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Exploring the driving factors of compound flood severity in coastal cities: a comprehensive analytical approach

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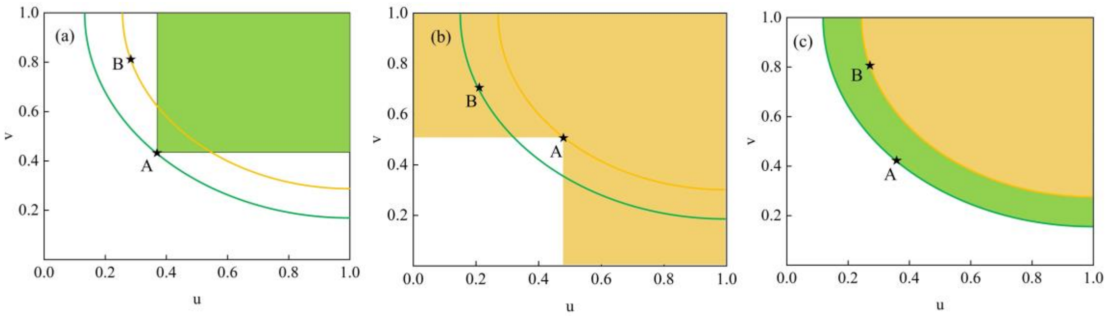

Figure S1 The schematic diagram of different types of return periods. (a) The green area represents the danger zone for the "And" return period, where point A is located. It's evident that the joint probability at point B is higher than point A, which implies that point B is considered a dangerous event. However, the danger zone doesn't include point B. Therefore, the "And" return period narrows down the danger area. (b) The yellow area corresponds to the danger zone for the "Or" return period. It's noticeable that point B has one variable significantly large while the other one quite small. In engineering applications, this might not be considered as a significant risk. Nevertheless, in the "Or" return period, point B is included in the danger zone. (c) A curve $C(u,v)=p$ divides the event domain into safe and dangerous areas. The yellow dangerous area is included in the green range. The bivariate return period under the condition $C(u,v)=p$ can be called "Kendall" return period.

S1 The design of tide level process

The design of tide level process is typically created using the equal-multiple method. However, when the typical tide level processes contain negative value, the magnification factor tends to lower the low tide levels, which leads to an exaggerated tide level range. In this study, a modified equal-multiple method is employed to design the tide level process. Firstly, a typical tide level event is selected based on an extensive dataset of tide level observations. Then, the design tide level process is calculated according to the following formula while controlling for the high tide levels:

$$\begin{cases} Z_i \geqslant \overline{Z}, & Z_{p,i} = \left(Z_i - \overline{Z}\right) \times k_{p,1} + \overline{Z} \\ Z_i < \overline{Z}, & Z_{p,i} = Z_i \times k_{p,2} + Z_i \end{cases} \tag{S1}$$

$$k_{p,1} = \frac{Z_p}{Z_{\max}} \tag{S2}$$

$$k_{p,2} = \frac{Z_{\min}}{Z_p} \tag{S3}$$

where Z_i represents the typical tide level at time i; $\overline{Z}$ is the average tide level of the typical tide level process; $Z_{p,i}$ is the designed tide level at time i for the p frequency;

$k_{p,1}$ is the ratio of the designed high tide level to the typical tide level for the p frequency; $k_{p,2}$ is the ratio of the typical tide level to the designed tide level for the p frequency; Z_{max} is the maximum tide level value in the typical tide level pattern; Z_{min} is the minimum tide level value in the typical tide level pattern; Z_p represents the designed tide level.

The above method may result in differences between the maximum value and the design values. Therefore, further adjustments are made to the designed tide process to obtain the final design tide level process.

$$k = \frac{Z_p}{\max\left(Z_{p,i}\right)} \tag{S4}$$

$$Z'_{p,i} = k \times Z_{p,i} \tag{S5}$$

where k is the correction coefficient, and $Z'_{p,i}$ is the final designed process.

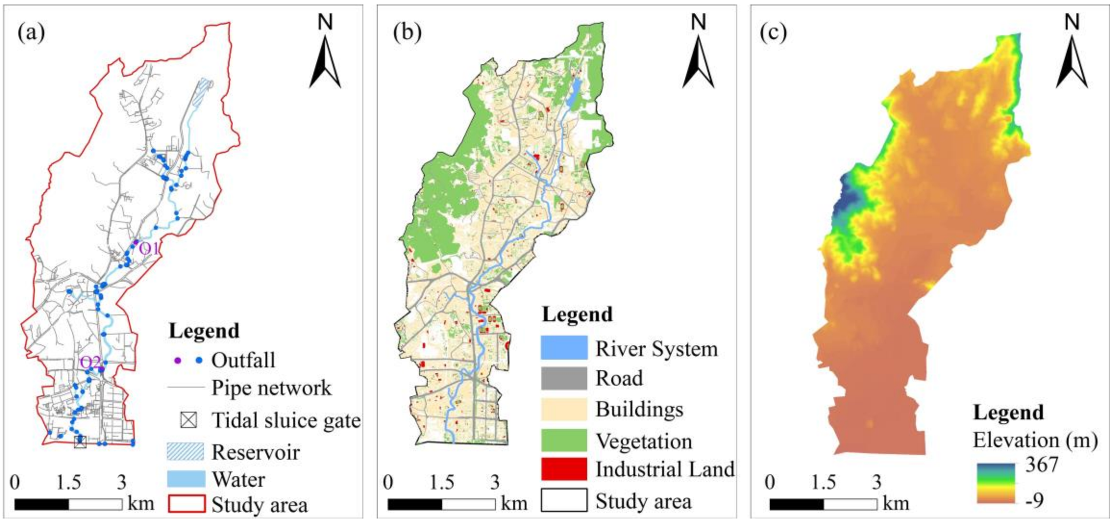

Figure S2 Model construction.

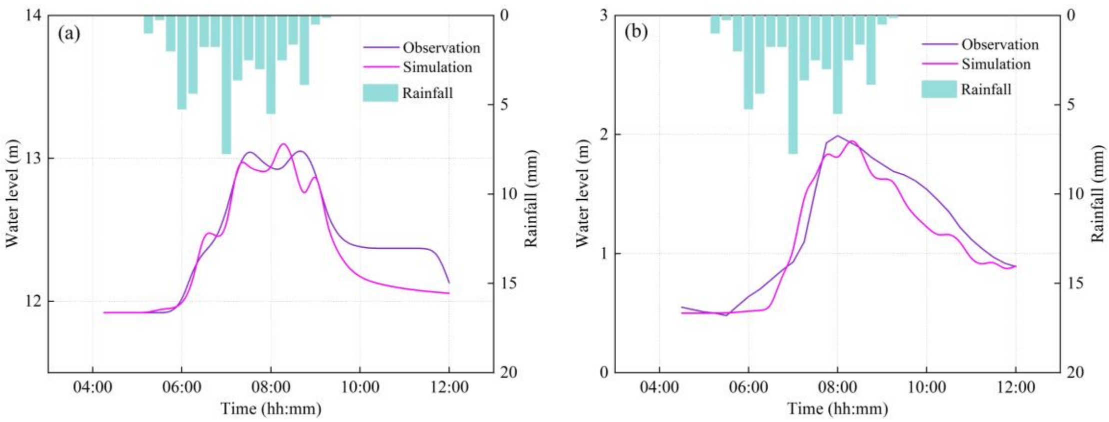

Figure S3 Comparison of observed and simulated water levels at two monitoring points: (a) L1 for manhole level; (b) L2 for river level.

S2 The design of tide level process

Considering the topography of the watershed and in combination with the direction of the drainage network, the drainage units are divided. The outlet number data from urban drainage network data are recorded in the outlet number set. The first inspection well number Y_i is searched upstream of the outlet number O_i, and then the pipelines with Y_i as the downstream inspection well are searched. The search results are checked for null values. If they are null, the search for the outlet O_i is completed, and the process proceeds to the next outlet. All the inspection wells, pipeline segments, and sub-watersheds upstream of the outlet form a drainage unit. The main drainage channels of the drainage network along the river and their inspection wells are assigned to various adjacent drainage units.

Table S1 The goodness-of-fit test for the marginal distribution functions

Durations (h)	Marginal distributions	Rainfall				Tide level			
		RMSE	AIC	BIC	K-S	RMSE	AIC	BIC	K-S
1	GEV	**0.035**	**335.690**	**341.303**	**0.104**	0.026	49.299	54.912	0.083
	Norm	0.093	357.198	360.940	0.188	0.590	49.716	53.458	1.000
	Gamma	0.082	350.256	353.998	0.188	**0.026**	**47.079**	**50.821**	**0.083**
	Weibull	0.099	364.278	368.020	0.188	0.035	50.007	53.750	0.083
3	GEV	**0.037**	**325.464**	**330.454**	**0.103**	0.044	41.501	46.492	0.128
	Norm	0.082	345.930	349.257	0.154	0.591	42.596	45.923	1.000
	Gamma	0.066	336.618	339.945	0.128	**0.045**	**39.488**	**42.815**	**0.128**
	Weibull	0.090	351.458	354.786	0.205	0.048	42.871	46.198	0.128
6	GEV	**0.031**	**437.009**	**442.685**	**0.122**	0.050	56.114	61.790	0.122
	Norm	0.086	460.232	464.016	0.163	0.588	54.676	58.460	1.000
	Gamma	0.066	449.016	452.799	0.122	0.054	54.531	58.314	0.102
	Weibull	0.086	462.671	466.455	0.163	**0.043**	**54.200**	**57.984**	**0.122**
12	GEV	**0.025**	**449.977**	**455.653**	**0.082**	0.061	64.034	69.709	0.143
	Norm	0.111	485.466	489.249	0.224	0.587	62.417	66.200	1.000
	Gamma	0.090	471.221	475.005	0.184	0.069	62.773	66.557	0.122
	Weibull	0.108	485.460	489.244	0.224	**0.054**	**61.608**	**65.392**	**0.143**
24	GEV	**0.031**	**491.344**	**497.198**	**0.077**	0.059	71.614	77.468	0.154
	Norm	0.124	533.271	537.173	0.231	0.588	72.491	76.393	1.000
	Gamma	0.106	517.973	521.876	0.212	**0.058**	**69.048**	**72.951**	**0.154**
	Weibull	0.118	532.585	536.487	0.212	0.054	73.716	77.619	0.173

Table S2 The goodness-of-fit test for the joint distribution functions of rainfall and tide level

Durations (h)	Copula	RMSE	AIC	BIC	K-S
1	Gaussian	0.035	-0.041	1.830	0.125
	t	0.035	3.956	9.570	0.125
	Frank	0.035	-0.161	1.710	0.125
	Gumbel	**0.036**	**-1.004**	**0.867**	**0.125**
3	Gaussian	0.041	0.711	2.663	0.154
	t	0.041	1.751	7.605	0.154
	Frank	**0.041**	**0.312**	**2.264**	**0.154**
	Gumbel	0.044	0.860	2.811	0.154
6	Gaussian	**0.036**	**-0.793**	**1.099**	**0.122**
	t	0.035	3.207	8.883	0.122
	Frank	0.038	0.352	2.244	0.143
	Gumbel	0.038	-0.080	1.812	0.163
12	Gaussian	**0.044**	**1.225**	**3.117**	**0.143**
	t	0.045	4.736	10.411	0.163
	Frank	0.045	1.643	3.535	0.163
	Gumbel	0.045	1.691	3.582	0.184
24	Gaussian	0.043	0.711	2.663	0.154
	t	0.043	1.751	7.605	0.173
	Frank	**0.043**	**0.312**	**2.264**	**0.154**
	Gumbel	0.044	0.860	2.811	0.154

Table S3 Comparison of different types of return period

RP (yr)	Rainfall (mm)	Tide level(m)	Or (yr)	And (yr)	Kendall (yr)
2	98.90	1.45	1.40	3.52	2.42
3	111.20	1.65	1.89	7.21	4.55
5	129.84	1.87	2.90	18.22	10.62
10	163.66	2.12	5.40	66.88	36.35
20	211.95	2.34	10.41	254.82	133.11
50	310.17	2.60	25.41	1543.63	785.87
100	424.12	2.79	50.41	6108.23	3082.09
200	589.74	2.97	100.41	24299.60	12205.61

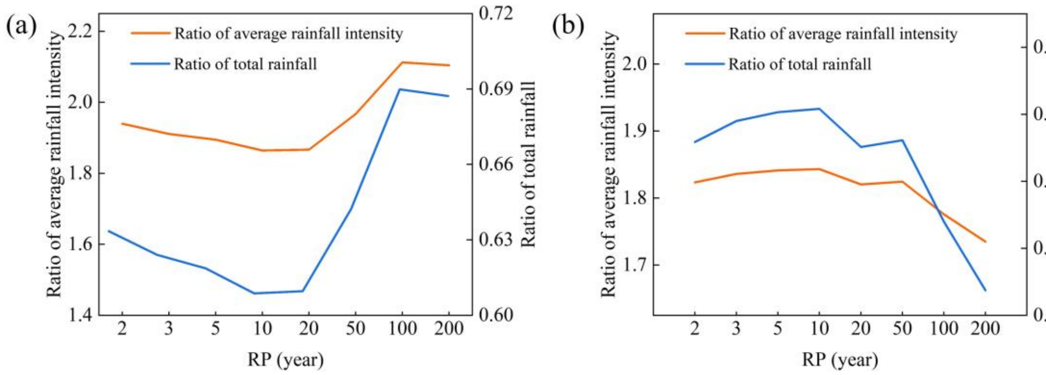

Figure S4 Comparison of rainfall characteristics. The ratio of 1-h duration to 3-h duration (a) and the ratio of 6-h duration to 12-h duration (b).

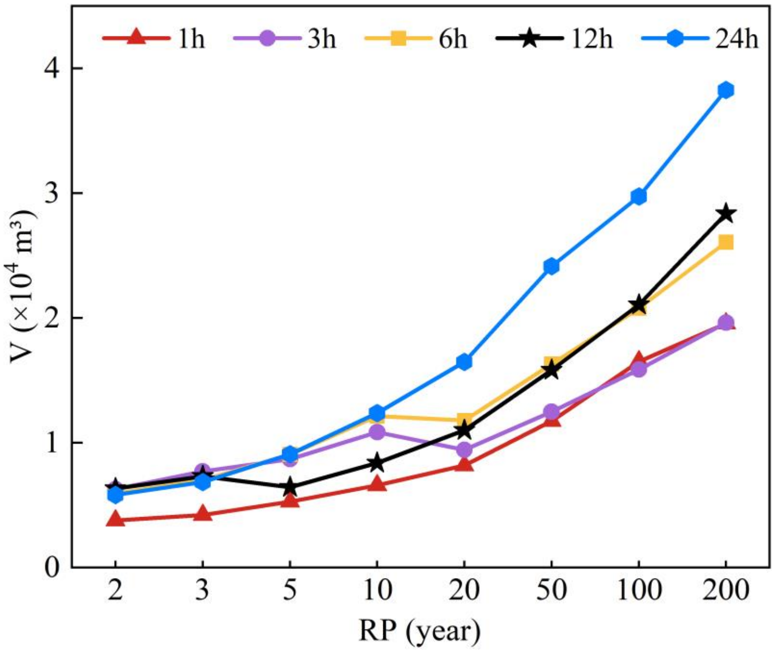

Figure S5 Comparison of flood volumes with different return periods and durations.

Table S4 Tidal sluice gate opening time

Durations (h)	1	3	6	12	24
2-yr RP	/	/	3:00	5:00	10:00
3-yr RP	/	/	3:00	5:00	10:00
5-yr RP	/	/	3:00	4:00	10:00
10-yr RP	/	/	3:00	4:00	10:00
20-yr RP	/	2:00	2:00	4:00	10:00
50-yr RP	/	2:00	2:00	4:00	10:00
100-yr RP	/	2:00	2:00	4:00	10:00
200-yr RP	/	2:00	2:00	4:00	6:00

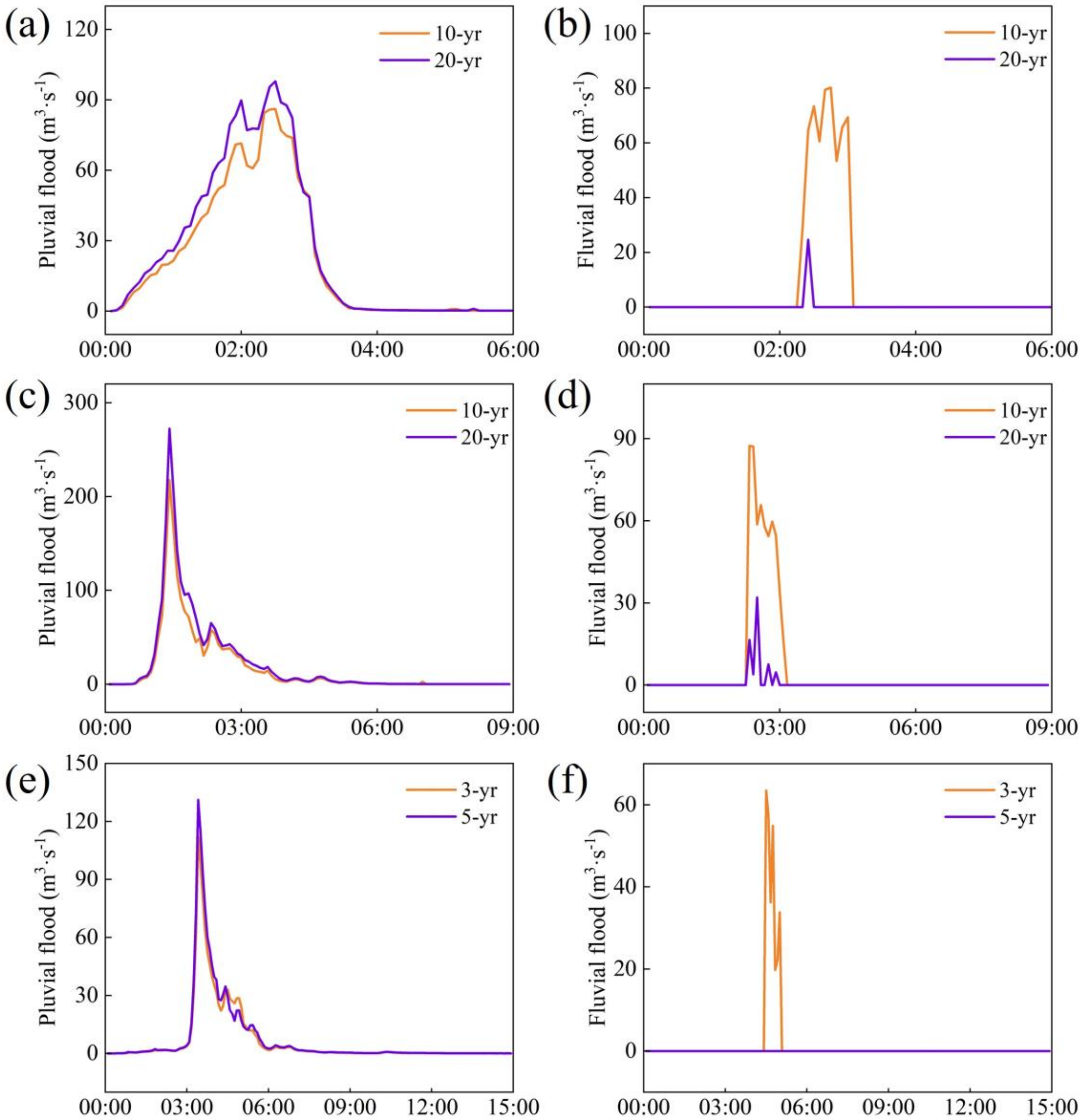

Figure S6 Comparison of flood processes with different return periods and different durations. The rainfall lasted for 3 h (a and b). The rainfall lasted for 6 h (c and d). The rainfall lasted for 12 h (e and f). The return periods are shown in the legend.