 2, Late 4

(d) Asakura: Early 9, Late 19

Figure 5. Relationship between R_{24} and R_1 at representative observation stations (probability extraction method)

There were no rainfall events corresponding to N ≥50 at Shintoku, and therefore the figure shows the results for the other 4 observation stations. At all four observation stations, there were rainfall events corresponding to heavy rain of R_1 ≥20 mm, and there was a tendency for c to decrease with increasing R_{24} and R_1. Also, at all four stations, both in terms of all results and in terms of c ≥0.85, the number of corresponding rainfall events increased in the late period compared to the early period.

Here, looking at the range of high R_{24} and R_1 (R_{24} ≥60 mm, R_1 ≥40 mm), it is evident that most of the rainfall events were in the late period. Considering events ofN ≥50 are events with a low frequency in terms of time-concentration c, this clearly indicates that events in which the rain falls in a manner that was unusual in the early period in terms of time-concentration of rainfall have increased recently in the range of high R_{24} and R_1.

However, the coefficients used to find N in this study were determined using AMeDAS rainfall amounts for all of Japan for 23 years from 1976 to 1998, according to Matsuda et al. (2001). This period is not identical to the AMeDAS observation period used for evaluation in this study, and the effects of this must be kept in mind. Also, the fact that the number of extracted events differed at each station and was particularly small at Maki, where only 6 events were extracted, suggests that the transformation coefficient of c also differs locally. This is a topic for future research.

Next, Figure 6 shows how R_{24} changed from the early period to the late period for the rainfall events extracted in Figure 5.

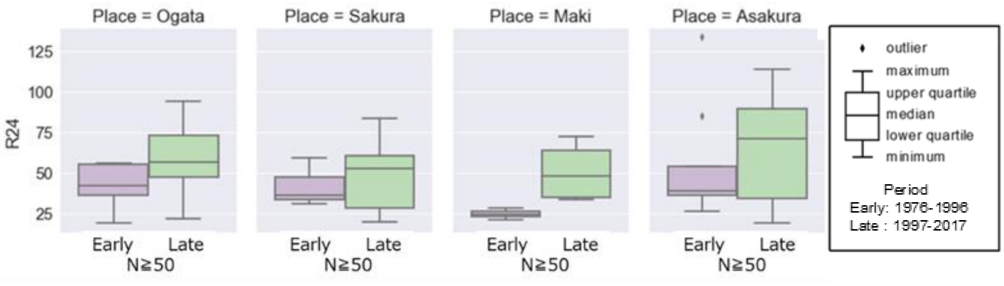


Figure 6. Change in$\boldsymbol{R_{24}}$at representative observation stations (probability extraction method)

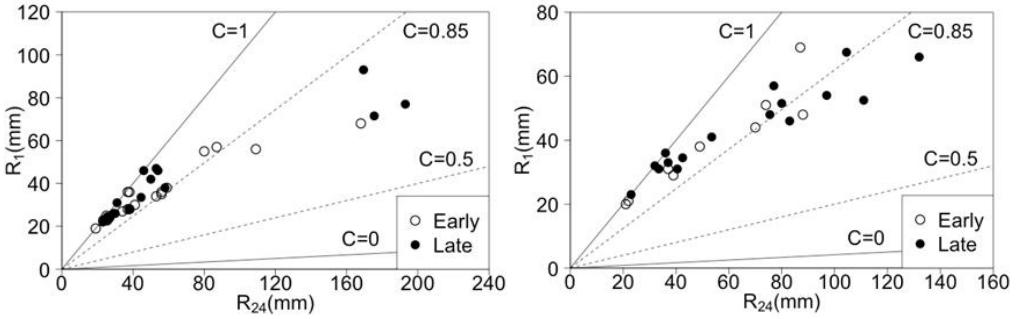
At all observation stations, both the median value and the upper quartile value increased. If the events regarded as outliers in the early period at Asakura are excluded, the maximum value also increased at all stations.

Combining these results, it is evident that rainfall events with high time-concentration c tended to increase in the late period at the representative observation stations (Figure 4), and examining the rainfall events with high time-concentration, it is evident that both 24-hour rainfall and 1-hour rainfall increased in the late period (Figures 5 and 6).

To investigate whether this trend occurred at the representative observation station only or similar trends were observed in the surrounding area, the same diagrams were drawn for four observation stations near to the Asakura observation station (Dazaifu, Kurume, Hita, and Soeda) (Figures 7 and 8).

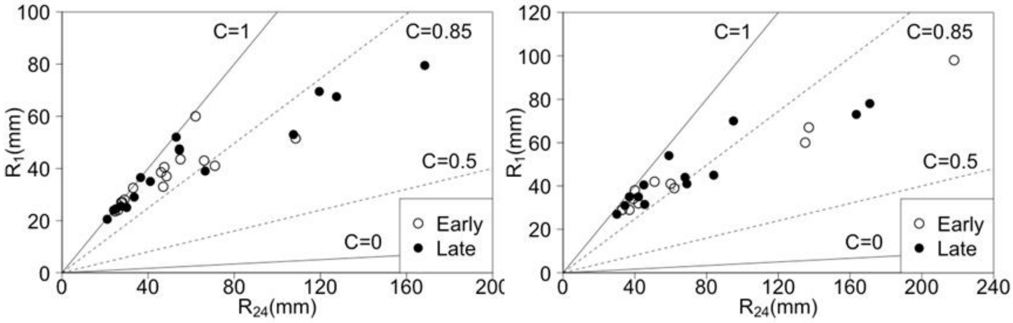
The number of rainfall events extracted using the probability extraction method increased in the late period compared to the early period at all stations around Asakura. However, with the exception of Kurume, the differences between the early and late periods were smaller than at Asakura (Asakura: increased from 9 (early) to 19 (late) events, Dazaifu: from 16 to 19 events, Kurume: from 9 to 16 events, Hita: from 15 to 16 events, and Soeda: from 11 to 13 events). Here, looking at the range of high R_{24} and R_1 (R_{24} ≥60 mm, R_1 ≥40 mm), the rainfall tended to increase in the late period at Kurume and Hita. However, at Dazaifu and Soeda, the rainfall can be described as greater in the early period, or similar in the early and late periods.

In Figure 8, no upward trend is seen in the box part of the figure from the early to the late period at Dazaifu or Soeda. However, this is considered to be influenced by the fact that extremely large values of R_{24} were treated as outliers. Although there is almost no change in the median value in the early and late periods at Hita, it is thought that overall, from the early period to the late period, rainfall events with a scale of R_{24} that has never been seen before for the size of R_1 are starting to be observed at Hita and Kurume.



(a) Dazaifu: Early 16,

(b) Kurume: Early 9, Late 16



(c)Hita: Early 15, Late 16

(d)Soeda: Early 11, Late 13

Figure 7. Relationship between R_{24} and R_1 at observation stations around Asakura (probability extraction method)

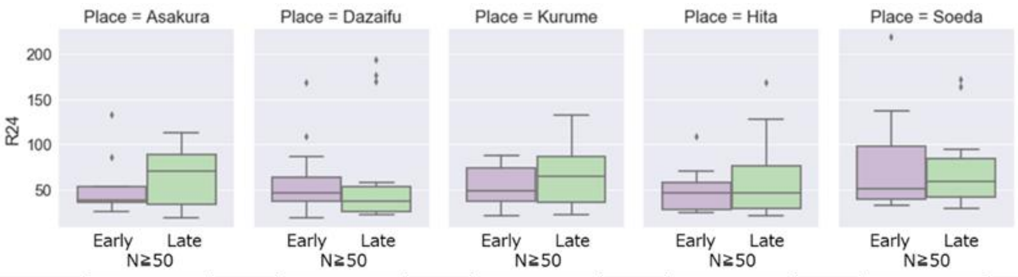


Figure 8. Change in R_{24} at observation stations around Asakura (probability extraction method)

The above results show that trends in time-concentration of rainfall differ from region to region. This suggests that these kind of changes over time in events with high time-concentration differ for each observation station, and a more detailed investigation is required.

4. CONCLUSIONS

This report quantified time-concentration of rainfall from hourly rainfall data over 42 years at weather observation stations in five areas of Japan, and analyzed the long-term changes. Overall, the results showed that rainfall with unprecedented high time-concentration has been observed in recent years and confirmed an upward trend in short-term intense rainfall.

However, differences in rainfall characteristics by region were found in part of this study. In particular, among the representative observation stations in the five target areas, Shintoku, Ogata, and Maki were located in snowy areas. In the AMeDAS precipitation measurements, snow, hail, etc. is melted to become liquid water and measured together with rain. This could have affected the results, and therefore a seasonal analysis is a future task. Also, the effects that these changes in time-concentration will have on the management of drainage facilities must be clarified.

5. REFERENCES

IPCC (2014): Outline of the IPCC Fifth Assessment Report-First working group (natural science basis)-, pp.27–30, Ministry of the Environment, Japan 2014(December 2014 version),http://www.env.go.jp/earth/ipcc/5th/pdf/ar5_wg1_overview_presentation.pdf, 04/16/2019.

Taira OZAKI, Norihiro ASANO, Taisuke ISHIGAKI, and Keiichi TODA (2014): Characteristics of Underground Mall Inundation by Flash Flooding in Short-Term Heavy Rainfall, Journal of Japan Society of Civil Engineers, Series B1 (Hydraulic Engineering), Vol. 70, No.4, I_1417–I_1422.

Japan Meteorological Agency (2016): Climate Change Monitoring Report 2016, pp.42–43.

Seisuke MATSUDA, Kunio OHTOSHI, Taku FUJIWARA, and Yongqiang QI (2001): A Method of Estimating Probable Precipitation, Journal of Japan Society of Hydrology & Water Resources, Vol. 14, No. 4, pp. 307-316.

Japan Meteorological Agency (2017): Weather Forecast Terminology—Intensity and Manner of Rainfall, http://www.jma/kishou/know/yougo_hp/amehyo.html, 04/16/2019.

National Research Institute for Earth Science and Disaster Prevention (2006): Disaster Prevention Basic Course—Fundamental Knowledge Edition, https://dil.bosai.go.jp/workshop/01kouza_kiso/ohame/rain.htm, 04/16/2019.

Reijiro TANAKA and Mutsumi KADOYA (1979):Study on the Rainfall Intensity Formula with three Parameters, Trans. Of JSIDRE, No.83, pp.1-8.

Shigehisa IWAI and Masayoshi ISHIGURO, Ouyousuimontoukeigaku (Applied Hydrological Statistics), p.68, Morikita Publishing Co., Ltd.