



# Up-to-date urban rainstorm intensity formulas considering spatial diversity in China

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## Abstract

With accelerating urbanization in China, urban waterlogging has had a serious impact on urban sustainable development and citizen welfare. Simple urban rainstorm intensity formulas with a monotonous frequency distribution type cannot meet the practical needs of urban drainage planning and design. This study focuses on the development of urban rainstorm intensity formulas based on spatial diversity in China. Using the annual maximum sampling method, rainstorm data of 607 cities throughout China were collected into a database, with a total of 24,933 rainfall samples (annual observations) under various specified precipitation durations. The database was used to verify that integrating the Pearson III and Gumbel distributions would constitute an optimal theoretical distribution type, owing to its small error and increased fitting precision. Modification and coordination of four important parameters in the rainstorm intensity formula were done using a digital elevation model, which improved the accuracy of the formula. In addition, precipitation distributions in China were treated from the perspective of topographic features to validate the calculations from up-to-date formulas. Accuracy assessment was accomplished using a national code (GB-50014-2006), GIS-based isograms, and authoritative results from the Hydrological Bureau of the Ministry of Water Resources. This work provides a comprehensive foundation for the establishment of an up-to-date rainstorm intensity formula for China, which can be used widely in different cities.

**Keywords** Rainstorm intensity formula · Theoretical frequency distribution · GIS-based isograms · Parameter modification · Spatial diversity

## Introduction

Urban rainstorm intensity formulas have been regarded as a major technical basis for analysing storm-water management systems, rainwater sewers and detention, and precipitation calculation in infrastructure construction, within the fields of

municipal planning, transportation, and architectural design. Because of accelerating urbanization and climate change, the increased frequency of extreme rainstorm events and rainstorm-related disasters has resulted in greater attention to the assessment and management of flood risk in urban areas (Freni et al. 2010). It has been reported by the Intergovernmental Panel on Climate Change (IPCC 2012) that by the end of twenty-first century, the occurrence of extreme rainfall events will become more frequent, with a reduction in the return period of an annual maximum precipitation amount. Urban floods typically stem from a complex combination of causes, including the capacity limitation of drainage systems during high-intensity rainfall, reduced permeability of soil in groundwater recharge areas due to constant urban expansion, and improper planning or competing demands on land use (Jha et al. 2012). Urban flooding and rainstorm-related disasters have resulted in tremendous economic loss and social problems. According to statistics, in 2016, 192 cities in China were flooded or damaged by waterlogging, which resulted in a direct economic

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loss of ¥364.33 billion (around \$54.16 billion), accounting for 0.49% of GDP in that year (The Ministry of Water Resources, PRC 2016). Loss in the Greater Toronto Area was roughly \$1 billion in 2013 (Insurance Bureau of Canada, 2015). Rapid urbanization and an unpredictable, changing climate requires a more accurate technical approach for the integration of flood risk management.

Research has built a solid theoretical foundation for urban rainstorm intensity formulas, with a focus on the relationship of intensity–duration–frequency (IDF). The expression of IDF relationships summarizes precipitation intensities for different durations and return periods (Chow et al. 1988). Based on historical measurements, relationships of IDF may be directly estimated and calculated for both point rainfall and spatial averages (Arnbjerg-Nielsen et al. 2013). Bayesian analysis was used to discover the relationship between uncertainties in IDF curves and risk of their misinterpretation (Huard et al. 2010). Weinerowaska-bords (2015) stated that typical IDF relationships do not provide a satisfactory fit between simulation and observation and advised more complex formulas with additional parameters. It could also be a means to review and update rainfall characteristics in future climate scenarios. However, developing future IDF curves that depend on only historical data are unjustifiable (Simonovic et al. 2016). More studies have determined the uncertainties of extreme precipitation IDF curves on the basis of future projections (DeGaetano and Castellano 2017; Tfwala et al. 2017; Mondal and Mujumdar 2017). Uncertainty of benchmarking periods in bias correction of future climate projections should not be ignored (Fadhel et al. 2017).

Research on simple urban rainstorm intensity formulas in China dates to the 1970s (Deng 1979). Theoretically, the mathematical expression described in Code for Design of Outdoor Wastewater Engineering GB-50014-2006 (revised in 2016)<sup>1</sup> (MOHURD et al. 2016) is

$$q = \frac{167 \times A_1 (1 + C \lg P)}{(t + b)^n}, \quad (1)$$

where  $q$  denotes the design rainstorm intensity [L/(s·hm<sup>2</sup>)];  $t$  indicates rainfall duration (min);  $P$  represents the design return period (year); and  $A_1$ ,  $C$ ,  $b$ , and  $n$  are four important parameters that should be derived and modified using the Gauss–Newton iterative algorithm. The accuracy of such formulas determines the feasibility of rainstorm drainage system design and the rationality of construction investment. The formulas require data analysis, frequency distribution features, theoretical frequency distribution types, and modification of four of their important parameters  $A_1$ ,  $C$ ,  $b$ , and  $n$ . Simple urban rainstorm formulas were established in China

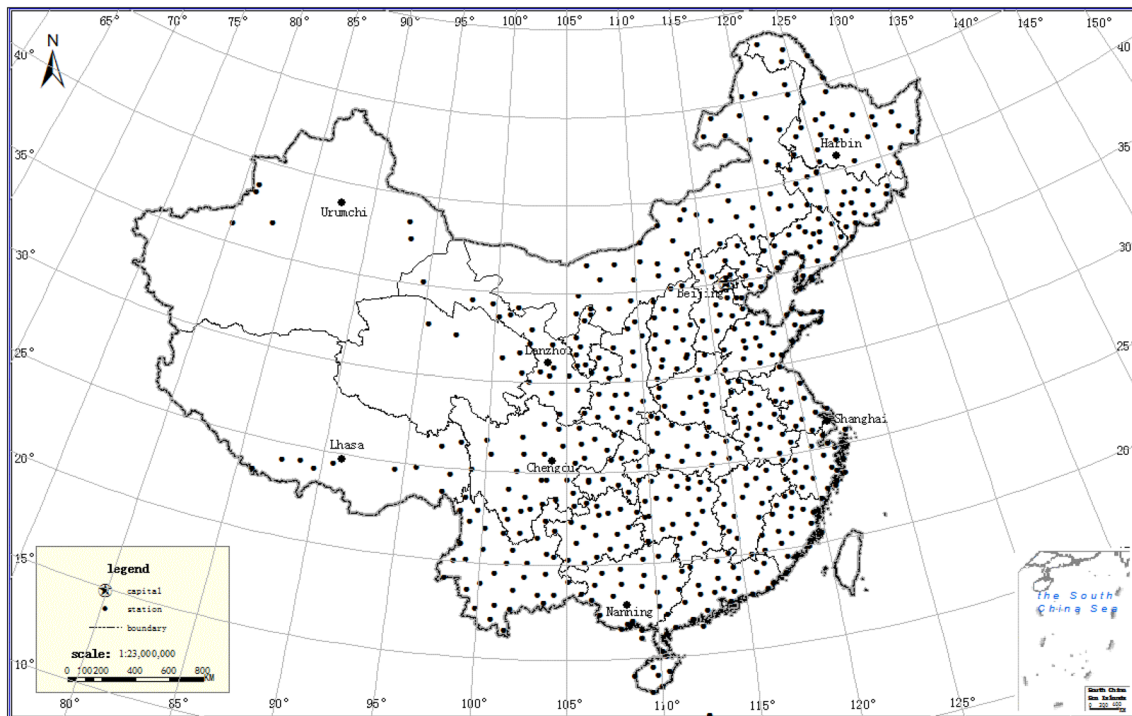
during the 1980s, with a single-frequency distribution type. However, one formula with four parameters cannot satisfy practical needs, due to inadequate data series, less representative sampling, and imperfect theoretical methods. On the spatial scale, one formula with four parameters might work locally, but more parameters might be required to obtain a formula that would be applicable at the regional scale. In addition, for the sampling method in particular, the commonly used annual multi-sampling method resulted in uncertainty of the rainstorm standard and less measurement of design frequency, which ultimately influenced the statistical accuracy of design rainstorm intensity (Shao et al. 2012). Therefore, formulas with more accurate parameters as well as their variations on the spatial scale must be a focus.

Several studies have shown that the spatial and temporal distributions of precipitation are uneven, given specific geographic features and climatic conditions (Deng et al. 2017; Shi et al. 2016; Wang et al. 2015). This would lead to discrepancies of precipitation among cities of various scales. Considering the spatiotemporal precipitation distribution, analysis considering spatial diversity in China is an alternative means to visualize and validate such formulas. From the aspects of drainage area, urban terrain, local climate, rainfall region classification, intensity statistics and mapping, and GIS-based platforms can be relied on to probe several factors related to the rainfall distribution, including geography, terrain, and rainfall patterns. Rainfall data from national meteorological and hydrological departments are used in the present analysis, assuring formula accuracy. Geographic factors, including geomorphology, inland underlying surfaces, and local climate, are also necessary to analyse urban rainstorm intensity.

Based on practical and theoretical needs, the objectives of this study are to (1) enhance and validate the accuracy of urban rainstorm intensity formulas, particularly that of four important parameters, considering the spatial diversity in China; (2) identify a more preferred sampling method to ascertain the fitting accuracy among various theoretical frequency distributions; (3) develop a more preferred theoretical distribution type as a foundation to modify the four important parameters for up-to-date urban rainstorm intensity formulas; and (4) validate the formulas and parameters using a national code (GB-50014-2006), GIS-based isograms, and authoritative results from the Hydrological Bureau of the Ministry of Water Resources.

On the basis of the above, this study consists of the following parts. After introducing the necessity of the research in the context of urbanization and severe impact from urban waterlogging, part 2 describes characteristics of the data collection, sampling methods, and frequency distribution types. Part 3 provides the results of selecting the proper sampling methods and frequency distribution types as well as the topographic features and spatial

<sup>1</sup> CDOWE for short.



**Fig. 1** Distribution of 607 rainfall observation sites in China

distribution of precipitation. Afterwards, validation assessment of formulas and parameters is discussed. Part 4 offers a review of the research results.

## Methodology

In general, results were obtained from the database of 607 cities in China using the proper sampling method. Research was conducted according to the following steps. First, process the data into annual series of maximum intensities for various durations with the annual maximum sampling method; second, calculate and compare the statistical elements ( $\sigma_{\text{abs}}$  absolute mean square error and  $\sigma_{\text{rel}}$  relative mean square error) necessary for sampling method selection; and third, calculate and compare  $\sigma_{\text{abs}}$  and  $\sigma_{\text{rel}}$  necessary for preferred frequency distribution types. Finally, accuracy and reliability of the up-to-date rainstorm intensity formulas are discussed. A digital elevation model was used to improve the accuracy of isograms by computing elevations, gradients, and exposures, and to validate the formula. Topographically based precipitation features, with the aid of a digital topographic map (1:250,000) officially provided by the State Bureau of Surveying and Mapping, will also be discussed to validate the accuracy of the formulas.

## Data

There are more than 4000 observation sites in China. Each has an associated database of standardized observations and contains a complete data series. The data reveal the rainstorm intensity distribution in a given urban area. We selected 607 rainfall observation sites after screening, scattered over 31 provinces and autonomous regions in China (Fig. 1).

The data series were constructed using the annual maximum sampling method, giving a total of 24,933 annual rainfall observations according to various precipitation durations. This series corresponds to years 1957 through 2006, and 90% of the data were from 1961 to 2006. The observation sites are all state-run and installed early in the period. Data series from the sites are complete and continuous, and were collected and recorded in compliance with national technical standards. Therefore, the data are considered to be of high quality and reliability.

Data collection was done through a computer input system and operational precipitation digitizing software. Such an approach assisted in data selection, reduction, processing, and statistics. Compared with simple data collection methods (visual observation and “coordinate excerption”), the precipitation digitizing platform eliminates spurious data that can influence data selection. Data series from the platform together with measured data after siphon testing

**Table 1** Comparison between sampling methods and theoretical distributions

Sampling methods	Theoretical distribution							
	Exponential distribution		Gumbel distribution		P-III distribution		P-III distribution (combined with Gumbel distribution)	
	$\sigma_{\text{abs}}$ (mm/min)	$\sigma_{\text{rel}}$ (%)	$\sigma_{\text{abs}}$ (mm/min)	$\sigma_{\text{rel}}$ (%)	$\sigma_{\text{abs}}$ (mm/min)	$\sigma_{\text{rel}}$ (%)	$\sigma_{\text{abs}}$ (mm/min)	$\sigma_{\text{rel}}$ (%)
Annual multi-sampling	0.01–0.12	1.39–7.30	0.01–0.1	1.43–6.52	0.01–0.14	1.73–6.32	0.01–0.12	1.33–5.31
	0.0460	3.2763	0.0407	2.9545	0.0471	3.972	0.0401	3.872
Annual maximum Sampling	0.01–0.12	1.039–7.69	0.01–0.09	1.79–5.73	0.02–0.11	1.74–5.67	0.01–0.08	1.57–5.04
	0.0491	4.819	0.0424	3.0678	0.0523	6.125	0.0410	3.0078

\* $\sigma_{\text{abs}}$  denotes absolute mean square error and  $\sigma_{\text{rel}}$  relative mean square error; it is stated in the “Code” GB-50014-2006;  $\sigma_{\text{abs}}$  should be less than or equal to 0.05 mm/min and  $\sigma_{\text{rel}}$  should be less than or equal to 5%

and correction were reorganized and compiled to build the database for the up-to-date urban rainfall intensity formula, which involved 607 cities in 31 Chinese provinces and autonomous regions. With the assistance of this platform, accuracy of data collection was enhanced and measurements standardized. Sampling became much more efficient and accurate.

## Methods

Two sampling methods, annual multi-sampling and annual maximum sampling, were compared. For annual multi-sampling, 6 or 8 rainfall extreme values were selected for a certain duration per year, as sub-samples of the data series. These sub-samples were sorted in descending order, and their top half was selected as the database. For annual maximum sampling, only one rainfall extreme value was selected and required for each period per year.

The frequency distribution of rainstorm intensity is the core of an urban rainstorm intensity formula, and the sampling method is important in the calculations. Rainfall data with various specified durations should be used, via empirical or theoretical frequency curves. One may use theoretical frequency distributions such as Pearson III (P-III),<sup>2</sup> Gumbel extreme, and exponential (Poisson) distributions. The P-III is regarded as the traditional distribution type in China; however, calculation of its coefficient of skewness and fitting its three parameters are very complicated and may lead to unreliable results. In addition, different calculation and fitting methods generate different biases. Based upon the preferred frequency distribution type, the P-III distribution combined with the Gumbel distribution, we used a Gauss–Newton iterative algorithm to derive the values of four parameters for each city using the uniform formula illustrated in the

introduction. In addition, related IDF curves can be plotted based upon calculations. According to the calculations of the up-to-date formula, we plotted the rainstorm isograms on the basis of the preferred frequency distribution type and derivation of four parameters for the formulas.

## Results and discussion

In all, 607 up-to-date rainstorm intensity formulas for 607 cities in China were formulated.<sup>3</sup> The design rainstorm intensity formulas are formulated according to the requirements of CDOWE as mentioned in the introduction. All the formulas follow the mathematical expression (1) with the modification of four parameters  $A_1$ ,  $C$ ,  $b$ , and  $n$ . Results of the selection of sampling methods and frequency distribution types and accuracy assessment of formulas based upon isograms are illustrated as follows.

### Selection of sampling methods and frequency distribution types

For sampling methods, annual multiple sampling and annual maximum sampling are the most commonly used methods in China. Annual multiple sampling is used when data series are relatively short, covering periods of more than 10 years. This sampling method was used to augment the sample size because of an insufficient database, and about 6 or 8 rainfall extreme values were selected for each period per year as sub-samples of the data series. In contrast, for annual maximum sampling, only one rainfall extreme value was selected and required for each corresponding period per year.

<sup>2</sup> The Pearson type III distribution could either be a gamma distribution or Chi-squared distribution.

<sup>3</sup> There were 607 formulas published in the Chinese version. Data source: Shao and Shao 2014. A New Generation of Urban Rainstorm Intensity Formula in China. China Architecture & Building Press. Beijing.

**Table 2** Geographic and climatic features of four representative cities

Cities	Geographic locations	Climate	Annual average precipitation (mm)
Shanghai	31.4°N, 121.45°E Coastal city in estuary of Yangtze River	Subtropical continental monsoon	1200
Nan-ning	22.63°N, 108.22°E In southern China and south of the Tropic of Cancer	Subtropical monsoon	1300
Ürümqi	43.47°N, 87.39°E In Northwest China with average altitude 800 m	Temperate continental	190
Xinlinhot	43.57°N, 116.07°E North of capital city Beijing	Semiarid continental monsoon in middle temperate zone	280

This facilitated the sampling process and demonstrates the variation of annual rainfall in a more independent and representative way. On the grounds of convenience of data selection and data series representativeness, the annual maximum sampling method was selected for this study.

In the two sampling methods selected above, (average) absolute mean square error ( $\sigma_{\text{abs}}$ ) and (average) relative mean square error ( $\sigma_{\text{rel}}$ ) are compared to ascertain the fitting accuracy among three theoretical distributions (Table 1). Theoretically, among three theoretical frequency distributions, the exponential distribution is more favourable to use for a design frequency less than 2 years, whereas the Gumbel distribution is preferred for a design frequency of 2–5 years. The P-III distribution is more favourable for an even larger design frequency. The combined P-III and Gumbel distribution was mainly based on Gumbel distribution, and the P-III distribution was utilized to modify the fitting parameters (including coefficient of variation  $C_v$ , coefficient of skewness  $C_s$ , and  $C_s/C_v$ ).

It is shown in Table 1 that  $\sigma_{\text{abs}}$  of the exponential, Gumbel and P-III distributions are larger than that of the combined P-III and Gumbel distribution for both sampling methods. Especially,  $\sigma_{\text{rel}}$  of the exponential, Gumbel and P-III distributions are larger than that of the combined P-III and Gumbel distribution for the annual maximum sampling method. Therefore, for the annual maximum sampling method,  $\sigma_{\text{abs}}$  and  $\sigma_{\text{rel}}$  of the combined P-III and Gumbel distribution revealed the best performance compared with other theoretical distributions. Referring to the requirements of CDOWE GB-50014-2006 (revised in 2016), the annual maximum sampling method and a design frequency of 2–5 years are more suitable for urban drainage design.

### Parameter modification of combined P-III and Gumbel distribution

As shown in Table 1, using the annual maximum sampling method, fitting accuracy of the combined P-III and Gumbel distribution was better than the other theoretical distributions

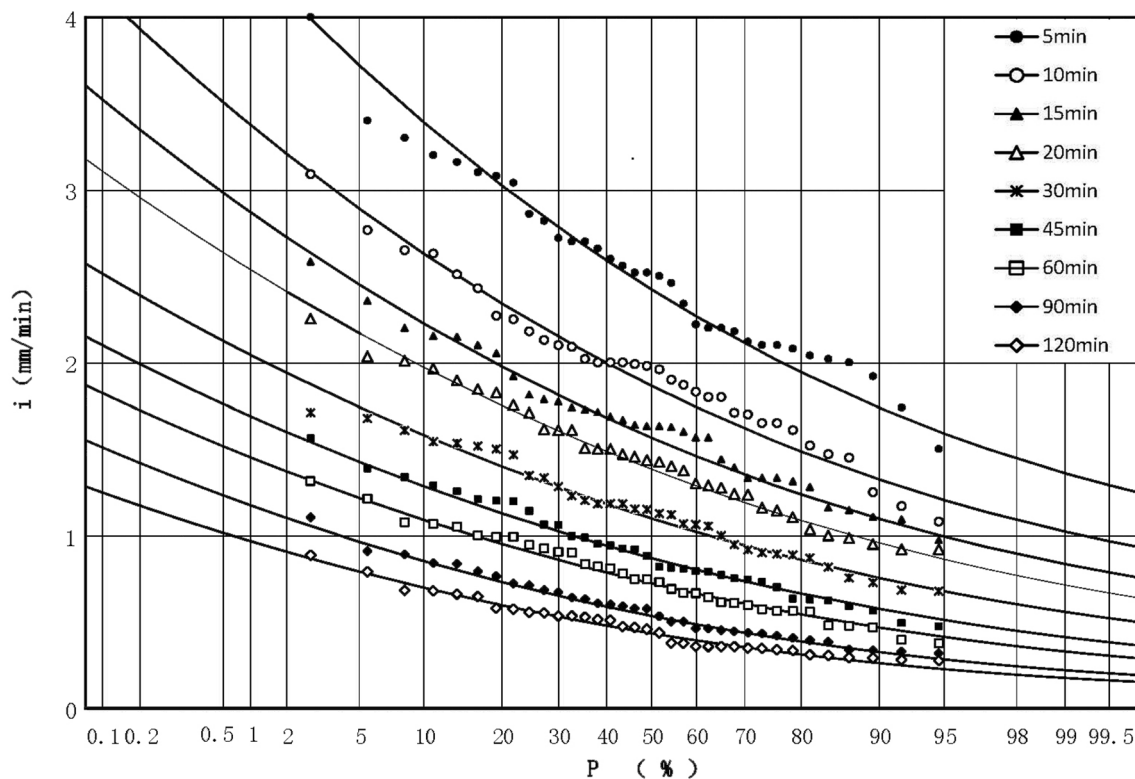
because of its smallest  $\sigma_{\text{abs}}$  or  $\sigma_{\text{rel}}$ . In conclusion, the combined P-III and Gumbel distribution was demonstrated to be a better theoretical distribution type because of its improved accuracy of fit.

IDF curves were plotted and adjusted based upon the Gumbel distribution.  $C_v$ ,  $C_s$ , and  $C_s/C_v$ , modified by the P-III distribution, were the three core fitting parameters. We took the cities of Shanghai, Nan-ning (located in the southwest of China), Ürümqi (located in the northwest of China), and Xinlinhot (located in the northern China) as examples. Compared with the coastal city of Shanghai, Nan-ning, Ürümqi, and Xinlinhot have varied climatic and topographic conditions (Table 2). Four clusters of IDF curves under 9 durations of 5, 10, 15, 20, 30, 45, 60, 90, and 120 min were plotted (Figs. 2, 3, 4 and 5) based on the calculations of  $\bar{H}$ ,  $C_v$ ,  $C_s$  and  $C_s/C_v$  (Table 3).

Furthermore, we made a statistical comparison of fitting parameters, as shown in Table 3. Here,  $\bar{H}$  represents the average rainfall intensity of the data series. It shows a tendency in which the mean  $\bar{H}$  of the southern cities (such as Nan-ning and Shanghai) is significantly larger than that of the northern cities (Xinlinhot and Ürümqi). The mean  $C_v$  of southern cities is smaller than that of northern cities. Cities with greater rainfall intensity  $\bar{H}$  would have a smaller  $C_v$ . That is, cities in the western inland (such as Ürümqi) have even smaller  $\bar{H}$  but larger  $C_v$ . On the basis of  $\bar{H}$  and  $C_v$ , cities with different climatic conditions and geographic locations would have varied rainfall intensity.

### Topographic features and spatial distribution of precipitation

The terrain in China varies regionally, with plains, mountains, plateaus, hills, and valleys. The areal proportion of mountainous regions and hills is relatively large, and there is generally greater relief in the west than the east. Based upon the data series with duration of 40 years from 607 observation sites, isograms of annual precipitation nationwide are plotted in Fig. 6. Some crucial topographic features were



**Fig. 2** Intensity–duration–frequency curves for Shanghai City

chosen to review the impact on annual precipitation magnitudes from the perspective of topographic relief (Table 4).

Topographic features of seven mountain ranges were considered for their unique locations at geographic divisions between three steps of China's terrain. The Qinling Mountains, Himalaya Mountains and Mount Wuyi are all prominent topographic features. Based on annual precipitation and topographic information, we plotted the rainstorm isograms according to average annual precipitation all over China in Fig. 6, which shows the following:

- Annual average regional precipitation less than 200 mm is found in the inland northwest, along the Qilian Mountains and southeast side of the Kunlun Mountains.
- The area outlined by the 400-mm isohyet traverses the Da Hinggan Mountains, Taihang Mountains, north side of the Hengduan Mountains, and east side of the Himalaya Mountains.
- The area outlined by the 800-mm isohyet crosses the Qinling Mountains and Hengduan Mountains.
- Annual regional precipitation of more than 1600-mm traverses Mount Wuyi and Nan-ning City.
- Influenced by the monsoon climate, precipitation in hilly areas is much greater than that on plains. In addition, precipitation of windward slopes of mountains is greater than that on leeward slopes.

- In general, precipitation in the eastern is much greater than in the west, and that in the south much greater than in the north.

The above analysis shows a pronounced geographic variation in rainfall extremes. Various levels of annual precipitation increase from west to east. The spatial distribution of rainfall from the data series of 40 years and 607 observation sites was consistent with the topographic relief of mountains.

Considering the codes and catchment time of urban drainage design in China, we chose a rainstorm with a design frequency of 2 years and duration of 20 min, the isograms for which are plotted in Fig. 7 based on a kriging method. This shows the distribution of precipitation and the following:

- Interior plateau precipitation is light, around 5 mm, with associated isohyets passing the west side of the Qilian, Kunlun and Himalaya mountains.
- The 10–20-mm isohyet crosses the west side of the DaHinggan and Taihang Mountains, and the west side of the Qinlin Mountains and Mount Wushan.
- The 20–25-mm isohyet passes the east side of the Da Hinggan and Taihang Mountains, Mount Wushan, and the Xuefeng Mountains.

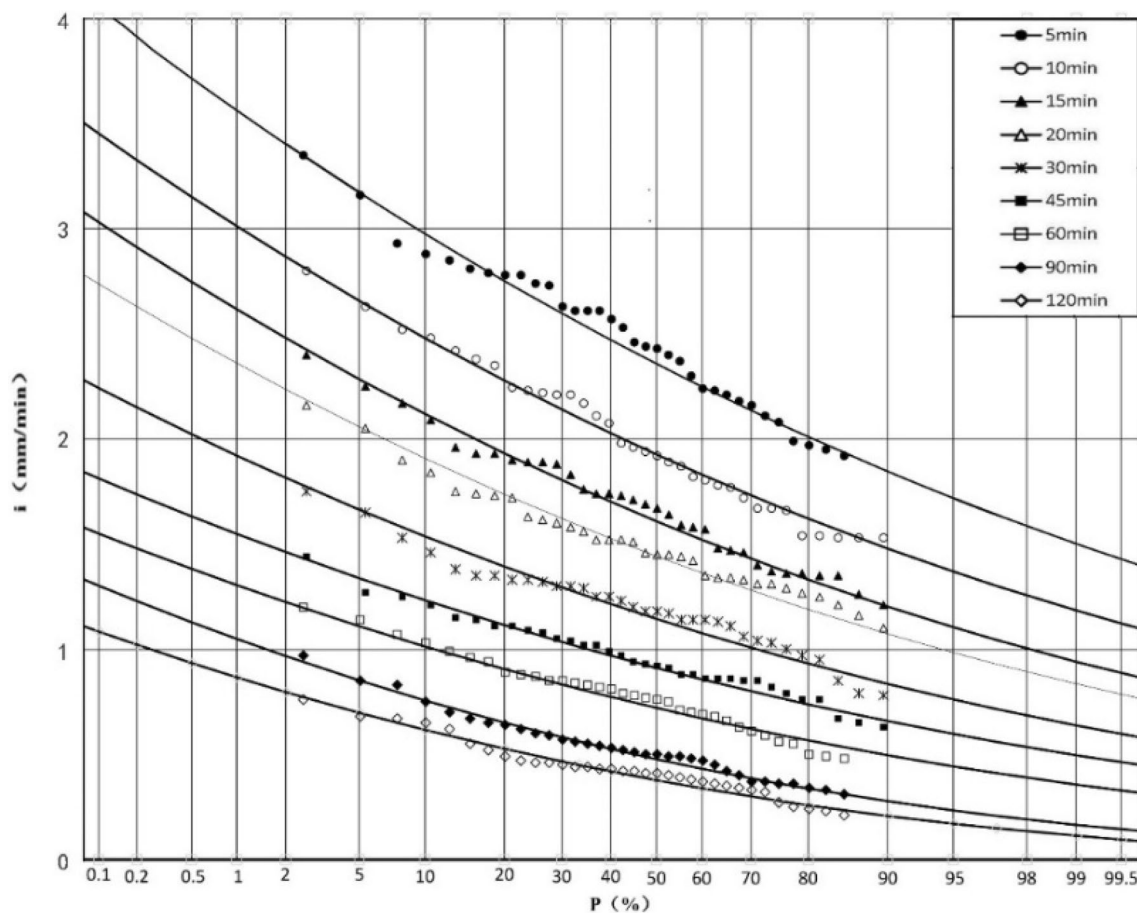


Fig. 3 Intensity–duration–frequency curves for Nan-ning City

- The 25–30-mm (and greater) isohyet, in coastal areas of eastern China, traverses the east side of Mount Wuyi.
- From east to west in the country, the design rainstorm amounts along the windward slopes of mountains are much greater than those on leeward slopes.
- In general, the design rainstorm amount in the east is much greater than in the west and that in the south is much greater than in the north.

In summary, compared with Fig. 6, design rainstorm magnitudes are consistent with changes of annual precipitation in the 40-year data series from 607 observation sites, which are also consistent with the topographic relief of the mountains.

**Accuracy assessment for formula**

It is stated in the “Code for Design of Outdoor Wastewater Engineering” GB-50014-2006 (revised in 2016) that for a return period of 2–10 years, average absolute mean square error for normal intensity should not exceed 0.05 mm/min; for a much higher intensity, average relative mean square

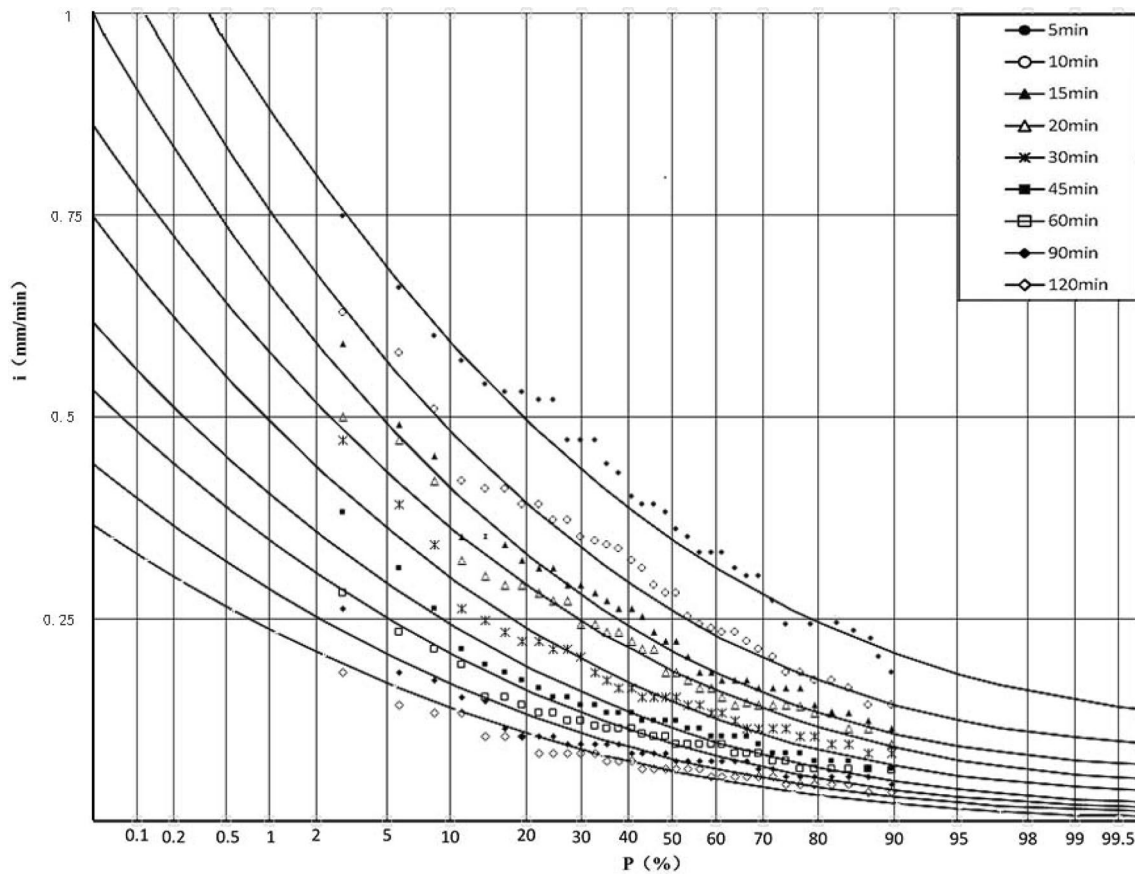
error should not exceed 5%. Among urban rainstorm intensity formulas after parameter modification, using the combined P-III and Gumbel distribution and calculating and comparing mean square errors, the applicability rate of the formula is 99.6% for a return period of 2–100 years and 100% for 2–20 years.

**Accuracy assessment for isograms**

Based on the plotted isograms, 200 cities were randomly selected together with their rainstorm intensity formulas. Design rainfall was calculated and compared under different return periods according to specified durations. Taking absolute and relative mean square errors as benchmarks, the distribution mean absolute error was 0.048 mm and mean relative error 4.99%. Both these satisfy the precision requirements of GB-50014-2006.

**Comparison with authoritative results**

To verify the accuracy of research results from the up-to-date urban rainstorm intensity formulas, we compared



**Fig. 4** Intensity–duration–frequency curves for Ürümqi

research findings in the authoritative atlas of rainstorm statistical parameters in China (published by the Hydrological Bureau of the Ministry of Water Resources and Nanjing Research Institute of Water Conservancy). Those findings are commonly used to calculate design rainstorms of five durations (10 min, 60 min, 6 h, 24 h, and 3 days) and a design frequency in excess of 5 years. The up-to-date urban rainstorm intensity formula was used for shorter durations, and is also suitable for a design frequency of 2–5 years. For the selection on theoretical distributions, the P-III distribution was used as the theoretical model in the authoritative atlas, and the ratio between coefficient of skewness and coefficient of variation ( $C_s/C_v$ ) was set to 3.5 for all durations. However, the up-to-date urban rainstorm intensity formula used the combined P-III and Gumbel distribution to modify the parameters, using a return period of 2–100 years (mostly 2–20 years). Considering the improvements of up-to-date urban rainstorm intensity formula, we figure out a more accurate frequency distribution model to modify the fitting parameters, the combined Gumbel and P-III distribution, with improved fitting precision. In addition, up-to-date formula takes design

occurrence of 2–5 years into consideration which would be sufficient to improve the accuracy of practical engineering.

Table 5 compares results from the up-to-date urban rainstorm intensity formulas (as updated values) and the authoritative atlas (as reference values), with return periods 5 and 10 years and rainfall durations 10 and 60 min. Cities were selected by their characteristic locations and rainfall patterns. For instance, Lhasa and Ürümqi were chosen as typical of plateau areas, and Harbin and Beijing as typical of north-eastern China; Chengdu and Shanghai were chosen as representative of the central plains and coastal cities, respectively. Results from the formulas are consistent with research findings from the atlas. For urban drainage design, the return period would be more appropriate at 2–5 years. According to Table 5, for a return period of 5 years, differences between updated and reference values are less than 8%, implying that the formula output is similar to the findings in the authoritative atlas. For a return period of 10 years, the difference is less than 10%, suggesting that the tendencies of updated and reference values are consistent.



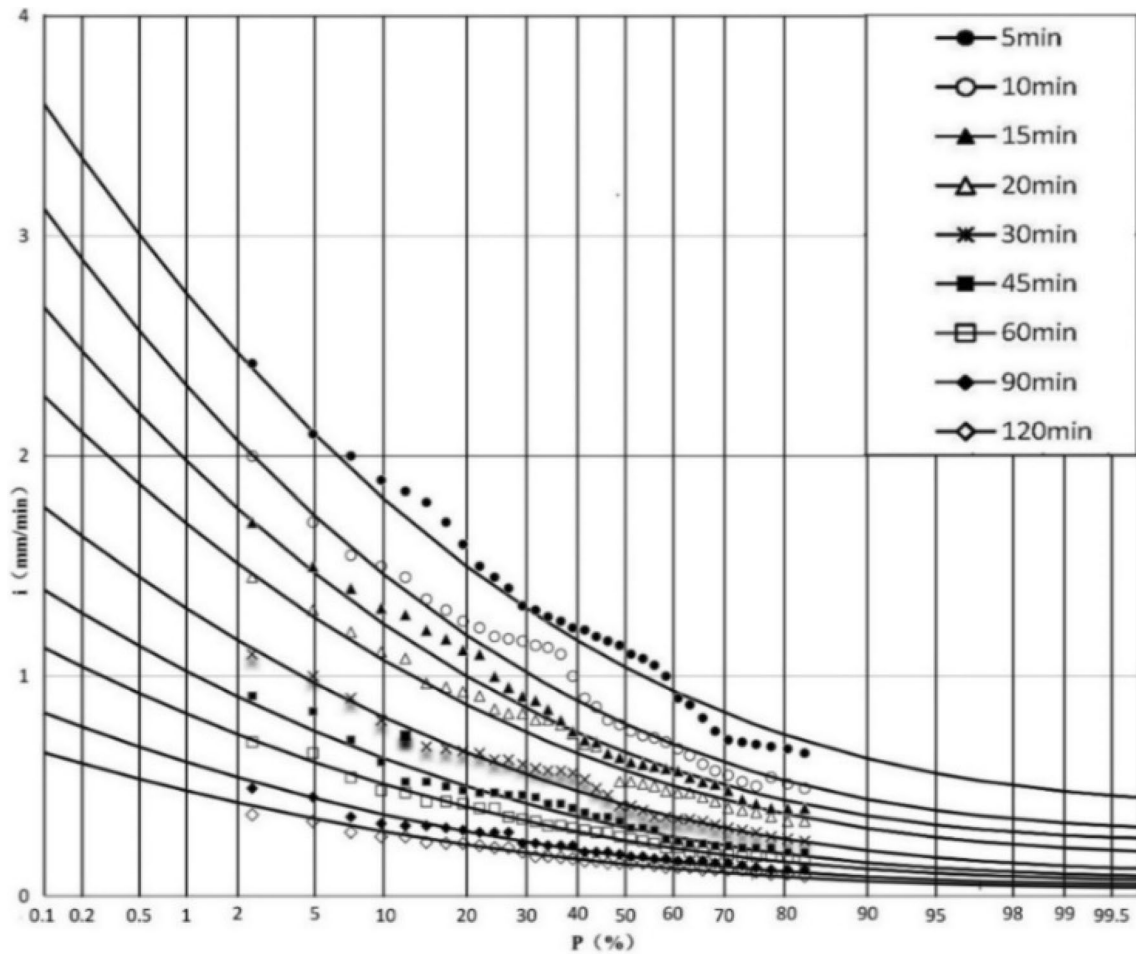


Fig. 5 Intensity–duration–frequency curves for Xinlinhot

Table 3 Core parameters among four representative cities with nine different durations

Cities	Shanghai				Nan-ning				Xinlinhot				Ürümqi			
	$\bar{H}$	$C_v$	$C_s$	$C_s/C_v$	$\bar{H}$	$C_v$	$C_s$	$C_s/C_v$	$\bar{H}$	$C_v$	$C_s$	$C_s/C_v$	$\bar{H}$	$C_v$	$C_s$	$C_s/C_v$
5 min	2.51	0.23	0.69	3	2.55	0.18	0.45	2.5	1.27	0.43	1.33	3.1	0.42	0.40	1.20	3.0
10 min	1.93	0.27	0.78	2.9	2.12	0.19	0.49	2.6	0.96	0.45	1.35	3.0	0.31	0.46	1.38	3.0
15 min	1.63	0.28	0.76	2.7	1.84	0.20	0.52	2.6	0.78	0.48	1.44	3.0	0.25	0.50	1.45	2.9
20 min	1.43	0.28	0.73	2.6	1.65	0.20	0.52	2.6	0.66	0.49	1.32	2.7	0.23	0.50	1.35	2.7
30 min	1.14	0.29	0.75	2.6	1.37	0.21	0.55	2.6	0.49	0.54	1.40	2.6	0.19	0.53	1.43	2.7
45 min	0.90	0.31	0.78	2.5	1.11	0.21	0.55	2.6	0.36	0.55	1.43	2.6	0.15	0.55	1.43	2.6
60 min	0.75	0.33	0.83	2.5	0.92	0.23	0.60	2.6	0.29	0.56	1.46	2.6	0.13	0.56	1.46	2.6
90 min	0.57	0.38	0.95	2.5	0.63	0.29	0.75	2.6	0.21	0.56	1.46	2.6	0.11	0.56	1.46	2.6
120 min	0.46	0.38	0.95	2.5	0.55	0.30	0.78	2.6	0.17	0.57	1.43	2.5	0.09	0.57	1.43	2.5
Mean	1.26	0.31	0.80	2.6	1.42	0.22	0.58	2.6	0.58	0.51	1.40	2.7	0.21	0.51	1.40	2.7

**Conclusions**

This study reviewed the modification and validation of up-to-date urban rainstorm intensity formulas for 607 cities on

the basis of spatial diversity in China. Analysis was based upon a 40-year data series. Sampling methods and theoretical frequency distributions were discussed in accordance with the codes of urban drainage design. It has also verified that a combined P-III and Gumbel distribution type

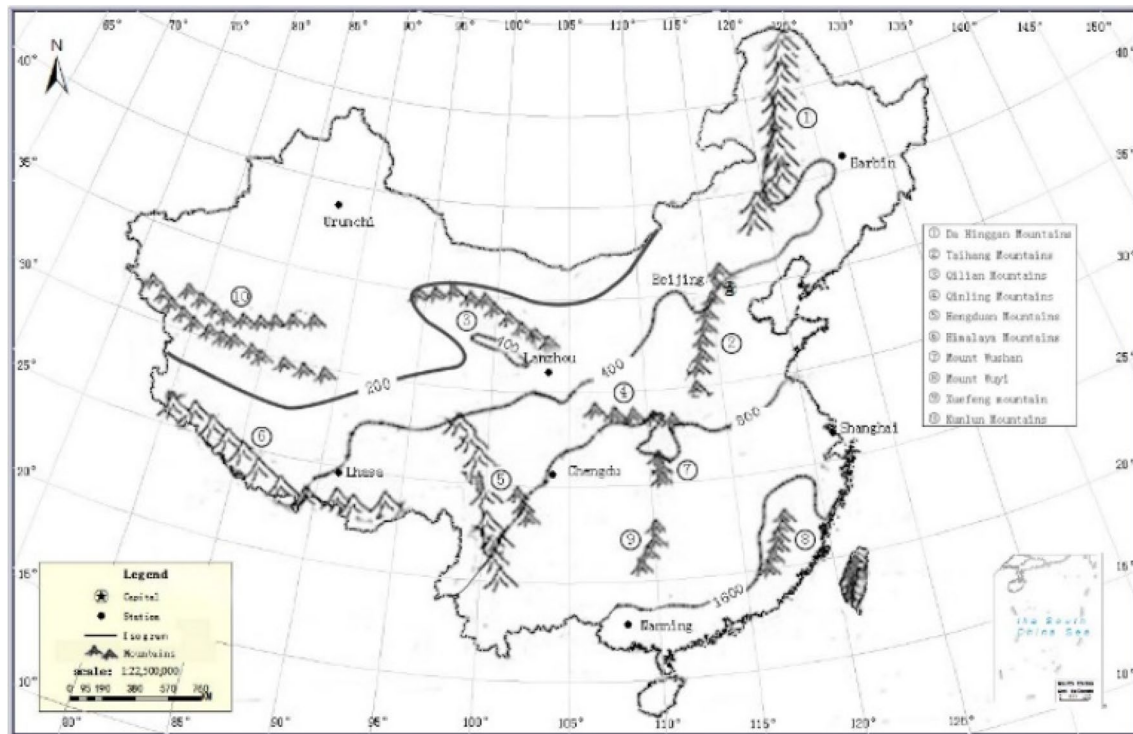


Fig. 6 Isograms of annual precipitation over 40 years from 607 observation sites

Table 4 Summary of geographic features with elevation and geographic importance

Geographic features	(Absolute) Elevation	Geographic importance
Kunlun Mountains	5500–6000 m on average	Division of the first and second steps
Qilian Mountains	Over 4000 m on average	
Hengduan Mountains	4000 m on average	
Da Hinggan Mountains	1100–1400 m on average	Division of the second and third steps
Taihang Mountains	Over 1200 m on average	
Mount Wushan	2400 m on average	
Xuefeng Mountain	Max 1934 m	
Qinling Mountains	3771.2 m on average	The south and north division of China’s terrain
Himalaya Mountains	7000–8000 m on average	Natural division of East Asian Continent and South Asian Subcontinent
Mount Wuyi	Max 2157.8 m	The summit in the southeast part of China

under the maximum sampling methods was demonstrated to be a superior theoretical distribution type. This reduced spurious data and increased fitting accuracy according to statistical comparison. Four representative cities, Shanghai, Nan-ning, Xinlinhot, and Ürümqi, were illustrated to modify three fitting parameters,  $C_v$ ,  $C_s$ , and  $C_s/C_v$ , utilizing the combined distribution model. Comparing the topographic and climatic features, southern cities with greater rainfall intensity on average would have a smaller  $C_v$ . Northern cities are with smaller  $C_v$  but larger rainfall intensity.

With the application of GIS and other technologies, databases for spatial analysis and the design rainstorm are combined, making the plotting of rainstorm isograms more efficient, objective, and rigorous. By integrating graphs and statistics, and considering climate, topography, design rainstorm isograms, and their combinations, we obtained the following results: (1) for the up-to-date urban rainstorm intensity formulas for different cities, the design rainfall can be calculated, and isograms of various return periods according to specified durations can be plotted to review the accuracy of formulas; (2) isograms objectively

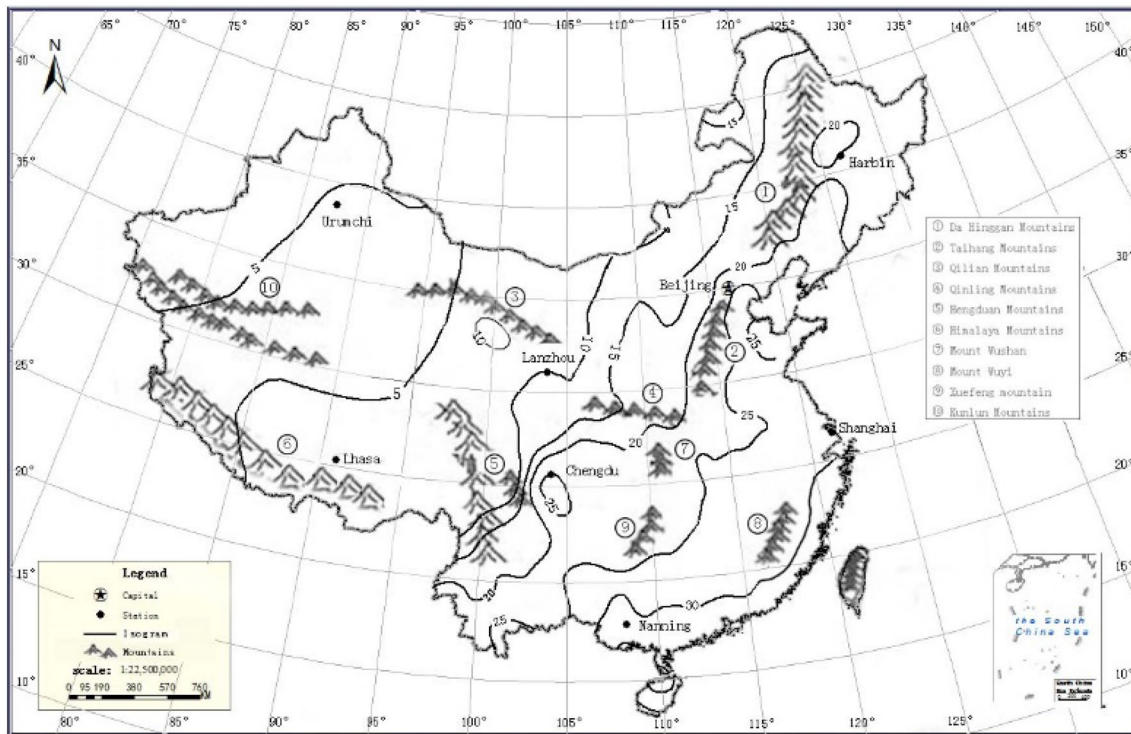


Fig. 7 Isograms of design rainstorm with design frequency 2 years and duration 20 min (after distribution type calibration)

Table 5 Comparison of updated and reference values

Return period	Intensity (mm/min)	Duration (min)											
		Lhasa		Ürümqi		Beijing		Harbin		Chengdu		Shanghai	
		10	60	10	60	10	60	10	60	10	60	10	60
5 years	Updated value	0.931	0.277	0.426	0.185	1.946	0.847	1.708	0.577	1.951	0.909	1.891	0.857
	Reference value	0.931	0.284	0.397	0.182	2.017	0.873	1.856	0.618	2.016	0.987	2.048	0.861
	%	0.00	-2.52	7.30	1.47	-3.52	-3.07	-7.97	-6.61	-3.22	-7.92	-7.67	-0.43
10 years	Updated value	1.110	0.330	0.520	0.225	2.225	0.968	2.013	0.680	2.274	1.059	2.201	0.989
	Reference value	1.162	0.347	0.591	0.227	2.464	1.067	2.219	0.755	2.352	1.152	2.438	0.989
	%	-4.48	-4.75	-12.01	-0.81	-9.70	-9.22	-9.28	-9.92	-3.32	-8.02	-9.72	0.00

\*Updated value refers to calculations from up-to-date urban rainstorm intensity formula of this research. Reference values are from research findings in authoritative atlas of rainstorm statistical parameters in China

reveal correlative factors of precipitation, which are related to topography, geography and climate. Results show that isograms of design rainstorm magnitudes are consistent with variations of topographic relief. Precipitation in hilly areas is much greater than on plains, and that on windward slopes is greater than on leeward slopes. Furthermore, precipitation in the eastern is much greater than in the west and that in the south much greater than in the north; (3) rainstorm intensity is altered substantially in regions affected by climatic factor, such as the monsoon climate. This causes precipitation in hilly areas, especially

for windward slopes of mountains, is much greater than that on plains; and (4) on general, distributions of short-duration rainstorms were in accord with topographic relief. Isograms and variations are in agreement with research findings in the authoritative atlas of rainstorm statistical parameters in China. Combining results from statistical and spatial analysis, formulas considering spatial diversity provide a more objective means of parameter modification and improve feasibility and accuracy.

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