Supplementary Tables (STs)

ST 1. Description of 3-D asymmetric (fully nested) Archimedean copula functions and their statistical properties tested in the present study

Asymmetric 3-D Archimedean copulas	$C_1(p,q,r)$	$\phi_2^{-1}\circ\phi_1(\cdot)$	Conditions
Frank	$-\theta_1^{-1}\log\{1-\left(1-e^{-\theta_1}\right)^{-1}\left(1-\left[1-\left(1-e^{-\theta_2}\right)^{-1}\left(1-e^{-\theta_2 p}\right).\left(1-e^{-\theta_2 q}\right)\right]^{\theta_1/\theta_2}\right).\left(1-e^{-\theta_1 r}\right)\}$	$-\ln\frac{\{1+e^{-t}(e^{-\theta_2-1})\}^{\theta_1/\theta_2}-1}{e^{-\theta_1}-1}$	$\theta_1<\theta_2$, where $\theta\in(0,\infty)$
Gumbel-Hougaard (G-H)	$e^{\left\{-\left(\left[(-\log p)^{\theta_2}+(-\log q)^{\theta_2}\right]^{\theta_1/\theta_2}+(-\log r)^{\theta_1}\right)^{1/\theta_1}\right\}}$	t^{θ_1/θ_2}	$\theta_1<\theta_2$, where $\theta\in[0,\infty)$
Clayton	$\left[\left(p^{-\theta_2}+q^{-\theta_2}-1\right)^{\theta_1/\theta_2}+r^{-\theta_1}-1\right]^{-1/\theta_1}$	$\frac{1}{\theta_1}\{(\theta_2 t+1)^{\theta_1/\theta_2}-1\}$	$\theta_1<\theta_2$, where $\theta\in(0,\infty)$
Note: θ_1 & θ_2 represents copula dependence parameters; p, q, r represents univariate marginal CDFs of the triplet flood variable $x_1=$ rain(say), $x_2=$ storm surges (say)& $x_3=$ river dsicharge (say) .			

ST 2. Statistical descriptions of 2-D parametric copulas in the bivariate joint analysis of flood attribute pairs

Copula function	2-D copula $C_\theta(x_1, x_2)$	Parameter range (θ)	Generating function (or generator) $\phi(t)$	Relation of Kendall's τ and θ (τ_θ)	Upper tail dependence coefficient measures ($\lambda_{\mathbf{up}}$)
Clayton	$\left[\max\{x_1^{-\theta} + x_2^{-\theta} - 1; 0\}\right]^{-1/\theta}$	$0 \le \theta < \infty$	$\frac{1}{\theta}(t^{-\theta} - 1)$	$\frac{\theta}{\theta + 2}$	0
Frank	$\frac{-1}{\theta}\ln\left(1 + \frac{(e^{-\theta x_1} - 1)(e^{-\theta x_2} - 1)}{(e^{-\theta} - 1)}\right)$	$-\infty < \theta < \infty$	$-\ln\left(\frac{e^{-\theta t} - 1}{e^{-\theta} - 1}\right)$	$1 + 4\left(\frac{D_1(-\ln\theta) - 1}{\ln\theta}\right)$ where $D_k(x)$ is the Debye function, for any positive integer k, $D_K(x) = \frac{k}{x^k}\int_0^x t^k/(e^t - 1)\,dt$ (Zhang and Singh 2006 and Wang et al., 2009)	0
Gumbel-Hougaard (GH)	$\exp\left\{-\left[(-\ln(x_1))^\theta + (-\ln(x_2))^\theta\right]^{\frac{1}{\theta}}\right\}$	$1 \le \theta < \infty$	$(-\ln t)^\theta$	$\frac{\theta - 1}{\theta}$	$2 - 2^{1/\theta}$
Joe	$1 - \left[(1 - x_1)^\theta + (1 - x_2)^\theta - (1 - x_1)^\theta(1 - x_2)^\theta\right]^{1/\theta}$	$1 \le \theta < \infty$	$-\ln(1 - (1 - t)^\theta)$		$2 - 2^{1/\theta}$
BB1 (Clayton-Gumbel)	$\left(1 + \left[(x_1^{-\theta} - 1)^\delta + (x_2^{-\theta} - 1)^\delta\right]^{1/\delta}\right)^{-1/\theta}$	$0 < \theta < \infty$; $1 \le \delta < \infty$			$2 - 2^{1/\delta}$
BB6 (Joe-Gumbel)	$1 - \left(1 - \exp - \left[\left((-\ln(1 - x_1)^\theta)\right)^\delta + \left((-\ln(1 - (1 - x_2)^\theta))^\delta\right)\right]^{1/\delta}\right)^{1/\theta}$	$1 \le \theta < \infty$; $1 \le \delta < \infty$			$2 - 2^{1/\theta\delta}$

BB7 (Joe-Clayton)	$1-\left[1-\left(\left(1-x_1^{\theta}\right)^{-\delta}+\left(1-x_2^{\theta}\right)^{-\delta}-1\right)^{-1/\delta}\right]^{1/\theta}$	$1 \le \theta < \infty$; $0 \le \delta < \infty$	$\left(1-(1-t)^{\theta}\right)^{-\delta}-1$		$2-2^{1/\theta}$
BB8 (joe-Frank)	$\frac{1}{\theta}\left(1-\left[1-\frac{1}{1-(1-\delta)^{\theta}}\left(1-(1-\delta x_1)^{\theta}(1-\delta x_2)^{\theta}\right)\right]^{\frac{1}{\delta}}\right)$	$1 \le \theta < \infty$; $0 \le \delta \le 1$	$-\ln\left[\frac{1-(1-\delta t)^{\theta}}{1-(1-\delta)^{\theta}}\right]$		$2-2^{1/\theta}$, when $\delta = 1$ Otherwise, $\boldsymbol{\lambda_{up}} = 0$
Note: θ is the copula dependence parameter of monoparametric copulas; θ & δ jointly are the copula dependence parameters for bi-parametric (or 2-parameter) Archimedean copulas such as BB1, BB6, BB7 & BB8					

ST 3. Basic descriptive statistics of the targeted compound flooding characteristics

Compound flood variables	Descriptive statistics
Annual maximum 24-hr rainfall (mm)	Min.: 33.00
	1st Quartile.: 63.42
	Median: 79.50
	Mean: 80.68
	3rd Quartile.: 93.35
	Max.:146.00
	Min.: -0.1950
	1st Quartile.: 0.0680
	Median: 0.2380

Maximum storm surge (m) (time interval = ±1days)	Mean: 0.2269
	3rd Quartile.: 0.3583
	Max.: 0.6580
Maximum river discharge (m3/sec) (time interval = ±1 days)	Min.: 760
	1st Quartile.:1085
	Median: 1615
	Mean: 1864
	3rd Quartile.:2162
	Max.: 5440

ST 4. The autocorrelation (or serial correlation) test using Q-statistics for individual flood characteristics

Flood variables	Test statistics	Lag size 30	Lag size 20	Lag size 10	Lag size 5
Annual maximum 24-hr rainfall (mm)	X-squared (Q-statistics)	23.812	13.917	5.4392	2.6815
	p-value	0.7804	0.8347	0.86	0.7489
Maximum storm surge (m) (Time interval = ±1days)	X-squared (Q-statistics)	29.54	25.836	14.499	10.403

	p-value	0.4894	0.1713	0.1514	0.06459
Maximum river discharge(m3/sec) (Time interval = ±1days)	X-squared (Q-statistics)	24.393	16.899	6.7806	2.3418
	p-value	0.7539	0.6595	0.746	0.8001
Critical value		43.77	31.4104	18.307	11.0705
Null Hypothesis is H_0		Accept (5% (0.05) level of significance or 95% (0.95) Confidence interval)	Accept (5% (0.05) level of significance or 95% (0.95) Confidence interval)	Accept (5% (0.05) level of significance or 95% (0.95) Confidence interval)	Accept (5% (0.05)level of significance or 95% (0.95) Confidence interval)
Existence of serial correlation within time series of flood characteristics		No	No	No	No
Hypothesis Testing H_0: The data exhibited no serial correlation (or autocorrelation). H_a: The data exhibited serial correlation.					

ST 5. Nonparametric Mann-Kendall (M-K) and modified M-K test for identifying monotonic time trend behavior within individual flood characteristics

Mann-Kendall (M-K) test						Modified Mann-Kendall (M-K) test		Investigation result	
Flood characteristics	Calculated Z value	Critical Z value	Sen's slope	S	Var (S)	Corrected Z_c	Corrected	Null Hypot	Existence of

		(Significance level $\alpha = 0.05\ or\ 5$)					Variance (V)	hesis H_0	Trend
Annual maximum 24-hr rainfall(mm)	z = 0.32195 (p-value = 0.7475)	±1.96	7.000000e-02	3.500000e+01	1.115300e+04	3.219460e-01(p-value = 7.474936e-01)	1.094507e+03	Accept	No
Maximum storm surge (m) (Time interval = ±1days)	z = 2.85 (p-value=0.004371)	±1.96	6.344828e-03	3.020000e+02	1.115400e+04	6.789031e+00 (p-value = 1.128892e-11)	1.965701e+03	Reject	Yes
Maximum river discharge(m3/sec) (Time interval = ±1days)	z= -0.45451 (p-value=0.6495)	±1.96	-3.8857143	-49.0000000	11153.0000000	-1.1613047 (p-value = 0.2455180)	1708.4022259	Accept	No

Note:

H_0 (Null hypothesis) = Time-invariant behavior within time series.

H_a (Alternate hypothesis) = Existence of monotonic time trend behavior within time series

Conclusion: Rejection of Null hypothesis $\mathbf{H_0}$ clearly reveals the existence of monotonic time trend behavior within time series of Maximum Storm Surge (m) (Time interval = ±1days) observations

Where;

Corrected Z_c = Z statistic after variance Correction; Sen's Slope = Sen's slope

ST 6. Test for homogeneity of selected flood variables

Flood variables	Pettitt (Estimated p-value)	SNHT test	Buishand	von Neumann	Overall conclusion
Annual Maximum 24-hr Rainfall (mm)	0.362 > 0.05 (significance level)	0.739 > 0.05 (significance level)	0.747 > 0.05 (significance level)	0.749 > 0.05 (significance level)	Time series is homogenous
Storm Surge (m) (Time interval = ±1days)	0.167 > 0.05 (significance level)	0.030 < 0.05 (significance level)	0.088 < 0.05 (significance level)	0.032 < 0.05 (significance level)	Time series is not homogenous
River Discharge (m3/sec) (Time interval = ±1 days)	0.777 > 0.05 (significance level)	0.734 > 0.05 (significance level)	0.558 > 0.05 (significance level)	0.315 > 0.05 (significance level)	Time series is homogenous
Note: The p-value has been computed using 10000 Monte Carlo simulations.					

ST 7. Selection of the univariate marginal probability distribution

		Estimated parameters of the candidate functions		
1-D parametric distributions	Probability density function (PDFs)	Annual maximum 24-hr Rainfall (mm)	Maximum storm surge (m) (Time interval = ±1days)	Maximum river discharge (Time interval = ±1 days)
Gamma	$f(x) = \frac{x^{\alpha-1}}{\beta^{\alpha}\Gamma(\alpha)} e^{\frac{-x}{\beta}}$ $\alpha \text{ (shape)} > 0,\ \beta\text{(rate)} > 0$	α (shape) = 11.66 β(rate) = 0.14	NA	α (shape) = 3.75 β(rate) = 0.002

Lognormal	$f(x) = \frac{e^{-0.5\left(\frac{\ln(x)-\mu}{\sigma}\right)^2}}{(x)\sigma\sqrt{2\pi}}$ $\sigma > 0$ (shape parameter); μ (scale parameter);	meanlog (σ (shape)) = 4.34 sdlog (μ (scale)) = 0.29	NA	meanlog (σ (shape)) = 7.39 sdlog (μ (scale)) = 0.50
Logistic	$f(x) = \frac{e^{-\frac{(x-\mu)}{s}}}{s(1+e^{-\frac{(x-\mu)}{s}})^2}$ $\mu =$ location, $s =$ scale, $x \in (-\infty, \infty)$	μ (location) = 78.93 s (scale) = 13.20	μ (location) = 0.001 s (scale) = 0.098455885 (0.01	μ (location) = 16 s (scale) = 551.56
Weibull	$f(x) = \frac{\alpha}{\beta}\left(\frac{x}{\beta}\right)^{\alpha-1} e^{-\left(\frac{x}{\beta}\right)^{\alpha}}$ $\alpha > 0$ (shape), $\beta > 0$ (scale)	α (shape) = 3.48 β (scale) = 89.47	NA	α (shape) = 1.82 β (scale) = 2115.79
GEV (Generalized Extreme Value)	f(x) = $\frac{1}{\sigma}e^{-(1+kz)^{-1/k}}(1+kz)^{-1-1/k}$ for $k \neq 0$ $= \frac{1}{\sigma}e^{(-1-e^{(-z)})}$ for $k = 0$; k, σ, μ signifies for shape, scale & their location parameter, such that, $\sigma > 0$ & $z \equiv \frac{(x-\mu)}{\sigma}$ Domain : $1 + k\,(x-\mu)/\sigma$ for $k \neq 0$ & $-\infty < x < +\infty$ for $k = 0$	μ (location) = 70.38 *k* (scale) = 20.42 *σ* (shape) = -0.079	μ (location) = -0.05 k (scale) = 0.18 σ (shape) = -0.36	μ (location) = 1272.80 k (scale) = 519.36 σ (shape) = 0.47
Gumbel (or Gumbel Max)	$f(x) = \frac{1}{\sigma}e^{(-z-e^{-z})}$, where $z = \frac{x-\mu}{\sigma}$ Domain: $-\infty < x < +\infty$ $\mu =$ scale, $\sigma > 0 =$ location	σ (location) = 69.53 μ (scale) = 20.09	σ (location) = -0.08 μ (scale) = 0.18	σ (location) = 1404.26 μ (scale) = 674.33

Normal (Gaussian)	$f(x) = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{1}{2}\left(\frac{x-\mu}{\sigma}\right)^2}$ $\mu \in \mathbb{R} = \text{mean(location)},\ \sigma^2 > 0 = \text{variance (squared scale)}$	μ (mean) = 80.67 σ (sd) = 24.00	μ (mean) = -7.966529e-19 σ (sd) = 1.726996e-01	μ (mean)= 1864.391 (164.3877) σ (sd) = 1114.666 (116.2062)
Note: NA indicates the given is not applicable to model storm surges observation due to some of its negative value.				

ST 8. Goodness-of-fit (GOF) test statistics of the fitted univariate distributions

		1-D FITTED PARAMETRIC FAMILY FUNCTION						
Compound flood variables	Fitness test statistics	Gamma	Lognormal	Logistic	Weibull	GEV	Gumbel (or Gumbel Max)	Normal
Annual maximum 24-hr rainfall (mm)	Kolmogorov-Smirnov statistic (K-S)	D = 0.077, p-value = 0.945	D = 0.070, p-value = 0.975	D = 0.069, p-value = 0.979	D = 0.121, p-value = 0.508	**D = 0.067, p-value = 0.984**	D = 0.074, p-value = 0.959	D = 0.113, p-value = 0.594
	Anderson-Darling statistic (A-D)	An = 0.224, p-value = 0.982	An = 0.198, p-value = 0.990	An = 0.346, p-value = 0.898	An = 0.735, p-value = 0.528	**An = 0.192, p-value = 0.992**	An = 0.216, p-value = 0.985	An = 0.574, p-value = 0.671
	CVM	omega2 = 0.02873 p-value = 0.981	omega2 = 0.027, p-value = 0.984	omega2 = 0.033, p-value = 0.966	omega2 = 0.102, p-value = 0.575	**omega2 = 0.025, p-value = 0.988**	omega2 = 0.032, p-value = 0.969	omega2 = 0.077, p-value = 0.711
Maximum storm surge (m) (Time	Kolmogorov-Smirnov statistic (K-S)	NA	NA	D = 0.090, p-value = 0.813	NA	D = 0.097, p-value = 0.732	D = 0.152, p-value = 0.210	**D = 0.088, p-value = 0.835**

interval = ±1days)	Anderson-Darling statistic (A-D)	NA	NA	An = 0.401, p-value = 0.847	NA	An = 0.375, p-value = 0.872	An = 1.210, p-value = 0.263	**An = 0.362, p-value = 0.884**
	CVM	NA	NA	omega2 = 0.067, p-value = 0.768	NA	omega2 = 0.064, p-value = 0.790	omega2 = 0.164, p-value = 0.348	**omega2 = 0.056, p-value = 0.835**
Maximum river discharge (Time interval = ±1 days	Kolmogorov-Smirnov statistic (K-S)	D = 0.144, p-value = 0.292	D = 0.125, p-value = 0.459	D = 0.157, p-value = 0.204	D = 0.142, p-value = 0.307	**D = 0.097, p-value = 0.777**	D = 0.145, p-value = 0.285	D = 0.160, p-value = 0.184
	Anderson-Darling statistic (A-D)	An = 1.0496, p-value = 0.331	An = 0.595, p-value = 0.651	An = 1.587, p-value = 0.157	An = 1.568, p-value = 0.161	**An = 0.348, p-value = 0.897**	An = 0.978, p-value = 0.368	An = 2.644, p-value = 0.041
	CVM	omega2 = 0.140, p-value = 0.419	omega2 = 0.079, p-value = 0.69	omega2 = 0.160, p-value = 0.358	omega2 = 0.212, p-value = 0.245	**omega2 = 0.059, p-value = 0.817**	omega2 = 0.116, p-value = 0.511	omega2 = 0.395, p-value = 0.074
Note: GEV is selected as the best-fitted distribution for rainfall, normal distribution for storm surge, and GEV for river discharge series. All three selected functions exhibited the minimum value of K-S, A-D and CvM tests (indicated by bold letter)								

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ST 9. Estimating copula dependence parameters via maximum pseudo-likelihood (MPL) estimator and their GOF test statistics and tail dependence measures of flood pairs (a) rainfall-storm surge (b) storm surge- river discharge (c) rainfall-river discharge

(a) For flood pair rainfall-storm surge	N = 1000 (No. of bootstrap sampling)

Copula function	Parameter estimates (θ) via MPL	S_n	p-value
Frank	2.049	0.0192	0.9246
Clayton	0.5081	0.0241	0.5500
Gumbel-Hougaard (GH)	1.26	0.0222	0.6618
Joe	1.318	0.0376	0.1803
BB1 (Clayton-Gumbel copula)	θ = theta = 0.3487 δ = delta = 1.1083	0.0169	0.9076
BB6 (Joe – Gumbel copula)	θ = theta = 1.000; δ = delta = 1.26	0.0221	0.7827
BB7 (Joe- Clayton copula)	θ = theta = 1.153; δ = delta = 0.433	0.0168	0.9016
BB8 (Joe- Frank copula)	θ = theta = 6; δ = delta = 0.31	0.0207	0.8297
Survival Clayton (Rotated Clayton copula by 180 degree)	0.4277	0.0306	0.5569
Survival Joe (Rotated Joe copula by 180 degree)	1.392	0.0295	0.5799
Survival Gumbel (Rotated Gumbel copula by 180 degree)	1.279	0.0195	0.8526
Survival BB1 (Rotated BB1 by 180 degrees)	θ = theta = 0.1035; δ = delta = 1.2308	0.0173	0.8986
Survival BB6 (Rotated BB6 by 180 degrees)	θ = theta = 1; δ = delta = 1.279	0.0195	0.8347
Survival BB7 (Rotated BB7 by 180 degrees)	θ = theta = 1.3020; δ = delta = 0.2423	0.0177	0.8786
Survival BB8 (Rotated BB8 by 180 degrees)	θ = theta = 2.17; δ = delta = 0.79	0.0192	0.019209

(b) For flood pair storm surge-river discharge		N = 1000 (No. of bootstrap sampling)	
Copula family	Parameter estimates (θ)	S_n	p-value
Frank	3.689	0.025026	0.5519
Clayton	0.8136	0.0501	0.07642
Gumbel-Hougaard (GH)	1.554	0.0177	0.8497
Joe	1.763	0.0280	0.3452
BB1 (Clayton-Gumbel copula)	θ = theta = 0.2297; δ = delta =1.4250	0.0187	0.8596
BB6 (Joe – Gumbel copula)	θ = theta =1.000 δ = delta = 1.554	0.0178	0.8776
BB7 (Joe- Clayton copula)	θ = theta = 1.5744 ; δ = delta = 0.5152	0.0189	0.8177
BB8 (Joe- Frank copula)	θ = theta = 3.8068; δ = delta = 0.6979	0.0198	0.8217
Survival Clayton (Rotated Clayton copula by 180 degree)	0.9023	0.0248	0.6948
Survival Joe (Rotated Joe copula by 180 degree)	1.649	0.0580	0.1683
Survival Gumbel (Rotated Gumbel copula by 180 degree)	1.518	0.0317	0.489
Survival BB1 (Rotated BB1 by 180 degrees)	θ = theta = 0.4843; δ = delta = 1.2712	0.0179	0.8556
Survival BB6 (Rotated BB6 by 180 degrees)	θ = theta = 1; δ = delta = 1.518	0.0317	0.53
Survival BB7 (Rotated BB7 by 180 degrees)	θ = theta = 1.367; δ = delta = 0.736	0.0183	0.8576

Survival BB8 (Rotated BB8 by 180 degrees)	θ = theta = 6; δ = delta = 0.48	0.0300	0.53

(c) For flood pair rainfall-river discharge		N = 1000 (No. of bootstrap sampling)	
Copula family	Parameter estimates (θ)	S_n	p-value
Frank	0.8414	0.0349	0.2293
Clayton	0.1276	0.0460	0.2193
Gumbel-Hougaard (GH)	1.104	0.0324	0.2363
Joe	1.156	0.0344	0.2323
BB1 (Clayton-Gumbel copula)	θ = theta = 1.665e − 07; δ = delta =1.104	0.0568	0.1444
BB6 (Joe – Gumbel copula)	θ = theta = 1; δ = delta = 1.1	0.0332	0.49
BB7 (Joe- Clayton copula)	θ = theta =1.1440 ; δ = delta =0.0295	0.0332	0.489
BB8 (Joe- Frank copula)	θ = theta = 1.5413; δ = delta = 0.7538	0.0529	0.1643
Survival Clayton (Rotated Clayton copula by 180 degree)	0.2052	0.0320	0.5210
Survival Joe (Rotated Joe copula by 180 degree)	1.152	0.0414	0.3701
Survival Gumbel (Rotated Gumbel copula by 180 degree)	1.112	0.0349	0.4820
Survival BB1 (Rotated BB1 by 180 degrees)	θ = theta = 0.1094; δ = delta = 1.0676	0.0297	0.5809
Survival BB6 (Rotated BB6 by 180 degrees)	θ = theta = 1; δ = delta = 1.112	0.0349	0.4630

Survival BB7 (Rotated BB7 by 180 degrees)	θ = theta = 1.0957; δ = delta = 0.1504	0.0292	0.5859
Survival BB8 (Rotated BB8 by 180 degrees)	θ = theta = 6; δ = delta = 0.15	0.0352	0.501

ST 10. Upper tail dependence coefficient (UTDC) measure of selected 2-D copulas

Flood pairs	Selected best-fitted 2-D copulas	Parametric coefficient of upper tail dependence (UTDC), λ_{up}	Non-Parametric coefficient of upper tail dependence (or empirical estimates), λ_{up}^{CFG}
Rainfall-Storm surge	BB7 (Joe- Clayton copula)	0.18	0.19
Storm surge-River discharge	Gumbel-Hougaard (GH)	0.43	0.34
Rainfall-River discharge	Survival BB7 (Rotated BB7 by 180 degrees)	0.0100	0.11
Note: The selected copulas exhibited minimum difference between parametric and nonparametric estimates of upper tail dependence coefficient (where nonparametric or empirical estimates of upper tail dependence λ_{up}^{CFG} estimators are suggested by Caperaa et al., 1997 and Frahm et al., 2005).			

ST 11. Fitting 2-D copulas in constructing second Tree-2 of D-vine structure-1 (case 1, when river discharge is a conditioning variable))

Selecting best-fitted copula in Tree-2, for case 1 (Conditioning variable - Maximum River discharge (Time interval = ±1 days))		Cramer von Mises functional statistics with parametric bootstrap procedure (N = 1000 (No. of bootstrap samples))	
Copula function	Parameter estimates (θ) via MPL	S_n	p-value
Clayton	0.3688	0.013216	0.9456
Gumbel-Hougaard (GH)	1.137	0.03482	0.1533
Frank	1.793	0.024211	0.6738

Joe	1.083	0.06362	0.01349
BB1 (Clayton-Gumbel copula)	θ = theta = 0.3688; δ = delta = 1	0.032113	0.527
BB6 (Joe – Gumbel copula)	θ = theta = 1; δ = delta = 1.135	0.051557	0.2622
BB7 (Joe- Clayton copula)	θ = theta = 1; δ = delta = 0.3691	0.032081	0.511
BB8 (Joe- Frank copula)	θ = theta = 6; δ = delta = 0.26	0.033576	0.492
Survival Clayton (Rotated Clayton copula by 180 degree)	0.1633	0.06925	0.1154
Survival Joe (Rotated Joe copula by 180 degree)	1.283	0.037065	0.4191
Survival Gumbel (Rotated Gumbel copula by 180 degree)	1.195	0.031274	0.537
Survival BB1 (Rotated BB1 by 180 degrees)	θ = theta = 5.436e − 08; δ = delta = 1.195	0.031274	0.5669
Survival BB6 (Rotated BB6 by 180 degrees)	$\theta = theta = 1; \delta = delta = 1.195$	0.031274	0.526
Survival BB7 (Rotated BB7 by 180 degrees)	$\theta = theta = 1.279787; \delta = delta = 0.008032$	0.036663	0.4441
Survival BB8 (Rotated BB8 by 180 degrees)	$\theta = theta = 1.7693; \delta = delta = 0.8966$	0.0197	0.8387
Note: Clayton copula (minimum value of S_n goodness-of-fit test statistics with p-value greater than 0.05) is identified as the most parsimonious 2-D copula in deriving the bivariate joint probability relationship in Tree-2 for case 1.			

ST 12. Fitting 2-D copulas in the second Tree-2 of the D-vine structure-2 (case 2, when storm surge is a conditioning variable)

Selecting best-fitted copula in Tree-2, for case 2 (Conditioning variable - Maximum storm surge (Time interval = $\pm$1 days))	Cramer von Mises functional statistics with parametric bootstrap procedure (N = 1000 (No. of bootstrap samples))

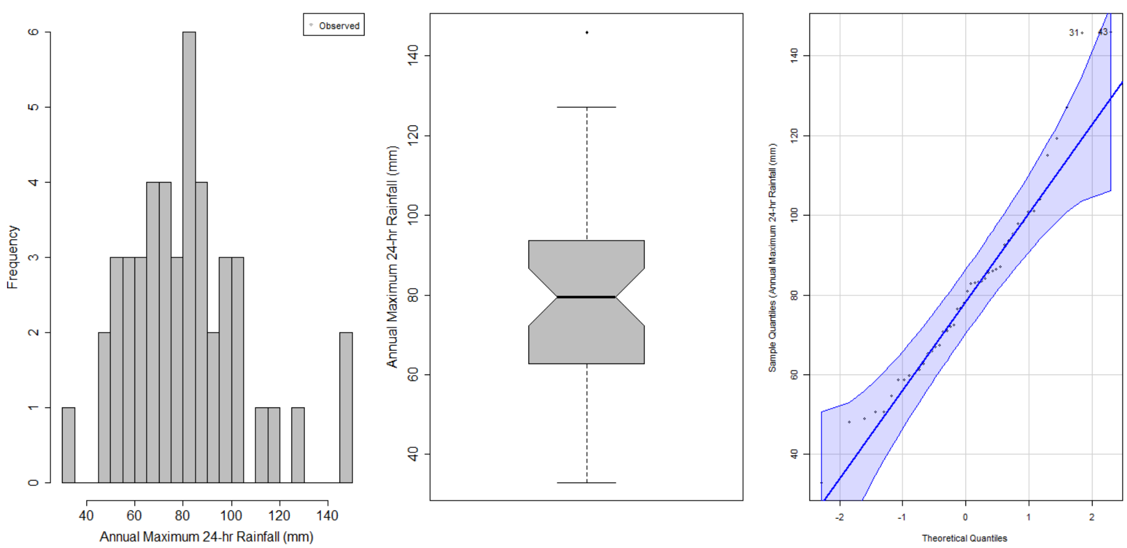
Copula function	Parameter estimates (θ) via MPL	S_n	p-value
Rotated Joe 90 degrees	-1.116	0.037336	0.4301
Rotated Gumbel 90 degrees	-1.076	0.039112	0.3871
Frank	-0.5235	0.041928	0.1014
Gaussian (or Normal)	-0.08233	0.043431	0.1823
Rotated BB1 90 degrees	θ = theta = par = -2.020e-08 δ = delta = par2 = -1.076	0.039112	0.4191
Rotated BB6 90 degrees	θ = theta = par = -1.11, δ = delta = par2 = -1	0.036546	0.4271
Rotated BB7 90 degrees	θ = theta = par = -1.117; δ = delta = par2 = -4.870e-08	0.037469	0.4001
Rotated BB8 90 degrees	θ = theta = par = -1.1901 δ = delta = par2 = -0.9672	0.042311	0.3821
Rotated BB1 270 degrees	θ = theta = par = -0.1157 δ = delta = par2 = -1.0324	0.042865	0.3492
Rotated BB6 270 degrees	θ = theta = par = -1 δ = delta = par2 = -1.07	0.036776	0.4131
Rotated BB7 270 degrees	θ = theta = par = -1.0518 δ = delta = par2 = -0.1287	0.042953	0.3472
Rotated BB8 270 degrees	θ = theta = par =-1.083 δ = delta = par2 = -1.000	0.031903	0.525
Note: Rotated BB8 270 degrees (minimum value of S_n goodness-of-fit test statistics with p-value greater than 0.05) is identified as the most parsimonious 2-D copula in deriving the bivariate joint probability relationship in the Tree-2 for case 2.			

ST 13. Fitting 2-D copulas in the second Tree-2 of the D-vine structure-2 (case 3, when rainfall is a conditioning variable)

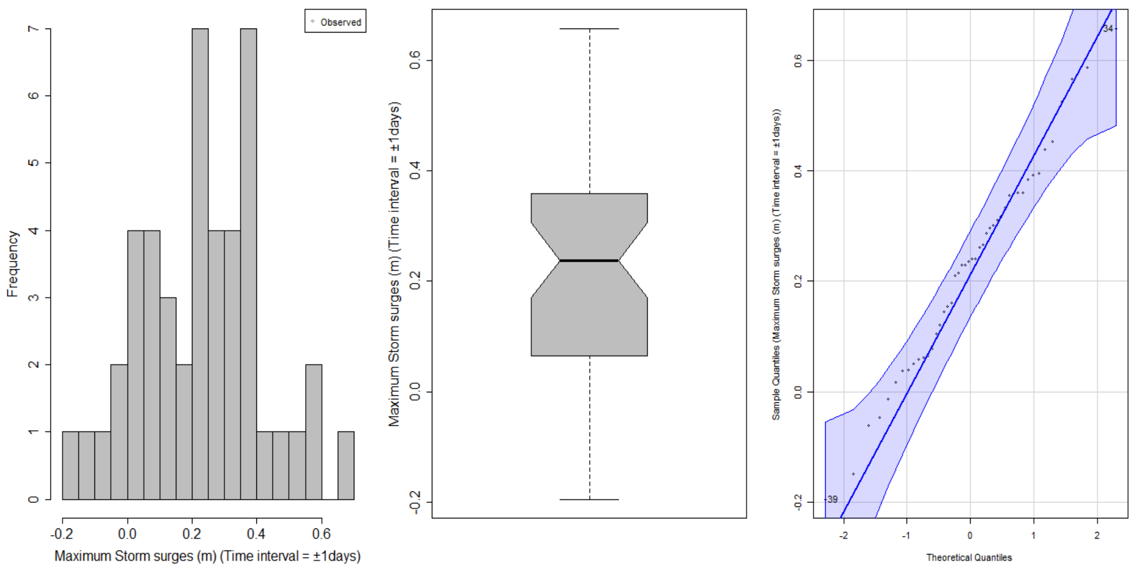
Selecting best-fitted copula in Tree-2, for case 3 (Conditioning variable - Annual maximum 24-hr rainfall) as center)		Cramer von Mises functional statistics with parametric bootstrap procedure (N = 1000 (No. of bootstrap samples))	
Copula function	Parameter estimates (θ) via MPL	S_n	p-value
Clayton	0.5898	0.058732	0.03846
Gumbel-Hougaard (GH)	1.506	0.027761	0.3062
Frank	3.689	0.020912	0.7897
Joe	1.688	0.053483	0.03147
BB1 (Clayton-Gumbel copula)	$\theta = \text{theta} = 0.1497; \delta = \text{delta} = 1.4002$	0.034008	0.4471
BB6 (Joe – Gumbel copula)	$\theta = \text{theta} = 1; \delta = \text{delta} = 1.506$	0.032806	0.468
BB7 (Joe- Clayton copula)	$\theta = \text{theta} = 1.4865; \delta = \text{delta} = 0.3679$	0.043757	0.3252
BB8 (Joe- Frank copula)	$\theta = \text{theta} = 6; \delta = \text{delta} = 0.5$	0.022662	0.7348
Survival Clayton (Rotated Clayton copula by 180 degree)	0.8046	0.051335	0.2143
Survival Joe (Rotated Joe copula by 180 degree)	1.467	0.10204	0.03147
Survival Gumbel (Rotated Gumbel copula by 180 degree)	1.406	0.056986	0.1783
Survival BB1 (Rotated BB1 by 180 degrees)	$\theta = \text{theta} = 0.4547; \delta = \text{delta} = 1.2104$	0.036916	0.3931
Survival BB6 (Rotated BB6 by 180 degrees)	$\theta = theta = 1; \delta = delta = 1.406$	0.056986	0.1643
Survival BB7 (Rotated BB7 by 180 degrees)	$\theta = theta = 1.2198; \delta = delta = 0.6657$	0.043056	0.2892

Survival BB8 (Rotated BB8 by 180 degrees)	$\theta = theta = 6$; $\delta = delta = 0.48$	0.031583	0.509
Note: Frank copula (minimum value of S_n goodness-of-fit test statistics with p-value greater than 0.05) is identified as the most parsimonious 2-D copula in deriving the bivariate joint probability relationship in Tree-2 for case 3.			

Supplementary Figures (SFs)

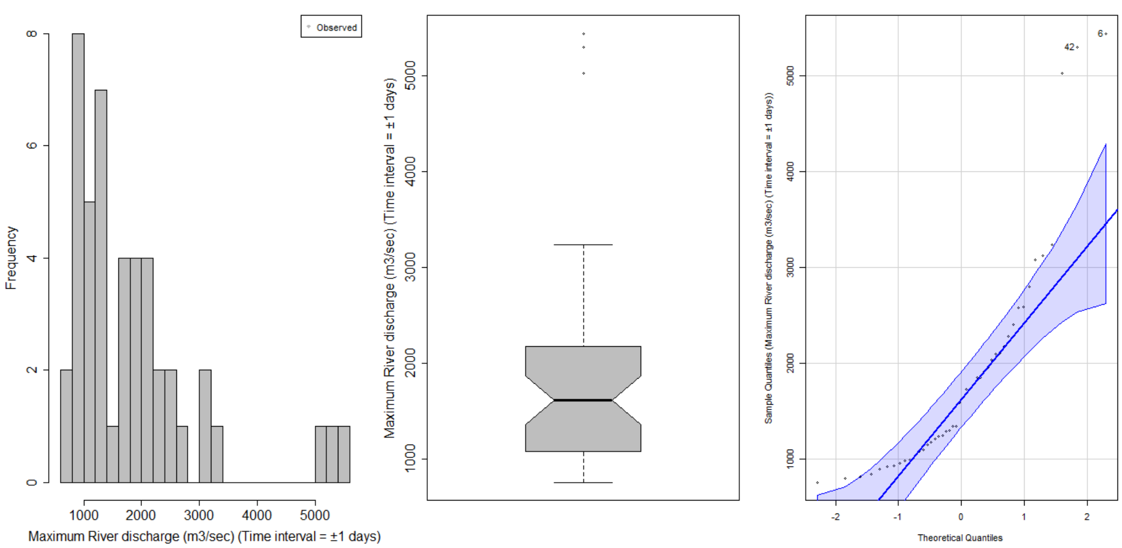


(a)



Observed
Frequency
Maximum Storm surges (m) (Time interval = ±1days)
Maximum Storm surges (m) (Time interval = ±1days)
Sample Quantiles (Maximum Storm surges (m) (Time interval = ±1days))
Theoretical Quantiles

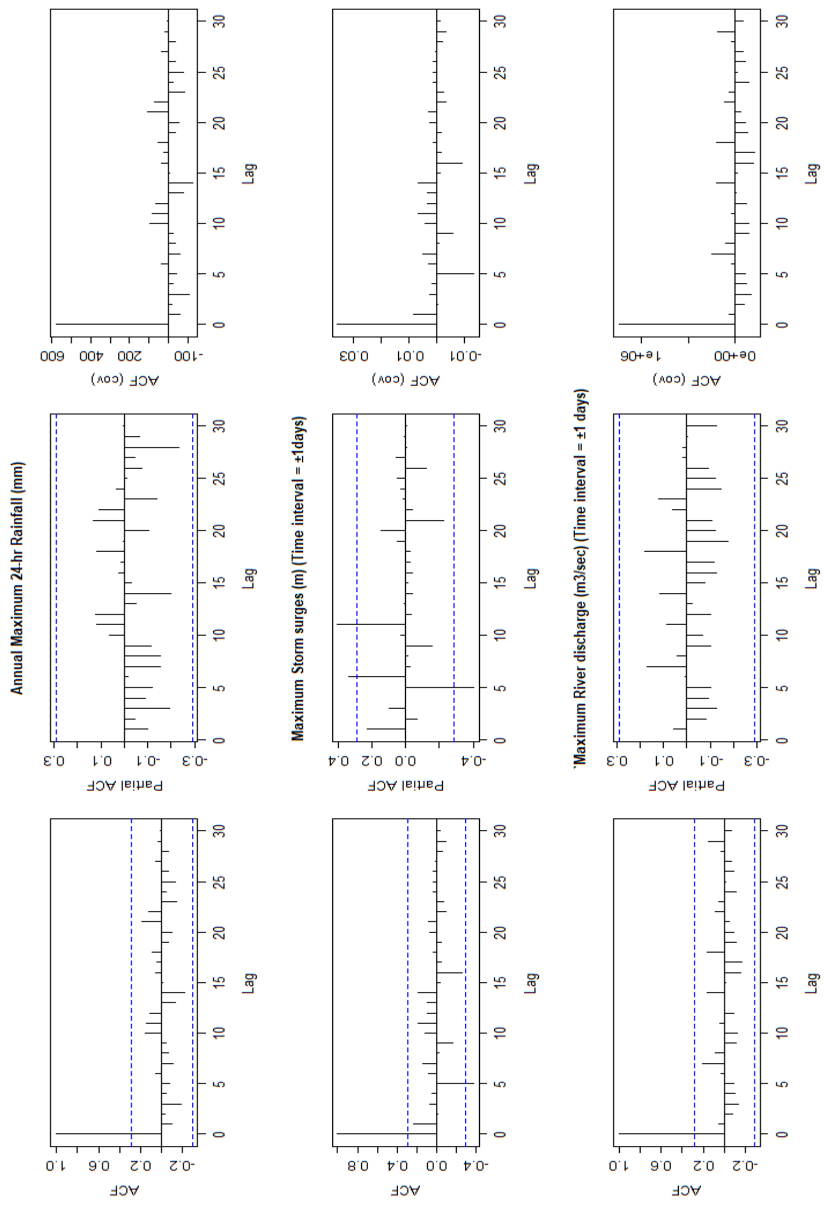
(b)



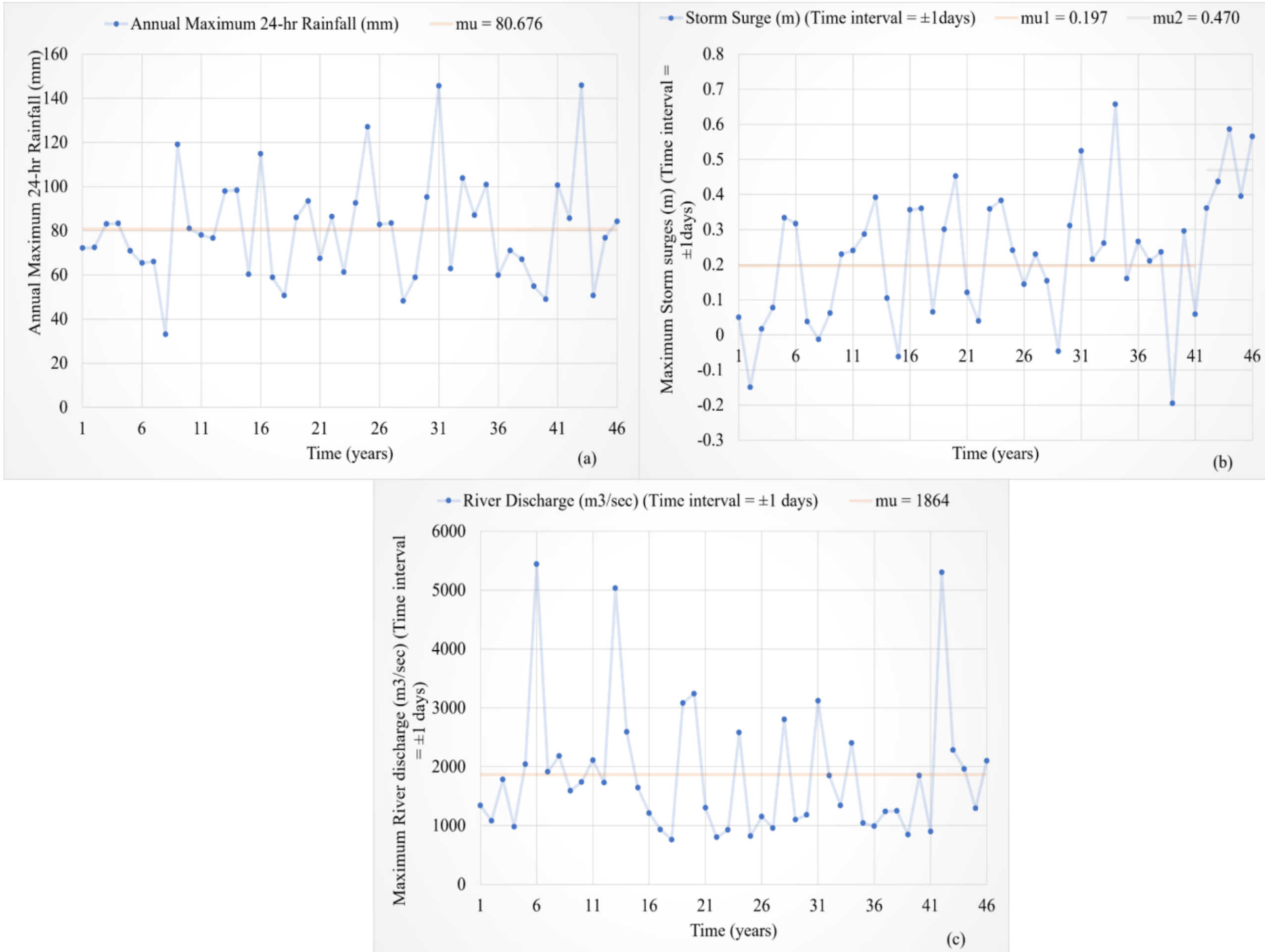
Observed
Frequency
Maximum River discharge (m3/sec) (Time interval = ±1 days)
Maximum River discharge (m3/sec) (Time interval = ±1 days)
Sample Quantiles (Maximum River discharge (m3/sec) (Time interval = ±1 days))
Theoretical Quantiles

(c)

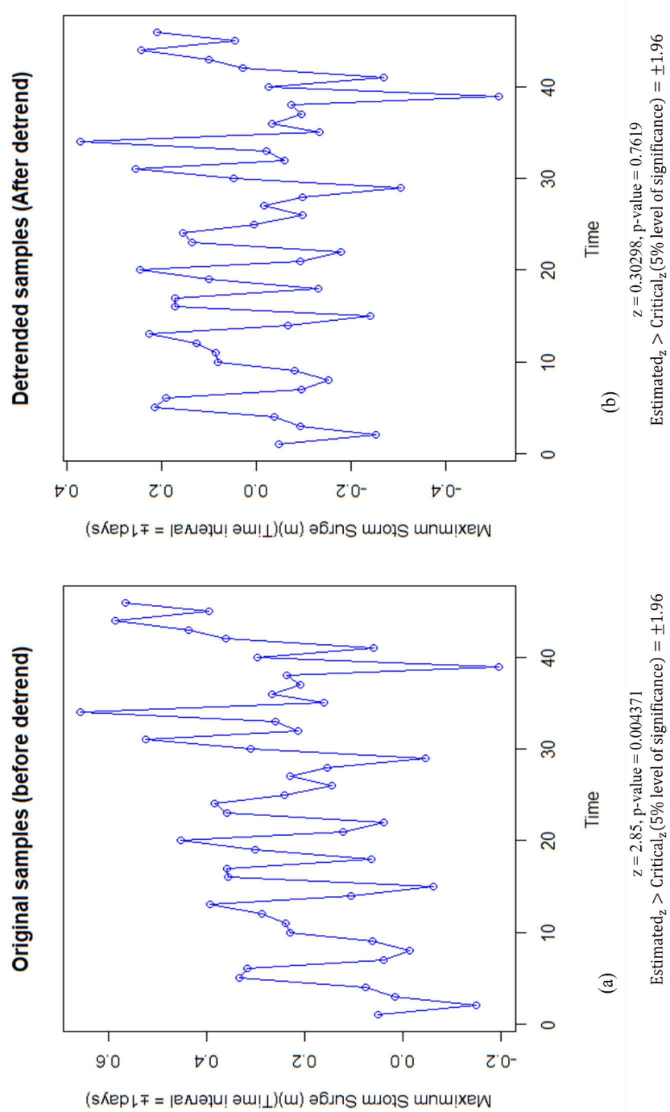
SF 1. Histogram plot, Box plot and Normal Q-Q (quantile-quantile) plot of selected flood characteristics (a) rainfall (R) (b) storm surges (SS) (c) river discharges (RD)



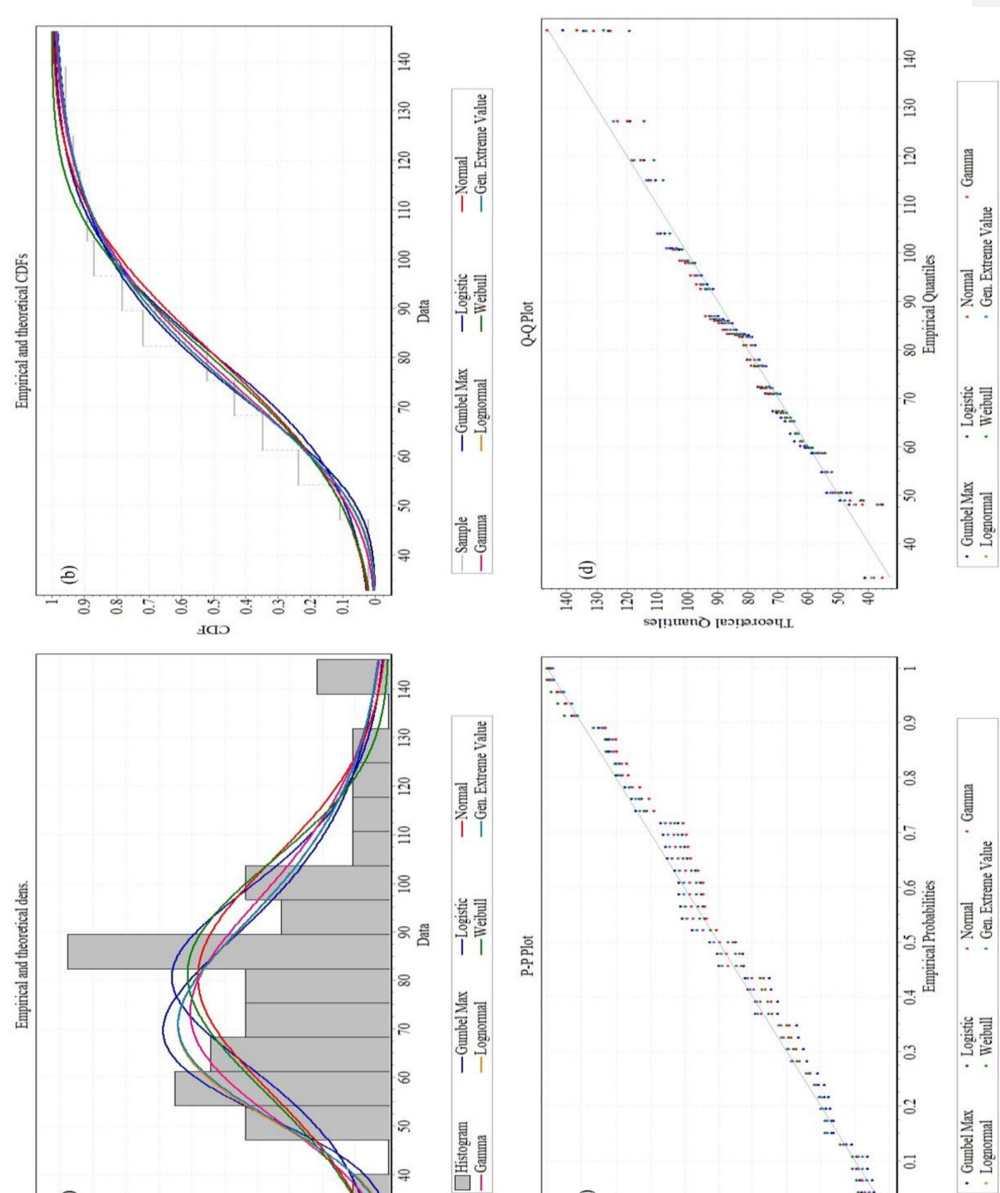
SF 2. Autocorrelation function (ACF) and partial ACF plots under different lag size


Annual Maximum 24-hr Rainfall (mm)
mu = 80.676
Annual Maximum 24-hr Rainfall (mm)
Time (years)
(a)
Storm Surge (m) (Time interval = ±1days)
mu1 = 0.197
mu2 = 0.470
Maximum Storm surges (m) (Time interval = ±1days)
Time (years)
(b)
River Discharge (m3/sec) (Time interval = ±1 days)
mu = 1864
Maximum River discharge (m3/sec) (Time interval = ±1 days)
Time (years)
(c)

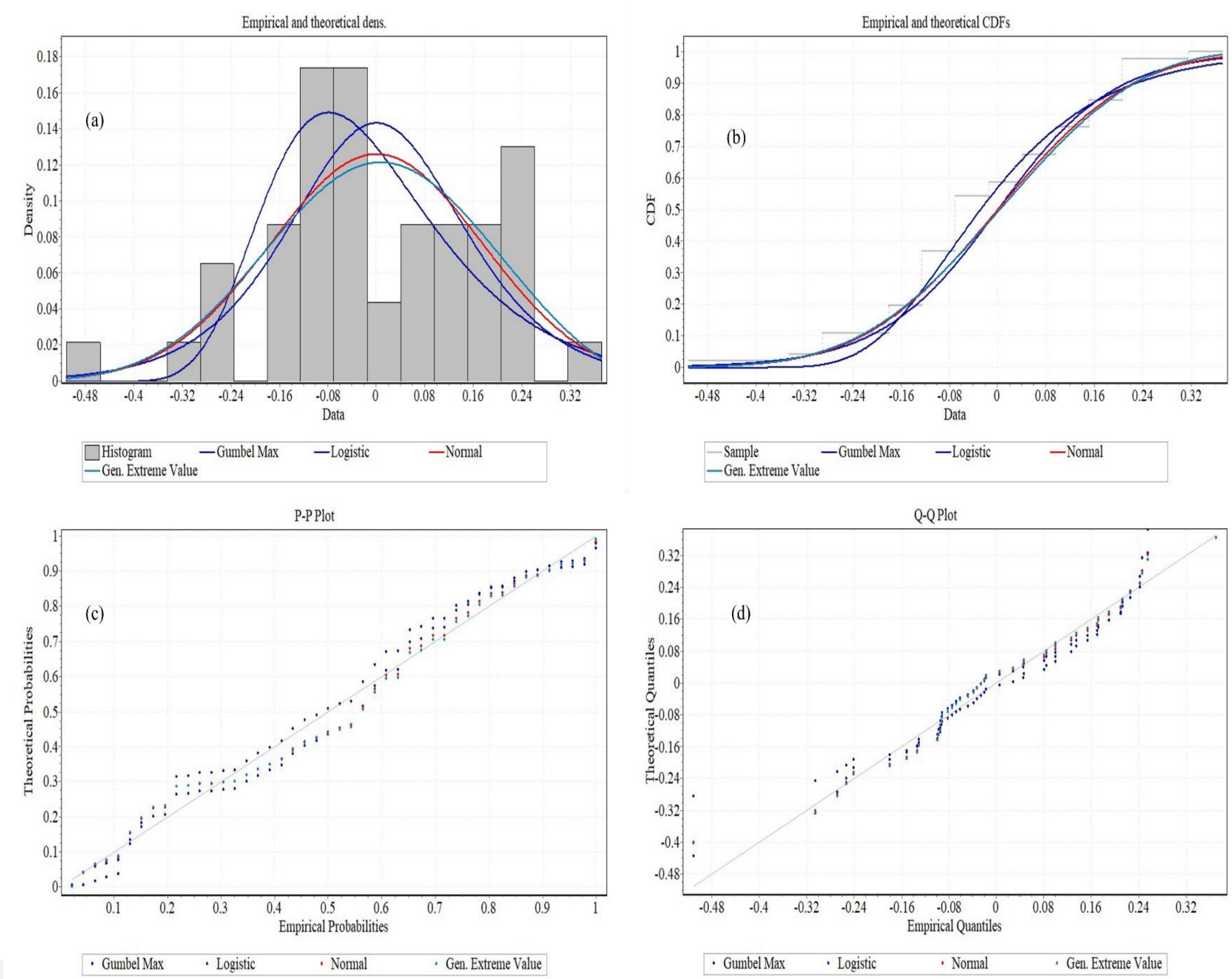
SF 3. Behavior of time series (a) annual maximum 24-hr rainfall (b) maximum storm surge (time interval = ±1 days) (c) maximum river discharge (time interval = ±1 days) [Note: Figure SF (b) indicates that time series of storm surge is not homogenous at two different times].



SF 4. Detrending or Prewhitening of the storm surge observations to remove time-trend behavior

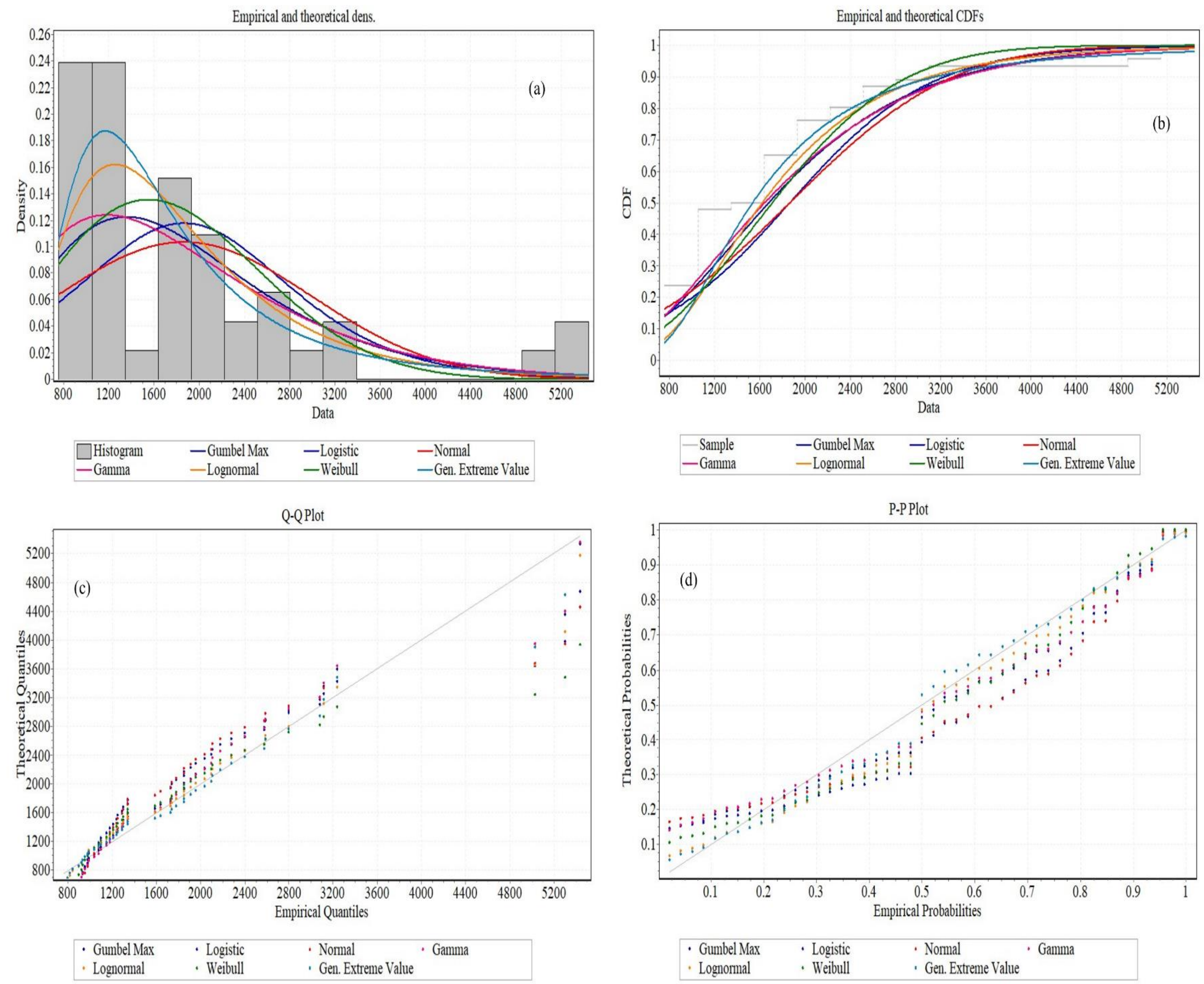

Empirical and theoretical dens.
(a)
Density
Data
Histogram
Gamma
Gumbel Max
Lognormal
Logistic
Weibull
Normal
Gen. Extreme Value
Empirical and theoretical CDFs
(b)
CDF
Data
Sample
Gamma
Gumbel Max
Lognormal
Logistic
Weibull
Normal
Gen. Extreme Value
P-P Plot
(c)
Theoretical Probabilities
Empirical Probabilities
Gumbel Max
Lognormal
Logistic
Weibull
Normal
Gen. Extreme Value
Gamma
Q-Q Plot
(d)
Theoretical Quantiles
Empirical Quantiles
Gumbel Max
Lognormal
Logistic
Weibull
Normal
Gen. Extreme Value
Gamma

(a)


Empirical and theoretical dens.
(a)
Density
Data
Histogram
Gumbel Max
Logistic
Normal
Gen. Extreme Value
Empirical and theoretical CDFs
(b)
CDF
Data
Sample
Gumbel Max
Logistic
Normal
Gen. Extreme Value
P-P Plot
(c)
Theoretical Probabilities
Empirical Probabilities
Gumbel Max
Logistic
Normal
Gen. Extreme Value
Q-Q Plot
(d)
Theoretical Quantiles
Empirical Quantiles
Gumbel Max
Logistic
Normal
Gen. Extreme Value

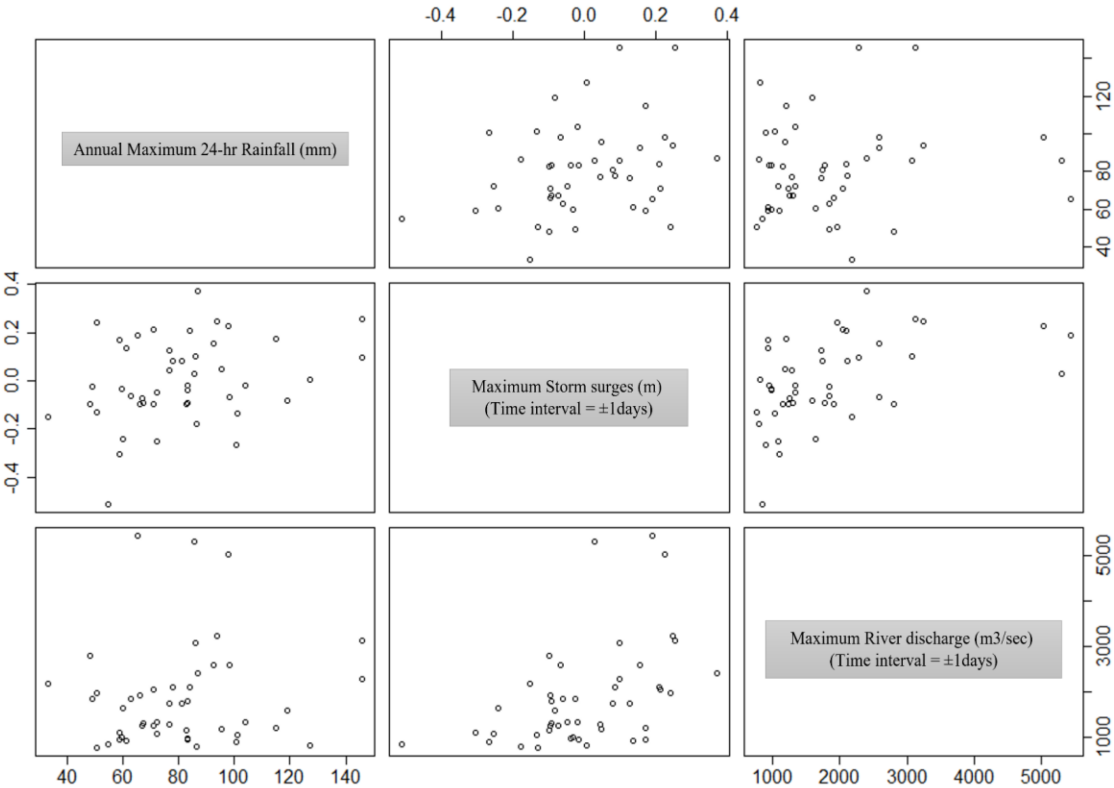
(b)

(c)

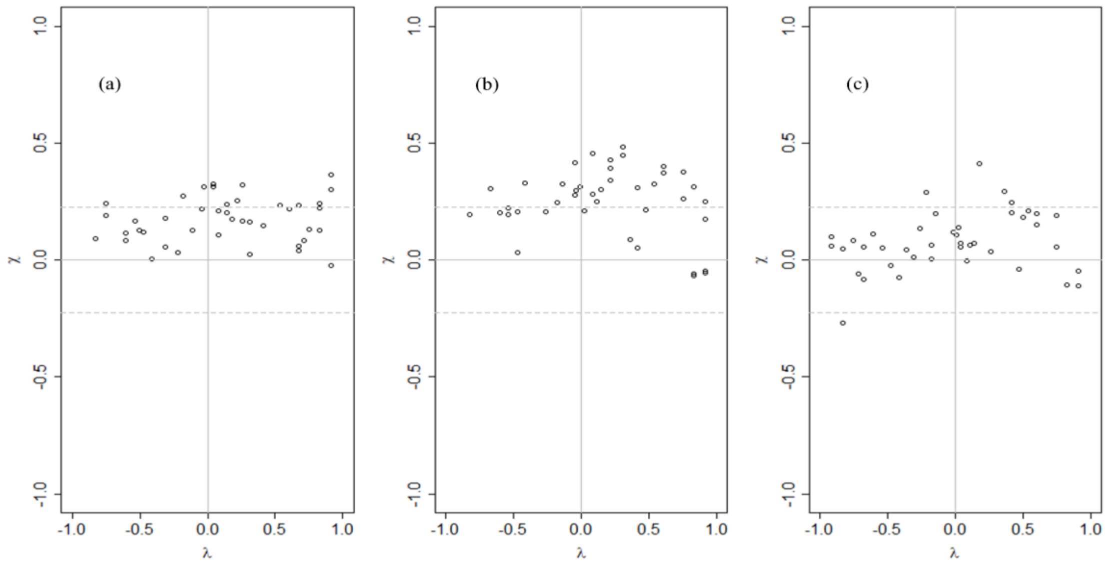


Empirical and theoretical dens.
(a)
Density
Data
Histogram
Gumbel Max
Logistic
Normal
Gamma
Lognormal
Weibull
Gen. Extreme Value
Empirical and theoretical CDFs
(b)
CDF
Data
Sample
Gumbel Max
Logistic
Normal
Gamma
Lognormal
Weibull
Gen. Extreme Value
Q-Q Plot
(c)
Theoretical Quantiles
Empirical Quantiles
Gumbel Max
Logistic
Normal
Gamma
Lognormal
Weibull
Gen. Extreme Value
P-P Plot
(d)
Theoretical Probabilities
Empirical Probabilities
Gumbel Max
Logistic
Normal
Gamma
Lognormal
Weibull
Gen. Extreme Value

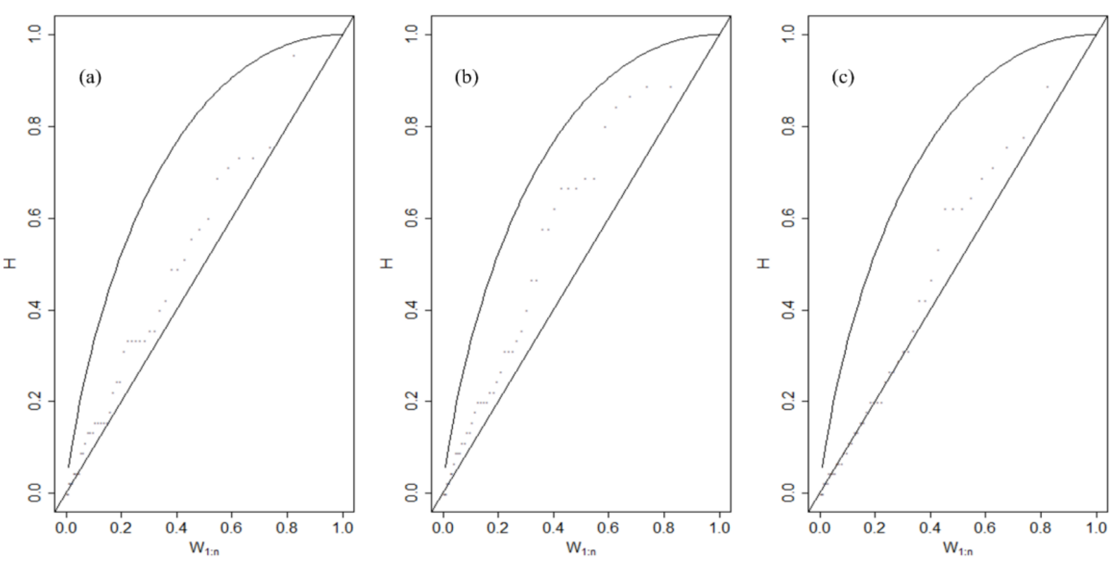
SF 5. Probability density function (PDF), cumulative distribution functions (CDF), quantile-quantile (Q-Q), and probability-probability (P-P) plot of candidate functions fitted to (a) rainfall (b) storm surge (c) river discharge series



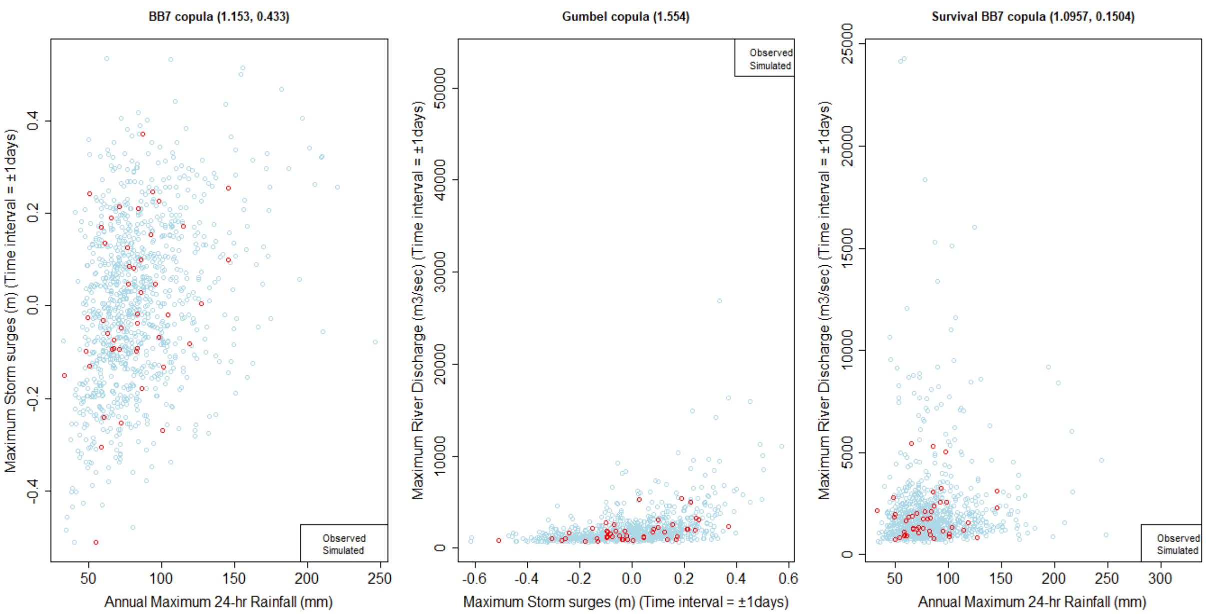
SF 6. 3-D scatterplot of selected flood characteristics



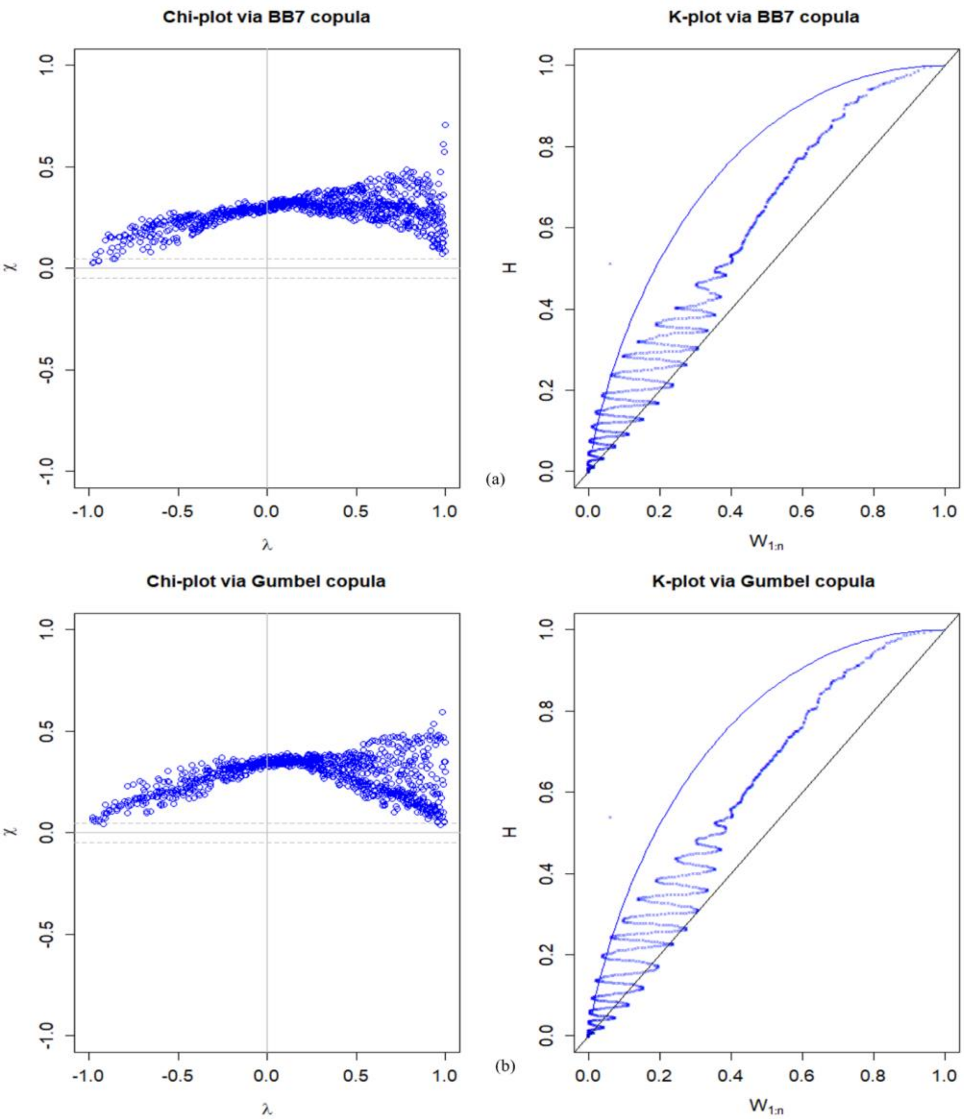
SF 7. Chi-plot between (a) rainfall (R)-storm surge (SS) (b) storm surge (SS)-river discharge (RD) (c) rainfall (R)-river discharge (RD)



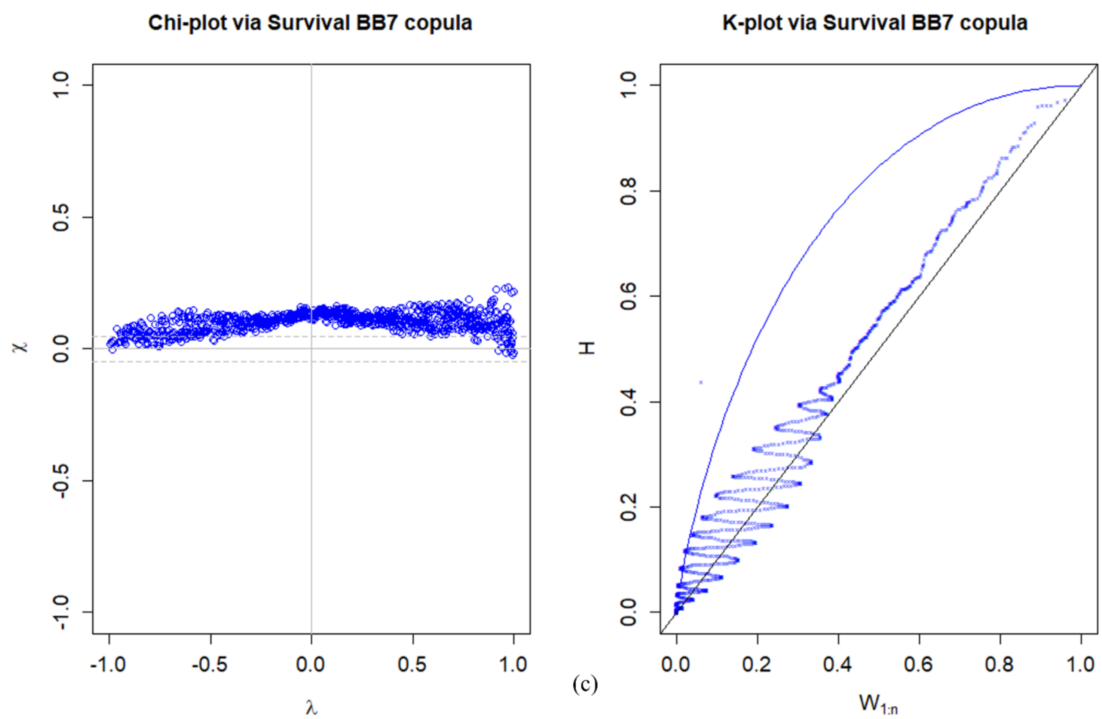
SF 8. Kendall's (K) plot between (a) rainfall (R) -storm surge (SS) (b) storm surge (SS) - river discharge (RD) (c) rainfall (R)-river discharge (RD)



SF 9. Overlapped 2-D scatterplot between observed and theoretical (sample size N=1000, obtained from best-fitted 2-D copulas, refer to ST 9 (a-c)) flood characteristics

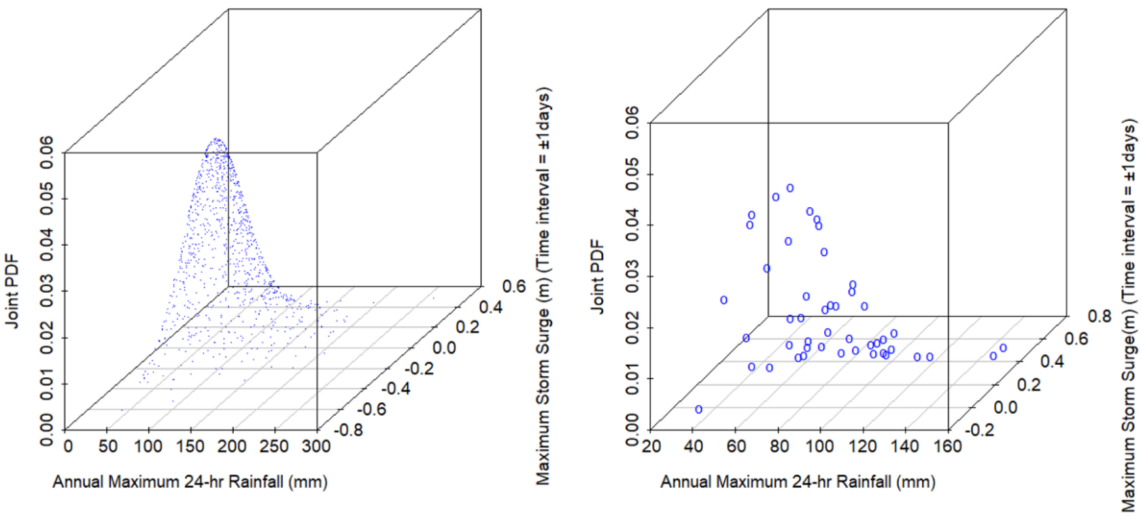


Chi-plot via BB7 copula
K-plot via BB7 copula
χ
λ
H
W1:n
(a)
Chi-plot via Gumbel copula
K-plot via Gumbel copula
χ
λ
H
W1:n
(b)

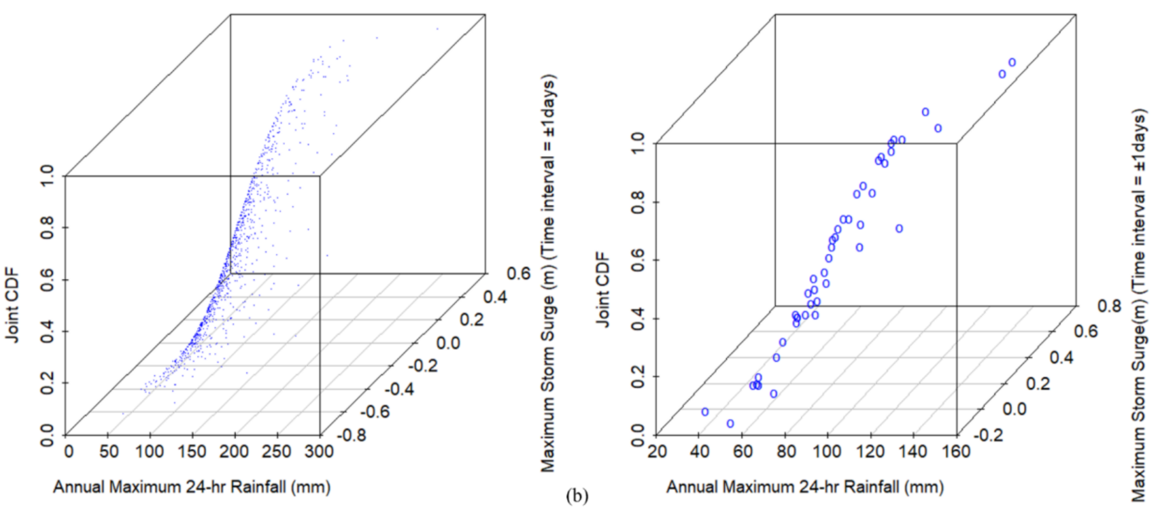


(c)

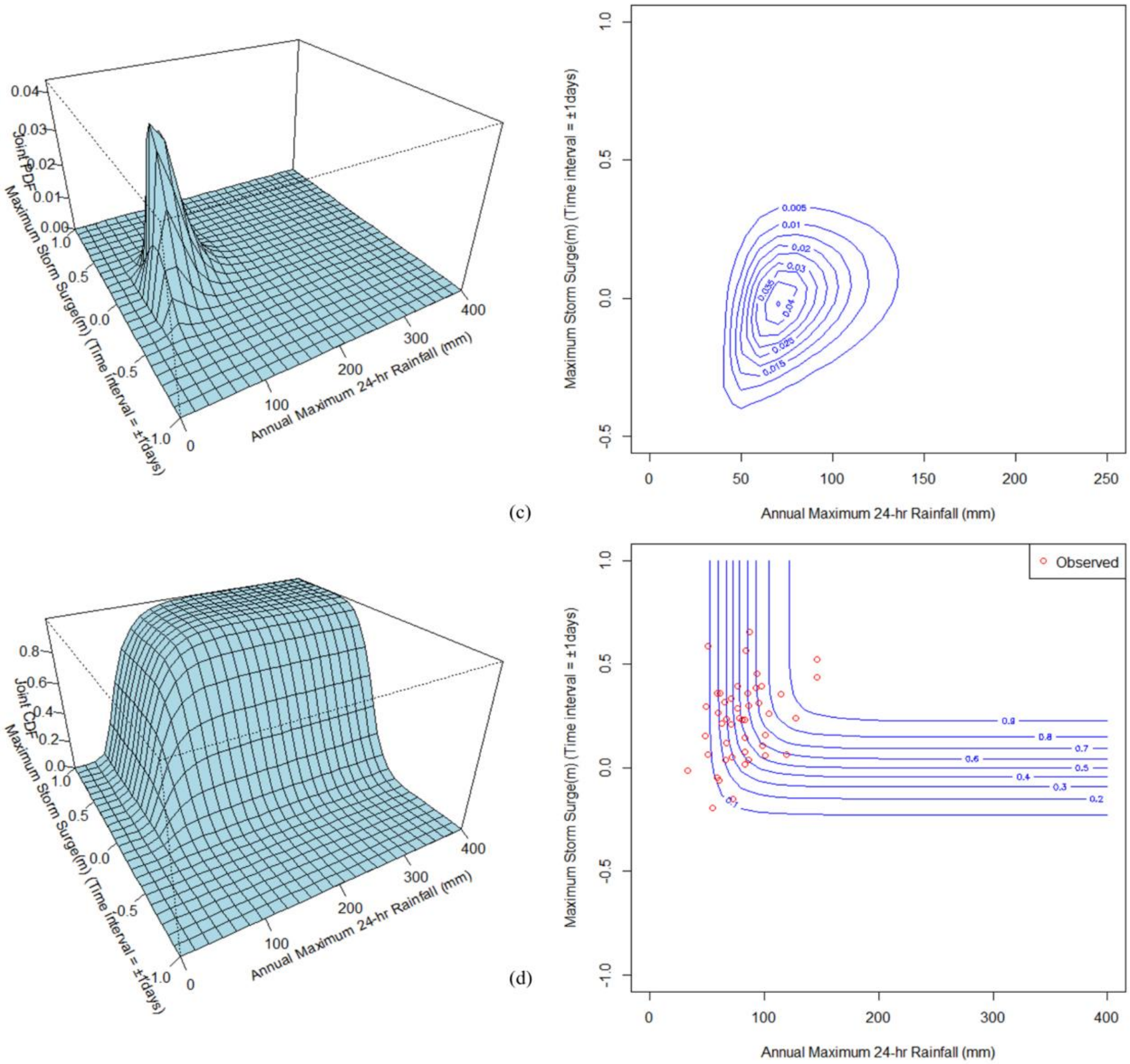
SF 10. Chi-plot and Kendall's (K) plot drawn using random sample (sample size, N=1000) simulated from the best fitted 2-copulas (refer to ST 9(a-c)) fitted to for flood pairs (a) Annual maximum 24-hr rainfall - Maximum storm surge (Time interval = ±1 days) (b) Maximum storm surge (Time interval = ±1 days) - Maximum river discharge (Time interval = ±1 days) (c) Annual maximum 24-hr rainfall - Maximum river discharge (Time interval = ±1 days).


Joint PDF
0.00
0.01
0.02
0.03
0.04
0.05
0.06
0
50
100
150
200
250
300
Annual Maximum 24-hr Rainfall (mm)
-0.8
-0.6
-0.4
-0.2
0.0
0.2
0.4
0.6
Maximum Storm Surge (m) (Time interval = ±1days)
Joint PDF
0.00
0.01
0.02
0.03
0.04
0.05
0.06
20
40
60
80
100
120
140
160
Annual Maximum 24-hr Rainfall (mm)
-0.2
0.0
0.2
0.4
0.6
0.8
Maximum Storm Surge(m) (Time interval = ±1days)

(a)

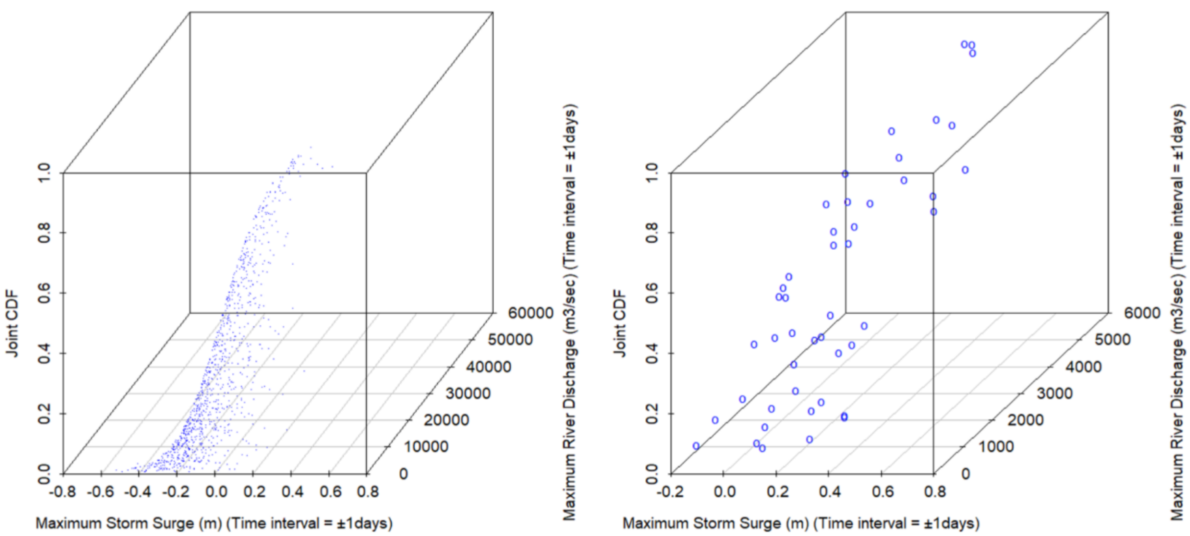

Joint CDF
0.0
0.2
0.4
0.6
0.8
1.0
0
50
100
150
200
250
300
Annual Maximum 24-hr Rainfall (mm)
-0.8
-0.6
-0.4
-0.2
0.0
0.2
0.4
0.6
Maximum Storm Surge (m) (Time interval = ±1days)
Joint CDF
0.0
0.2
0.4
0.6
0.8
1.0
20
40
60
80
100
120
140
160
Annual Maximum 24-hr Rainfall (mm)
-0.2
0.0
0.2
0.4
0.6
0.8
Maximum Storm Surge(m) (Time interval = ±1days)

(b)

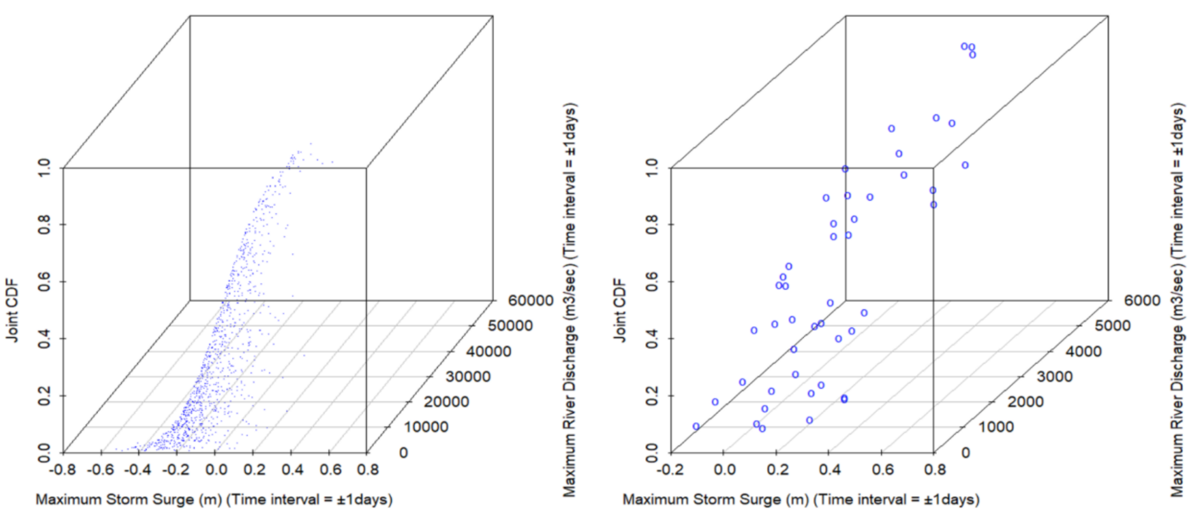


SF 11. Graphical illustration of the best-fitted BB7 copula in modeling dependence structure of the flood pair Annual maximum 24-hr rainfall (R) - Maximum storm surge (Time interval = ±1 days) (SS) via (a) 3-D scatterplot of the joint probability density functions (JPDF) plots (b) 3-D scatterplots of the joint cumulative

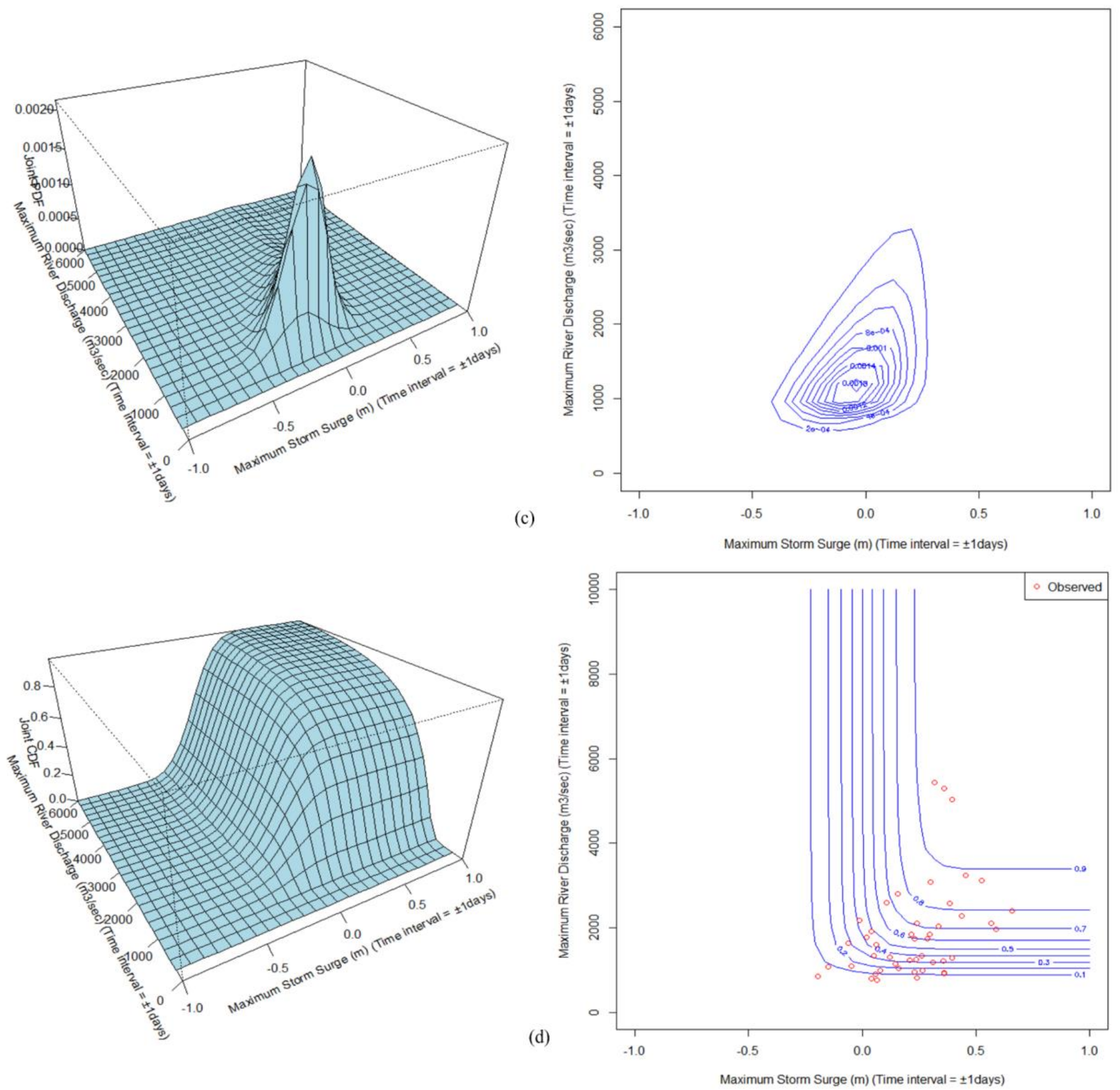
distribution functions (JCDF) plots (c) 3-D perspective plots of JCDF and their contour plot (d) 3-D perspective plot of JCDF and their contour plot


Joint CDF
Maximum Storm Surge (m) (Time interval = ±1days)
Maximum River Discharge (m3/sec) (Time interval = ±1days)
Joint CDF
Maximum Storm Surge (m) (Time interval = ±1days)
Maximum River Discharge (m3/sec) (Time interval = ±1days)

(a)

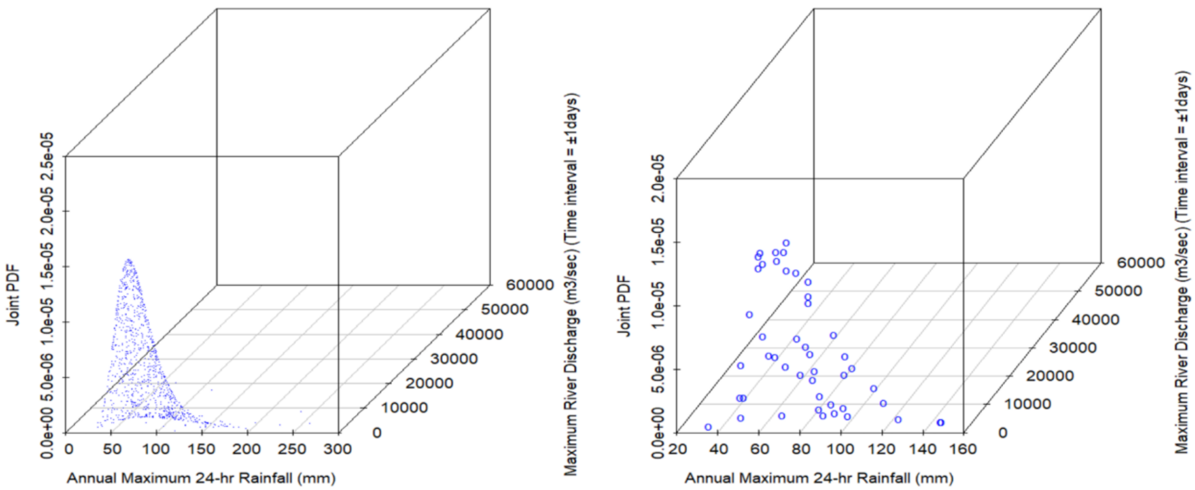

Joint CDF
Maximum Storm Surge (m) (Time interval = ±1days)
Maximum River Discharge (m3/sec) (Time interval = ±1days)
Joint CDF
Maximum Storm Surge (m) (Time interval = ±1days)
Maximum River Discharge (m3/sec) (Time interval = ±1days)

(b)

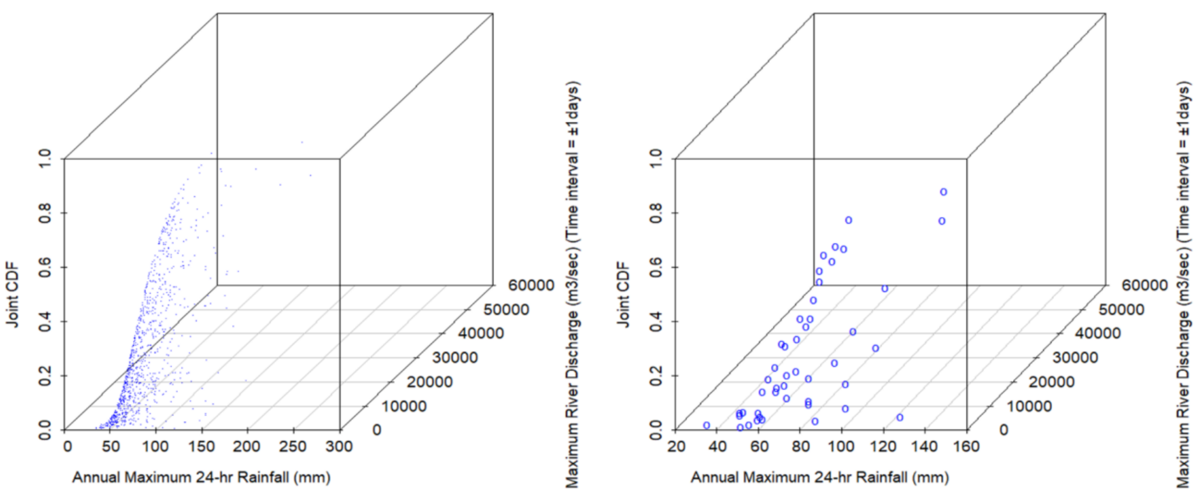


SF 12. Graphical illustration of best-fitted Gumbel-Hougaard (G-H) copula in modeling dependence structure of the flood pair Maximum storm surge (Time interval = ±1 days) (SS) - Maximum River discharge (Time interval = ±1 days) (RD) via (a) 3-D scatterplot of joint probability density functions (JPDF) plots (b)

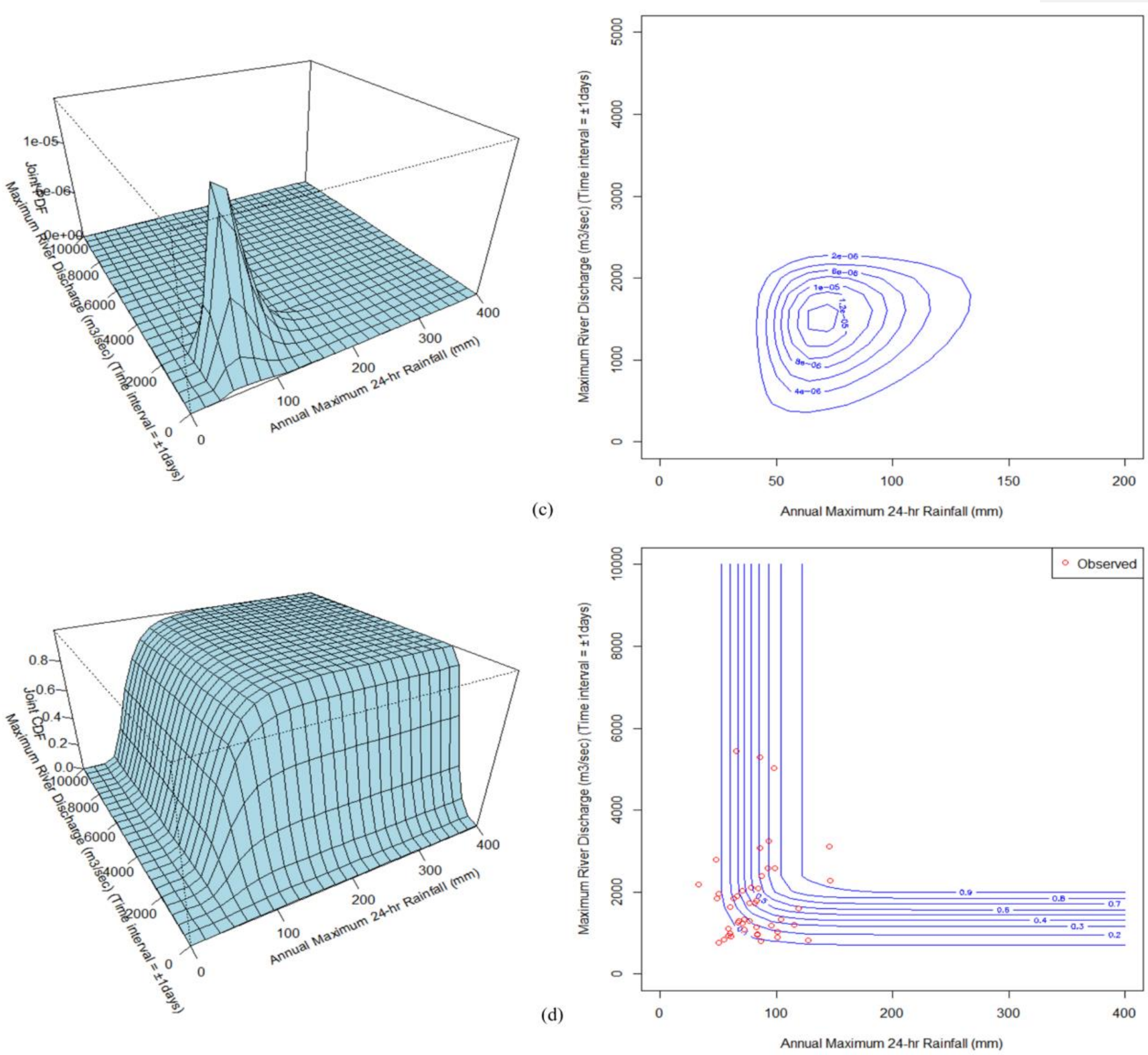
3-D scatterplots of joint cumulative distribution functions (JCDF) plots (c) 3-D perspective plots of JCDF and their contour plot (d) 3-D perspective plot of JCDF and their contour plot



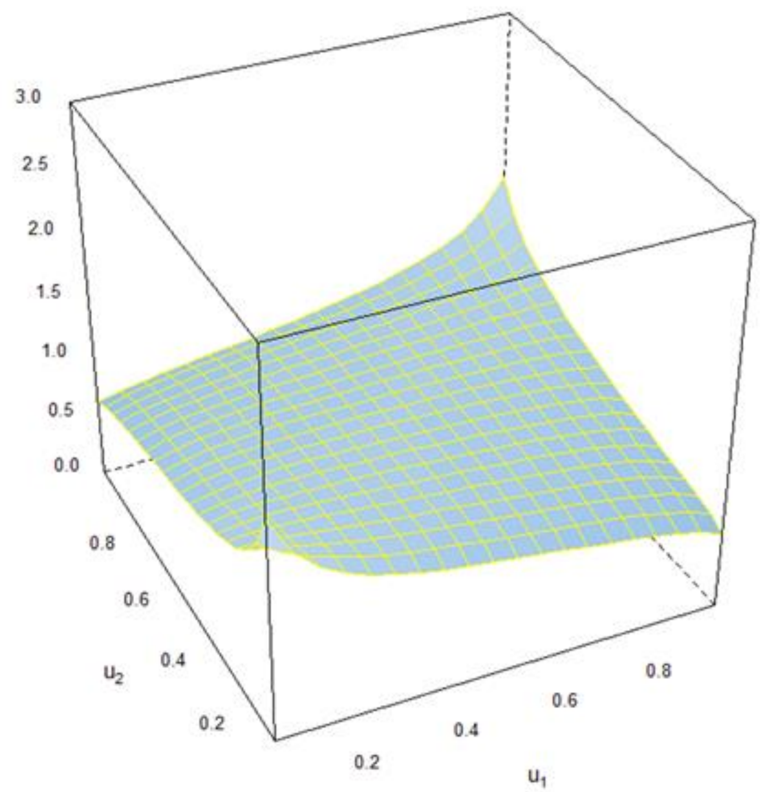
(a)



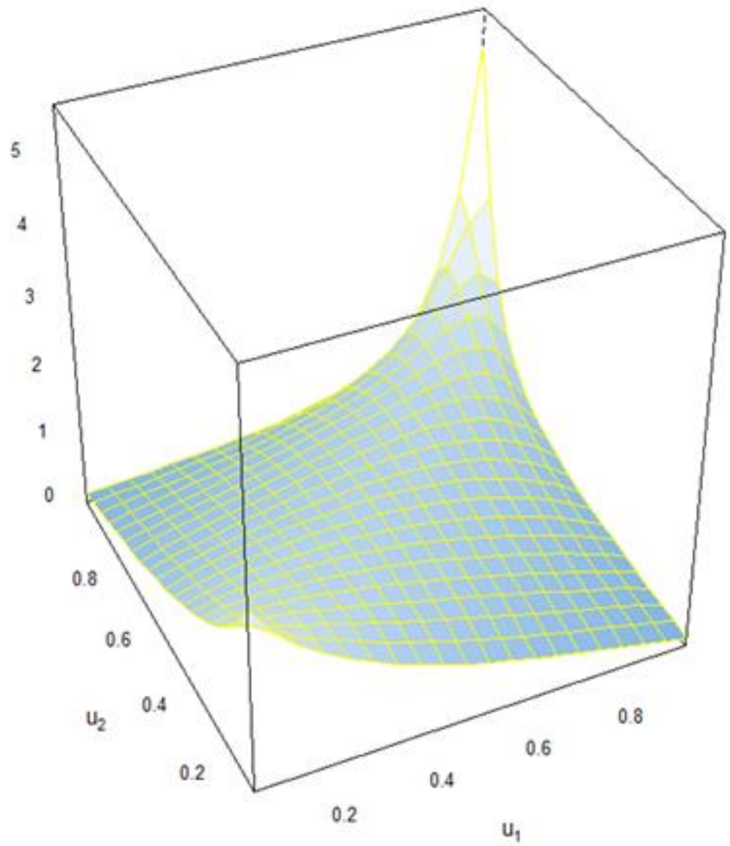
(b)



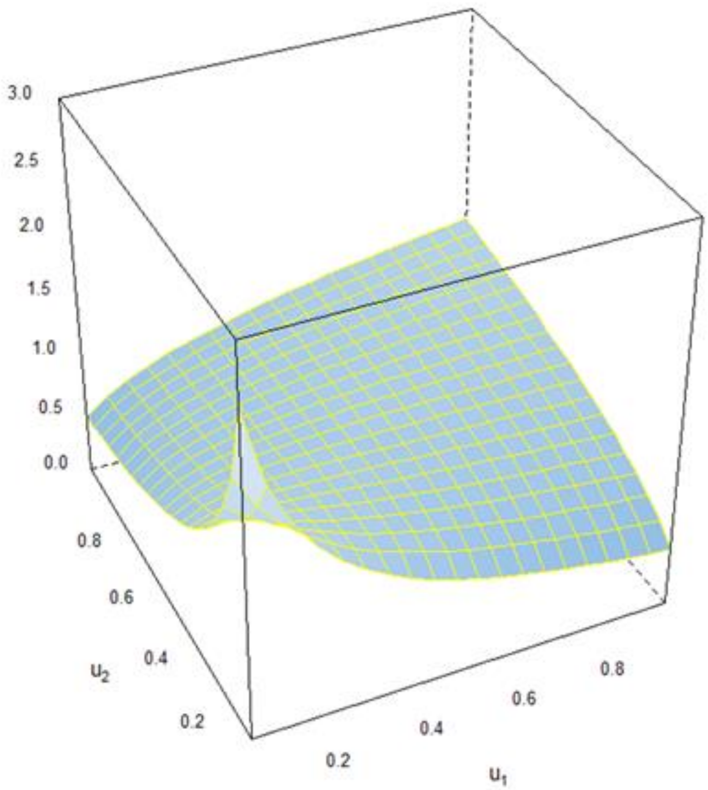
SF 13. Graphical illustration of best-fitted Survival BB7 copula in modeling dependence structure of the flood pair Annual maximum 24-hr rainfall (R) - Maximum River discharge (Time interval = ±1 days) (RD) via (a) 3-D scatterplot of joint probability density functions (JPDF) plots (b) 3-D scatterplots of joint cumulative distribution functions (JCDF) plots (c) 3-D perspective plots of JCDF and their contour plot (d) 3-D perspective plot of JCDF and their contour plot



(a)

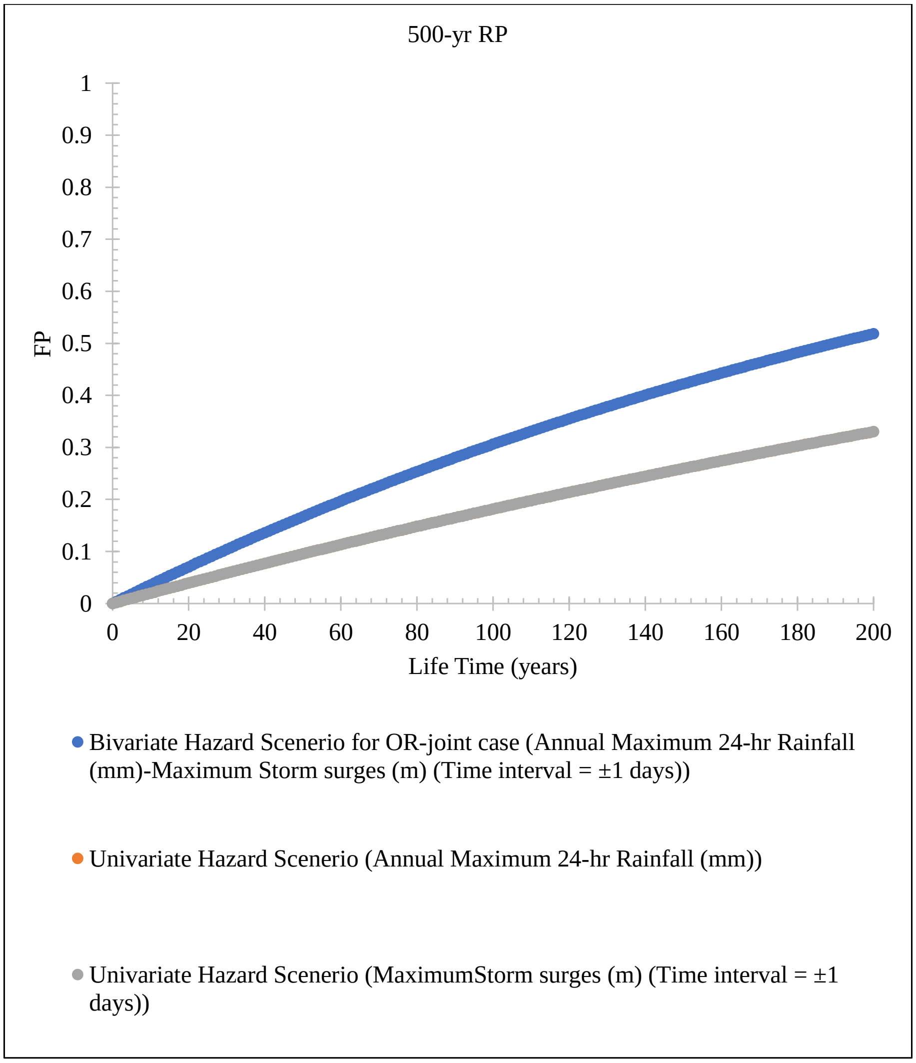


(b)



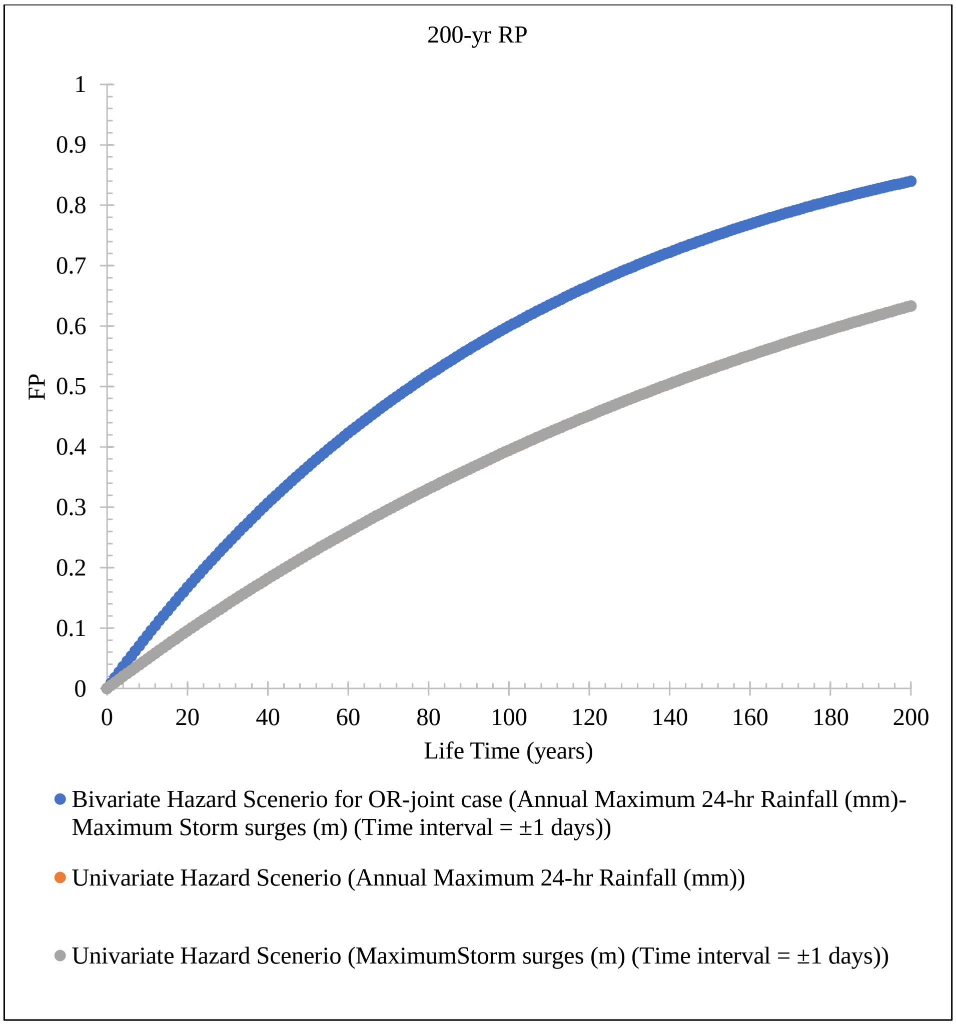
(c)

SF 14. Graphical illustration of the joint density of 2-D copulas families in the construction of 3-D D-vine copula structure-1 (case-1) (a) Survival BB7 copula fitted in Tree-1 (between rainfall (u_1) and river discharge (u_2)) (b) Gumbel copula fitted in Tree-1 (between storm surge (u_1) and river discharge (u_2) (c) Clayton copula fitted in Tree-2 (between rainfall and storm surge conditional to river discharge)

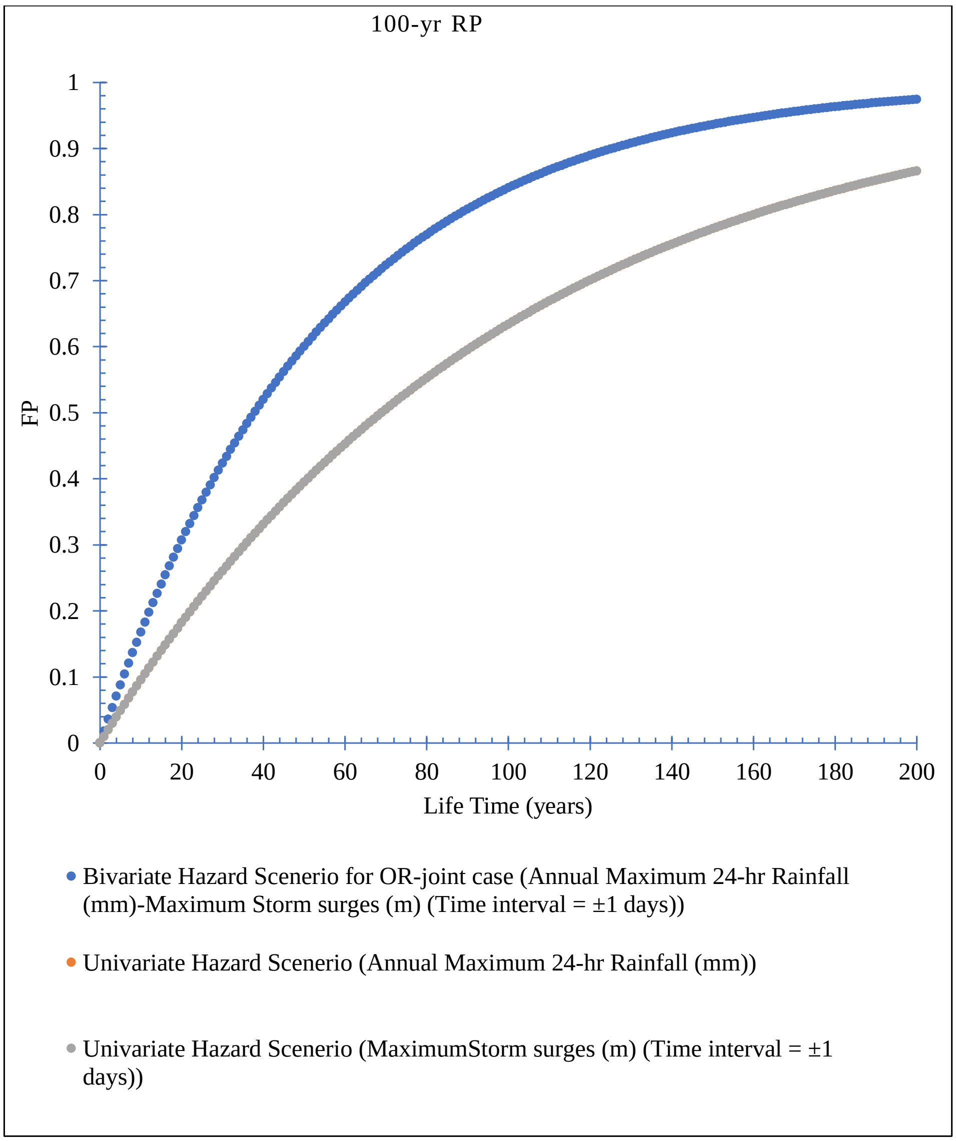


500-yr RP
FP
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
20
40
60
80
100
120
140
160
180
200
Life Time (years)
Bivariate Hazard Scenerio for OR-joint case (Annual Maximum 24-hr Rainfall (mm)-Maximum Storm surges (m) (Time interval = ±1 days))
Univariate Hazard Scenerio (Annual Maximum 24-hr Rainfall (mm))
Univariate Hazard Scenerio (MaximumStorm surges (m) (Time interval = ±1 days))

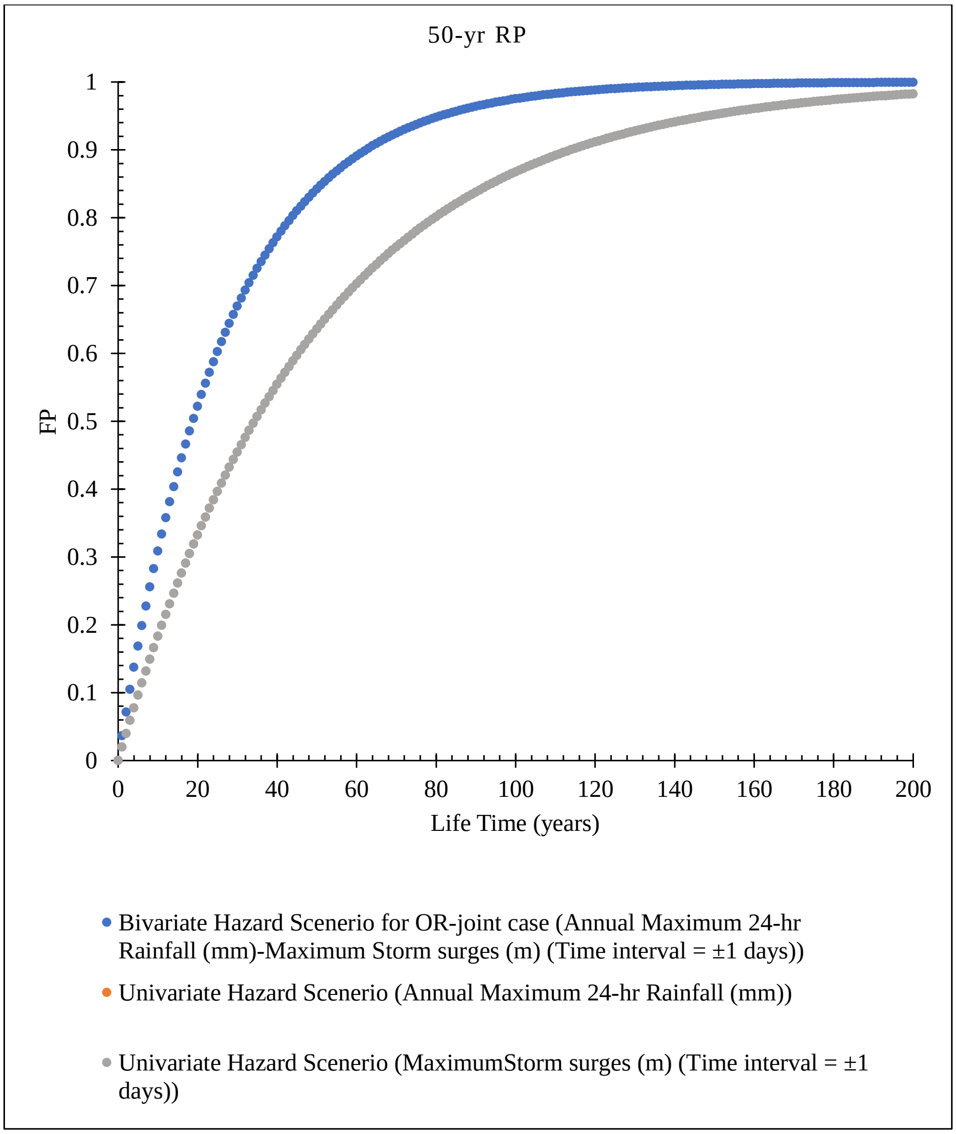
(a)


200-yr RP
FP
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
20
40
60
80
100
120
140
160
180
200
Life Time (years)
Bivariate Hazard Scenerio for OR-joint case (Annual Maximum 24-hr Rainfall (mm)-Maximum Storm surges (m) (Time interval = ±1 days))
Univariate Hazard Scenerio (Annual Maximum 24-hr Rainfall (mm))
Univariate Hazard Scenerio (MaximumStorm surges (m) (Time interval = ±1 days))

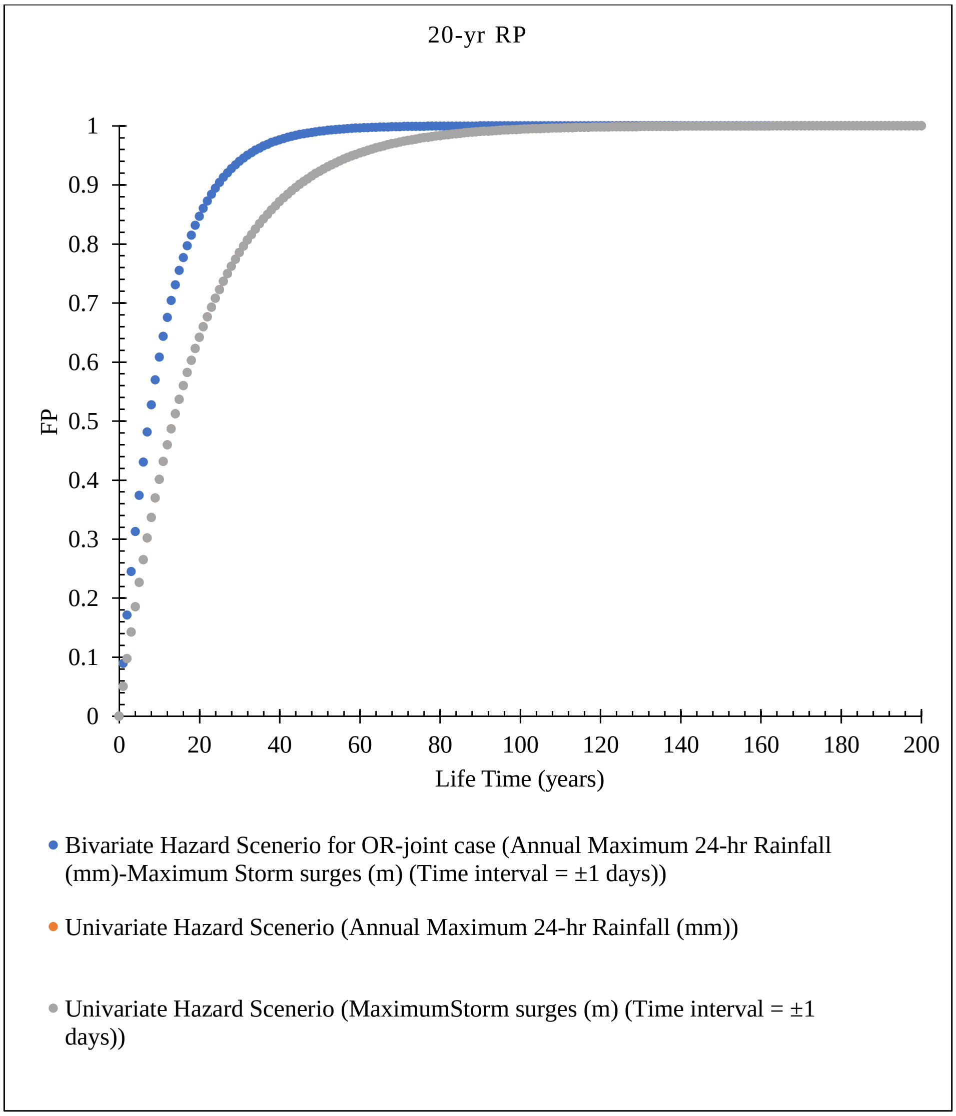
(b)


100-yr RP
FP
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
20
40
60
80
100
120
140
160
180
200
Life Time (years)
Bivariate Hazard Scenerio for OR-joint case (Annual Maximum 24-hr Rainfall (mm)-Maximum Storm surges (m) (Time interval = ±1 days))
Univariate Hazard Scenerio (Annual Maximum 24-hr Rainfall (mm))
Univariate Hazard Scenerio (MaximumStorm surges (m) (Time interval = ±1 days))

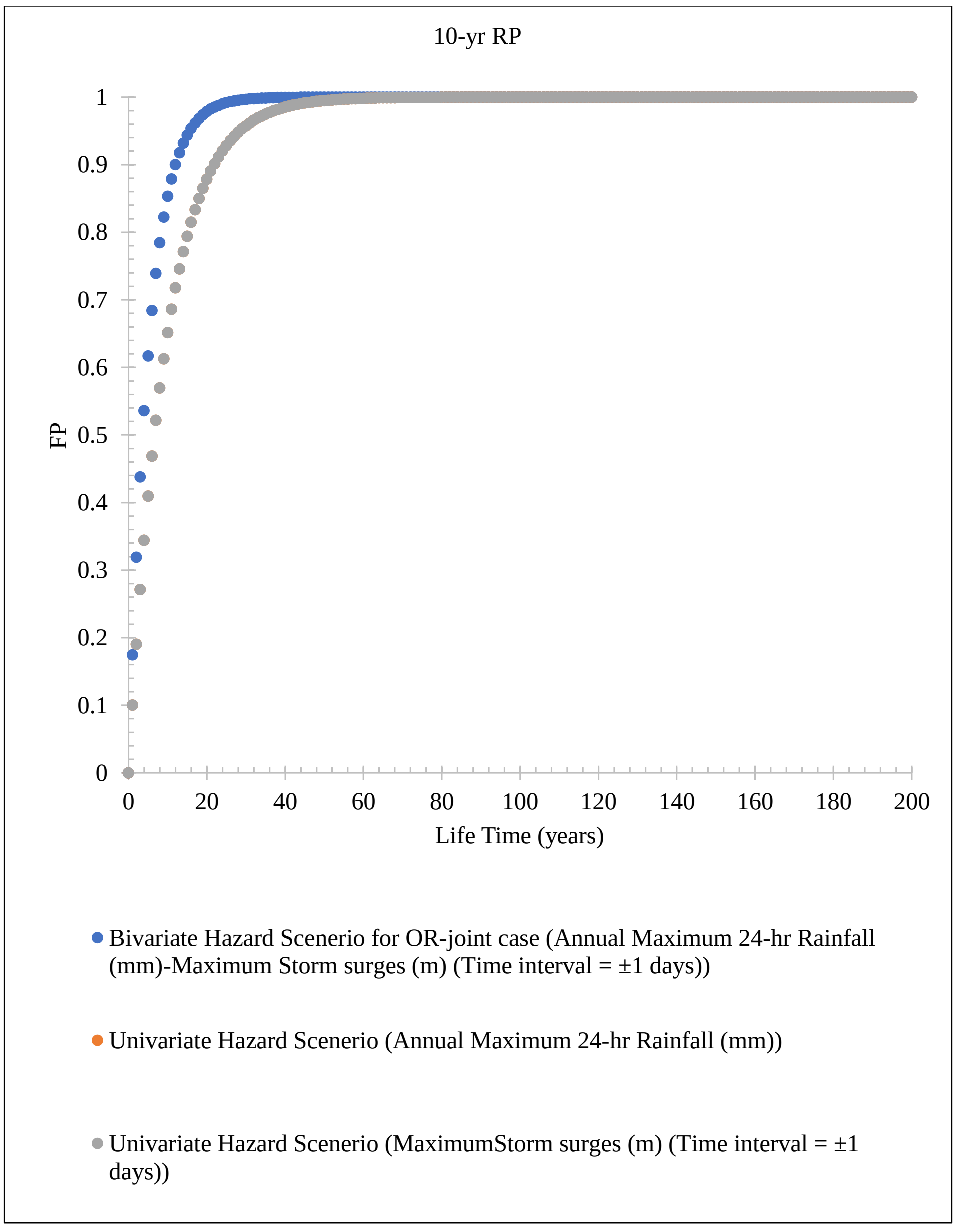
(c)


50-yr RP
FP
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
20
40
60
80
100
120
140
160
180
200
Life Time (years)
Bivariate Hazard Scenerio for OR-joint case (Annual Maximum 24-hr Rainfall (mm)-Maximum Storm surges (m) (Time interval = ±1 days))
Univariate Hazard Scenerio (Annual Maximum 24-hr Rainfall (mm))
Univariate Hazard Scenerio (MaximumStorm surges (m) (Time interval = ±1 days))

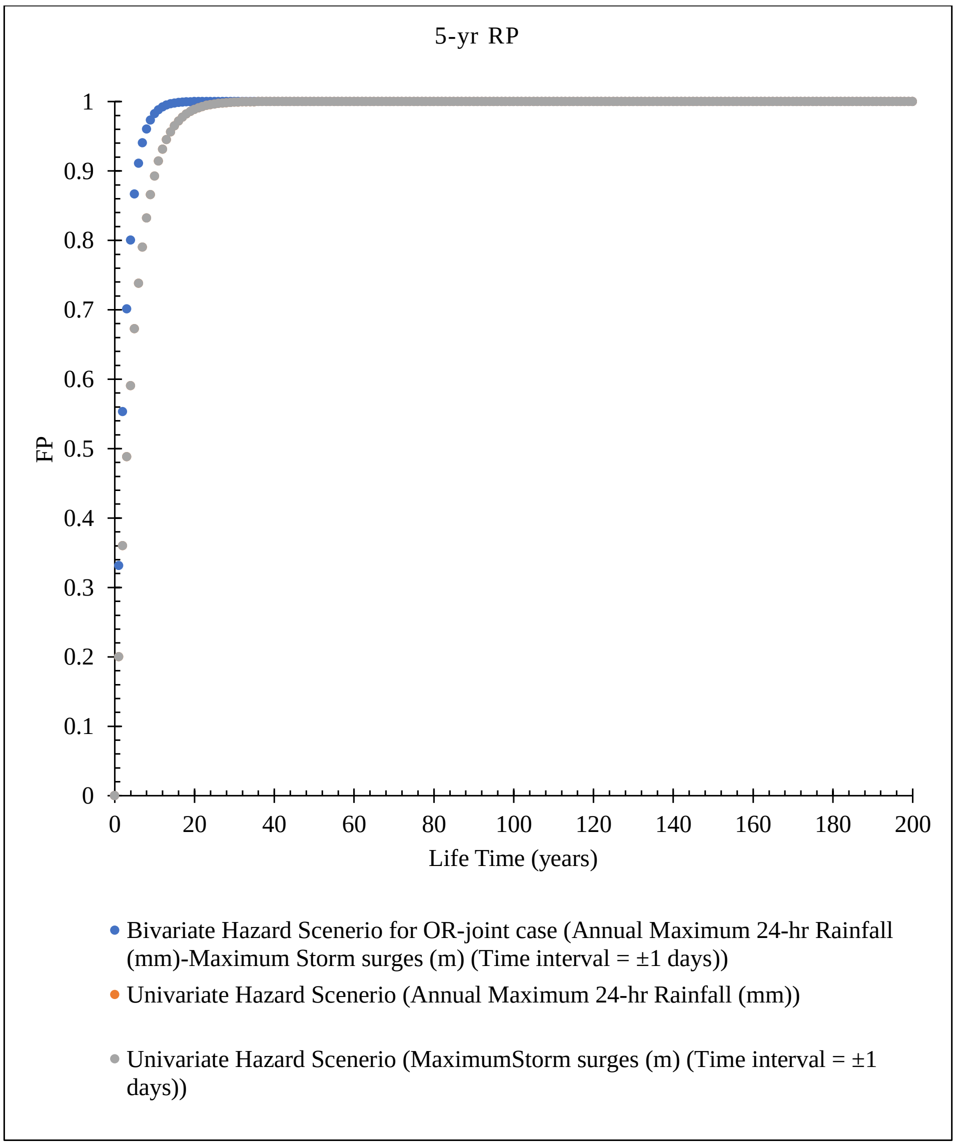
(d)


20-yr RP
FP
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
20
40
60
80
100
120
140
160
180
200
Life Time (years)
Bivariate Hazard Scenerio for OR-joint case (Annual Maximum 24-hr Rainfall (mm)-Maximum Storm surges (m) (Time interval = ±1 days))
Univariate Hazard Scenerio (Annual Maximum 24-hr Rainfall (mm))
Univariate Hazard Scenerio (MaximumStorm surges (m) (Time interval = ±1 days))

(e)

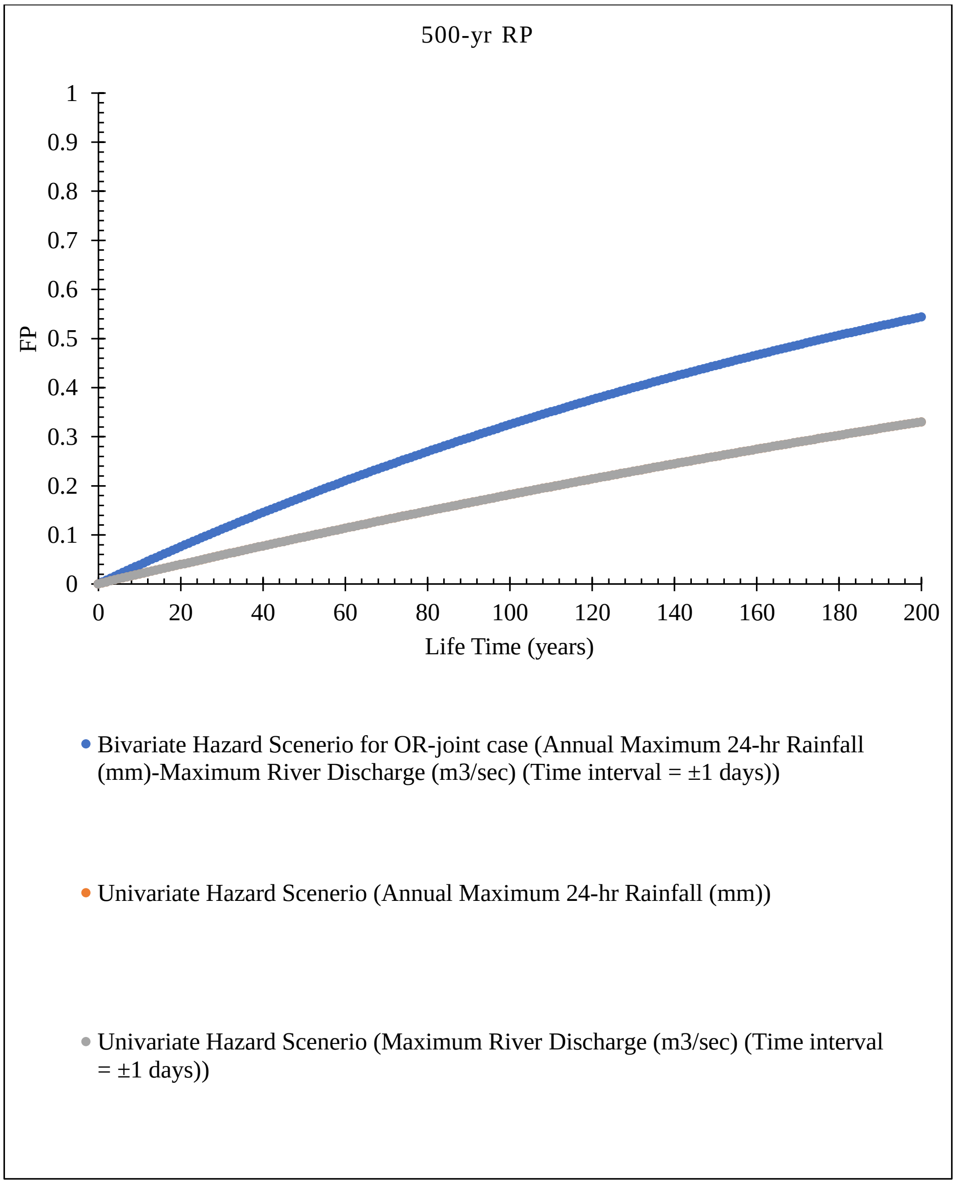

10-yr RP
FP
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
20
40
60
80
100
120
140
160
180
200
Life Time (years)
Bivariate Hazard Scenerio for OR-joint case (Annual Maximum 24-hr Rainfall (mm)-Maximum Storm surges (m) (Time interval = ±1 days))
Univariate Hazard Scenerio (Annual Maximum 24-hr Rainfall (mm))
Univariate Hazard Scenerio (MaximumStorm surges (m) (Time interval = ±1 days))

(f)

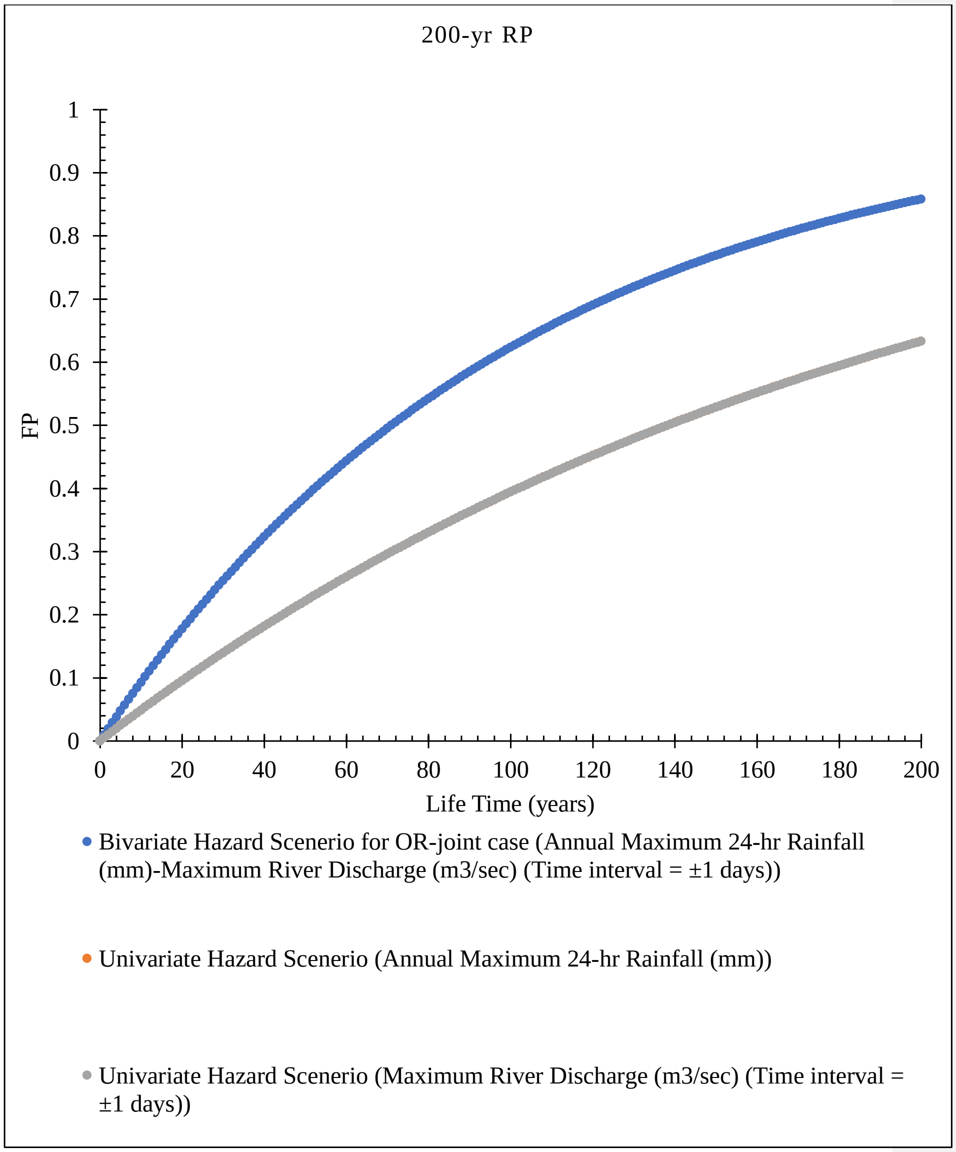


(g)

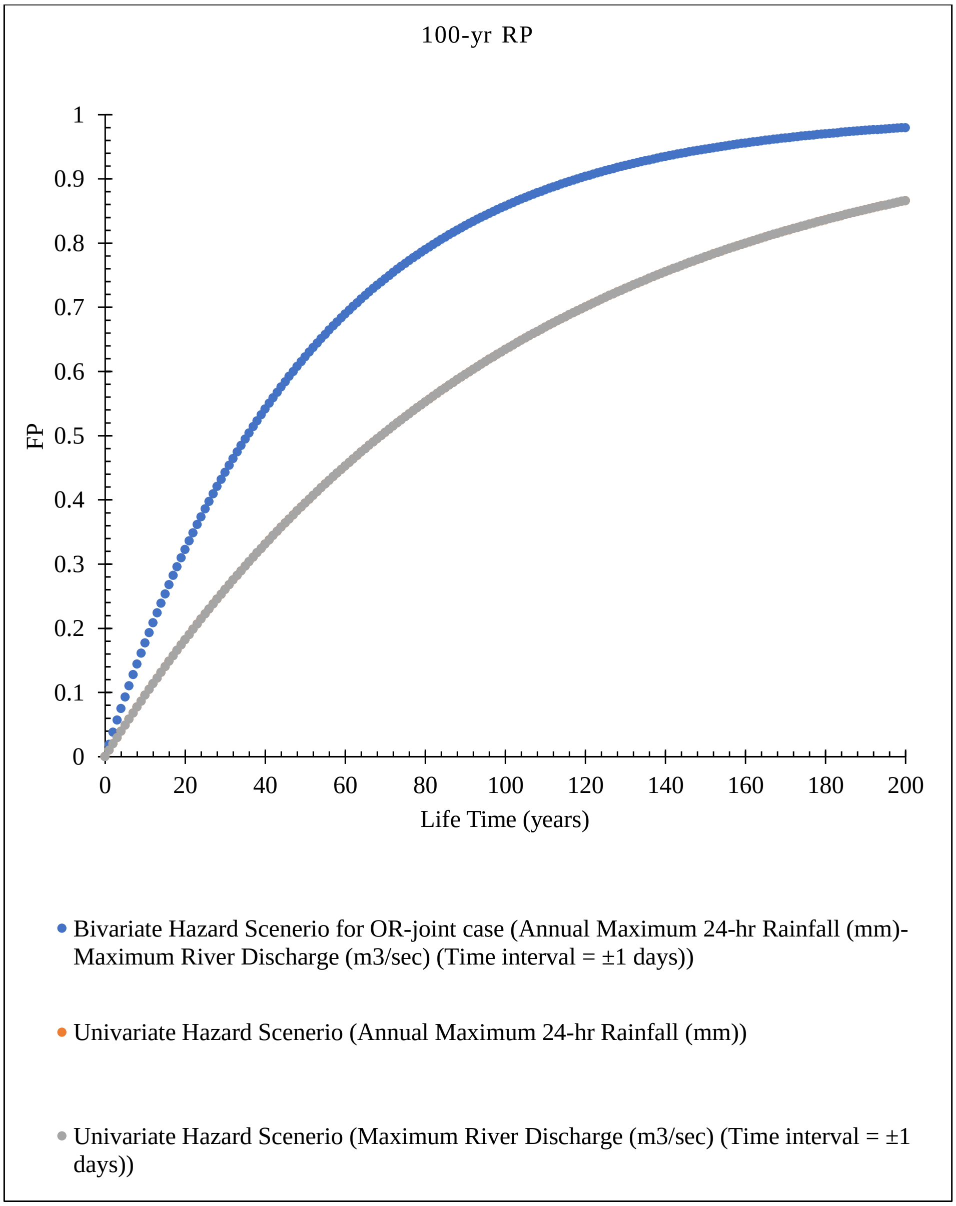
SF 15. Bivariate hydrologic risk of rainfall and storm surge observations estimated via OR-joint scenario for different return periods (a) 500-yr (b) 200-yr (c) 100-yr (d) 50-yr (e) 20-yr (f) 10-yr (g) 5-yr


500-yr RP
FP
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
20
40
60
80
100
120
140
160
180
200
Life Time (years)
Bivariate Hazard Scenerio for OR-joint case (Annual Maximum 24-hr Rainfall (mm)-Maximum River Discharge (m3/sec) (Time interval = ±1 days))
Univariate Hazard Scenerio (Annual Maximum 24-hr Rainfall (mm))
Univariate Hazard Scenerio (Maximum River Discharge (m3/sec) (Time interval = ±1 days))

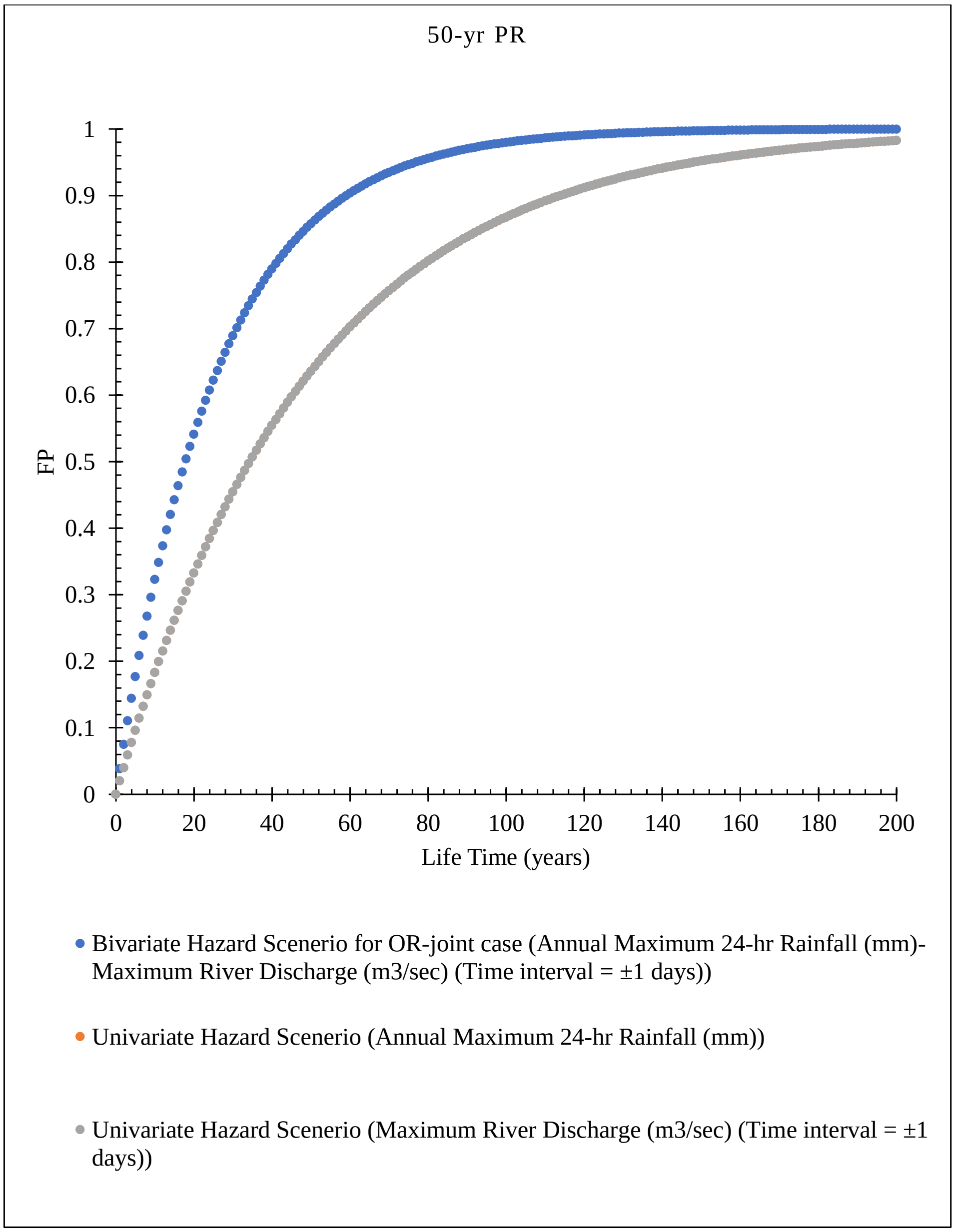
(a)


200-yr RP
FP
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
20
40
60
80
100
120
140
160
180
200
Life Time (years)
Bivariate Hazard Scenerio for OR-joint case (Annual Maximum 24-hr Rainfall (mm)-Maximum River Discharge (m3/sec) (Time interval = ±1 days))
Univariate Hazard Scenerio (Annual Maximum 24-hr Rainfall (mm))
Univariate Hazard Scenerio (Maximum River Discharge (m3/sec) (Time interval = ±1 days))

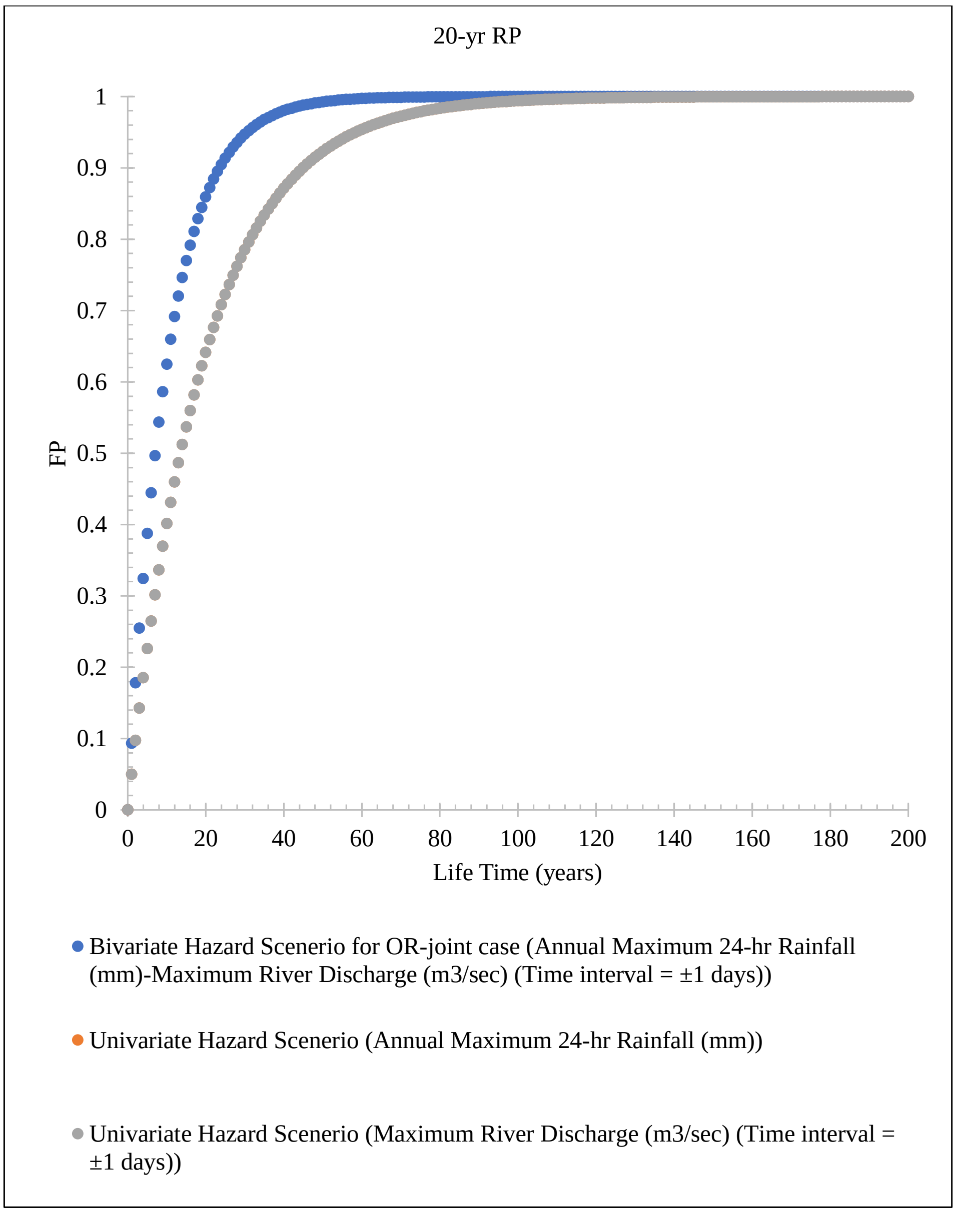
(b)


100-yr RP
FP
Life Time (years)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
0
20
40
60
80
100
120
140
160
180
200
Bivariate Hazard Scenerio for OR-joint case (Annual Maximum 24-hr Rainfall (mm)-Maximum River Discharge (m3/sec) (Time interval = ±1 days))
Univariate Hazard Scenerio (Annual Maximum 24-hr Rainfall (mm))
Univariate Hazard Scenerio (Maximum River Discharge (m3/sec) (Time interval = ±1 days))

(c)

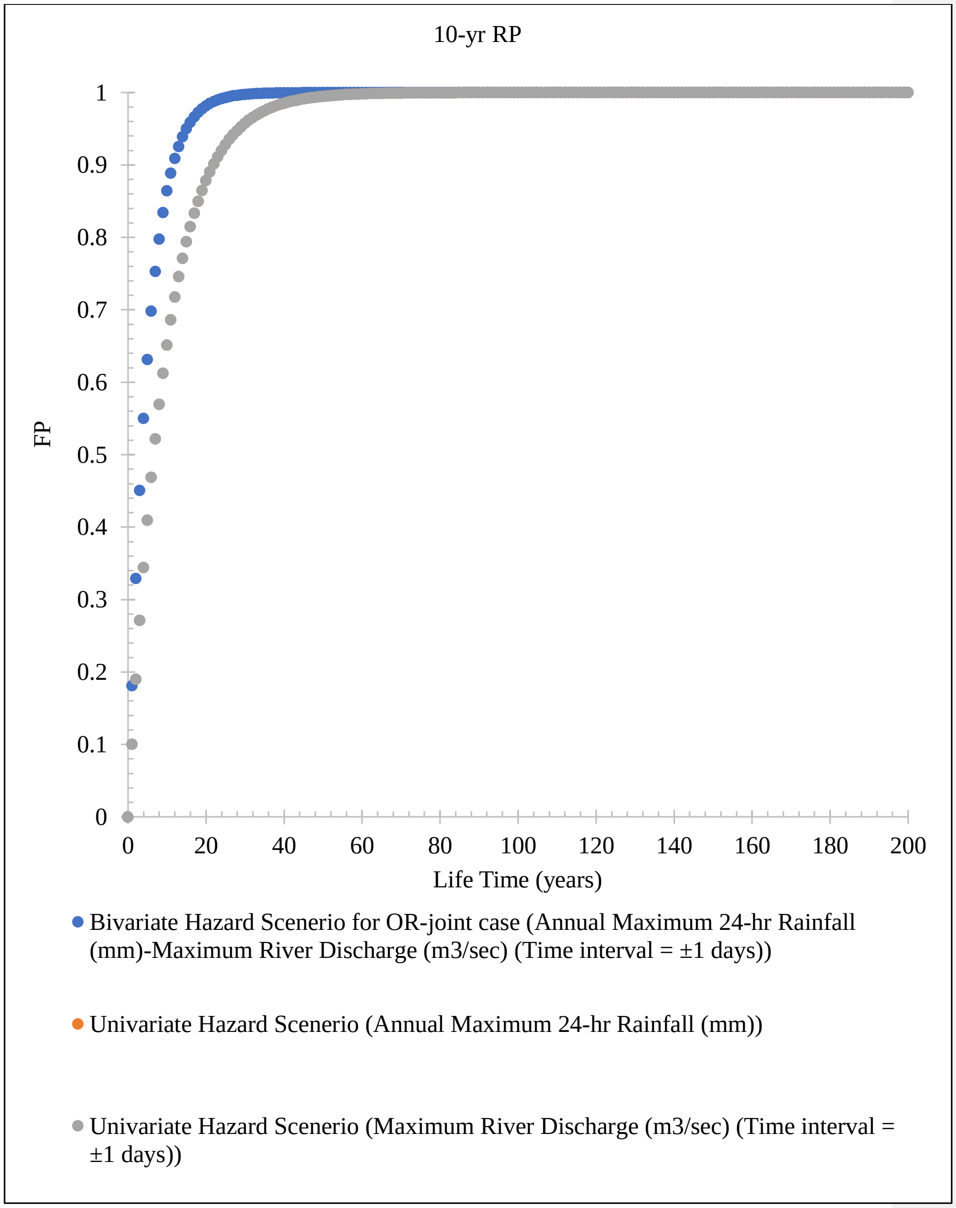

50-yr PR
FP
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
20
40
60
80
100
120
140
160
180
200
Life Time (years)
Bivariate Hazard Scenerio for OR-joint case (Annual Maximum 24-hr Rainfall (mm)-Maximum River Discharge (m3/sec) (Time interval = ±1 days))
Univariate Hazard Scenerio (Annual Maximum 24-hr Rainfall (mm))
Univariate Hazard Scenerio (Maximum River Discharge (m3/sec) (Time interval = ±1 days))

(d)



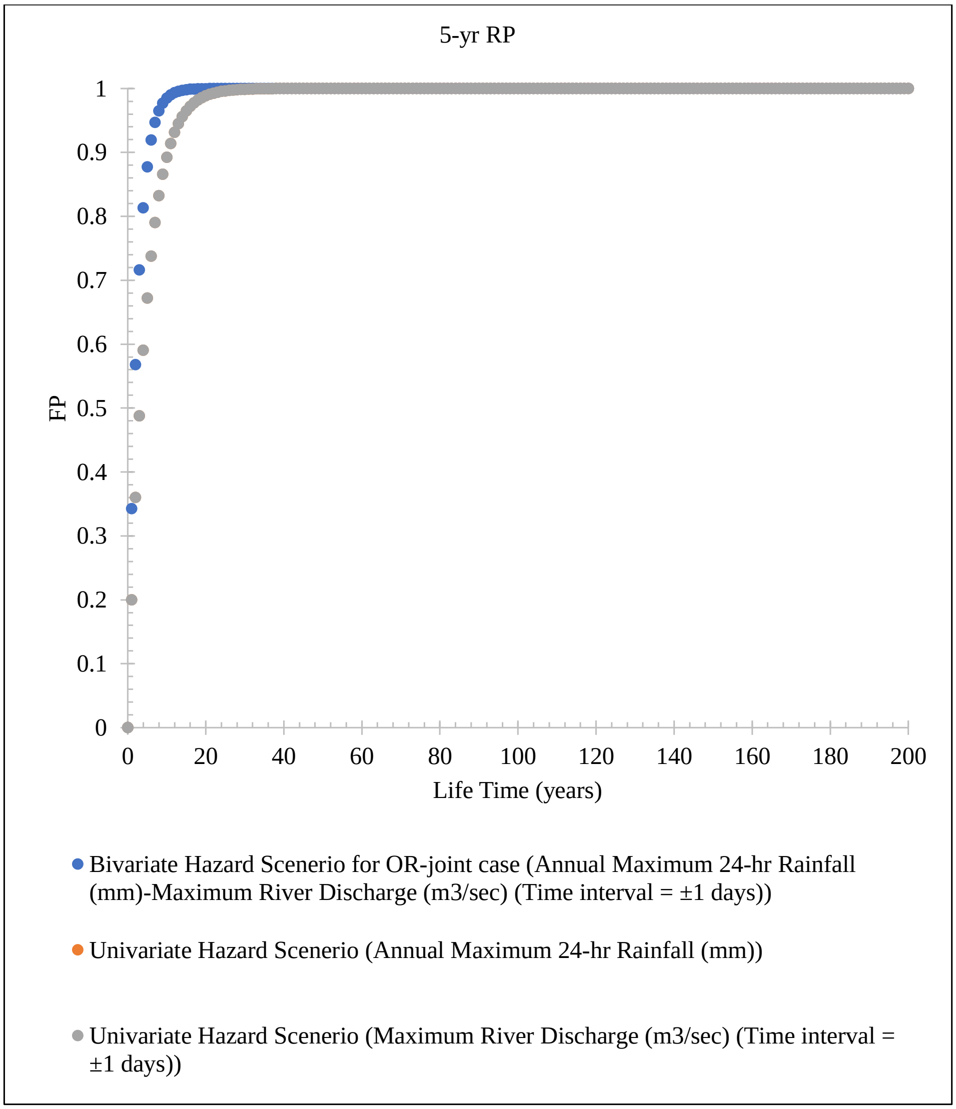
20-yr RP
FP
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
20
40
60
80
100
120
140
160
180
200
Life Time (years)
Bivariate Hazard Scenerio for OR-joint case (Annual Maximum 24-hr Rainfall (mm)-Maximum River Discharge (m3/sec) (Time interval = ±1 days))
Univariate Hazard Scenerio (Annual Maximum 24-hr Rainfall (mm))
Univariate Hazard Scenerio (Maximum River Discharge (m3/sec) (Time interval = ±1 days))

(e)



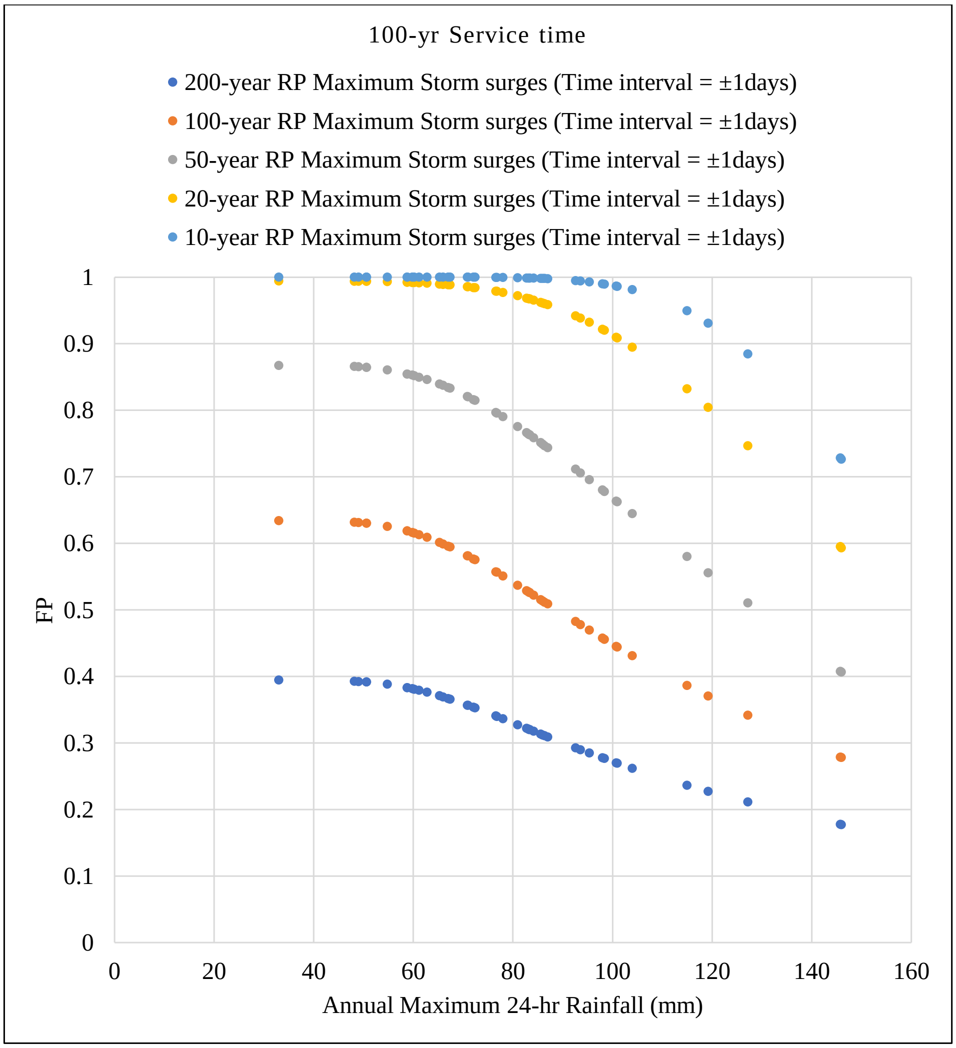
10-yr RP
FP
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0 20 40 60 80 100 120 140 160 180 200
Life Time (years)
Bivariate Hazard Scenerio for OR-joint case (Annual Maximum 24-hr Rainfall (mm)-Maximum River Discharge (m3/sec) (Time interval = ±1 days))
Univariate Hazard Scenerio (Annual Maximum 24-hr Rainfall (mm))
Univariate Hazard Scenerio (Maximum River Discharge (m3/sec) (Time interval = ±1 days))

(f)



(g)

SF 16. Bivariate hydrologic risk of rainfall and river discharge observations estimated via OR-joint scenario for different return periods (a) 500-yr (b) 200-yr (c) 100-yr (d) 50-yr (e) 20-yr (f) 10-yr (g) 5-yr

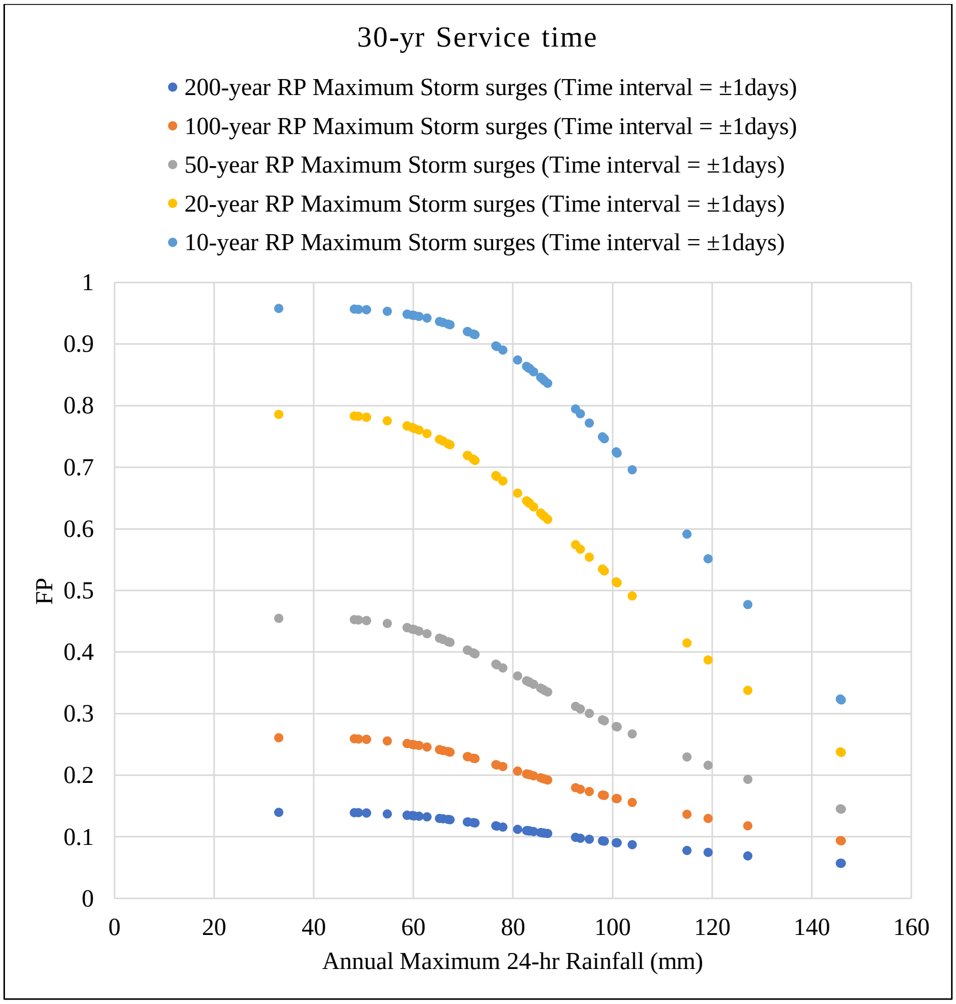


100-yr Service time
200-year RP Maximum Storm surges (Time interval = ±1days)
100-year RP Maximum Storm surges (Time interval = ±1days)
50-year RP Maximum Storm surges (Time interval = ±1days)
20-year RP Maximum Storm surges (Time interval = ±1days)
10-year RP Maximum Storm surges (Time interval = ±1days)
FP
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
20
40
60
80
100
120
140
160
Annual Maximum 24-hr Rainfall (mm)

(a)

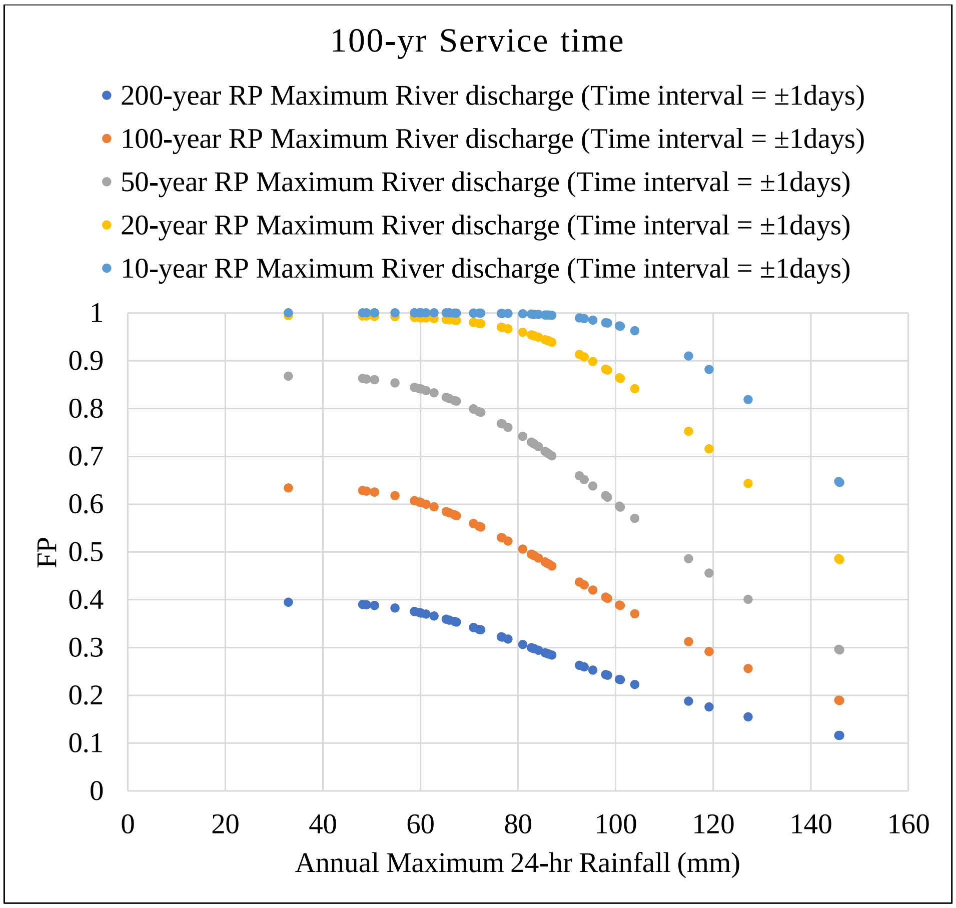

50-yr Service time
200-year RP Maximum Storm surges (Time interval = ±1days)
100-year RP Maximum Storm surges (Time interval = ±1days)
50-year RP Maximum Storm surges (Time interval = ±1days)
20-year RP Maximum Storm surges (Time interval = ±1days)
10-year RP Maximum Storm surges (Time interval = ±1days)
FP
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
0
20
40
60
80
100
120
140
160
Annual Maximum 24-hr Rainfall (mm)

(b)

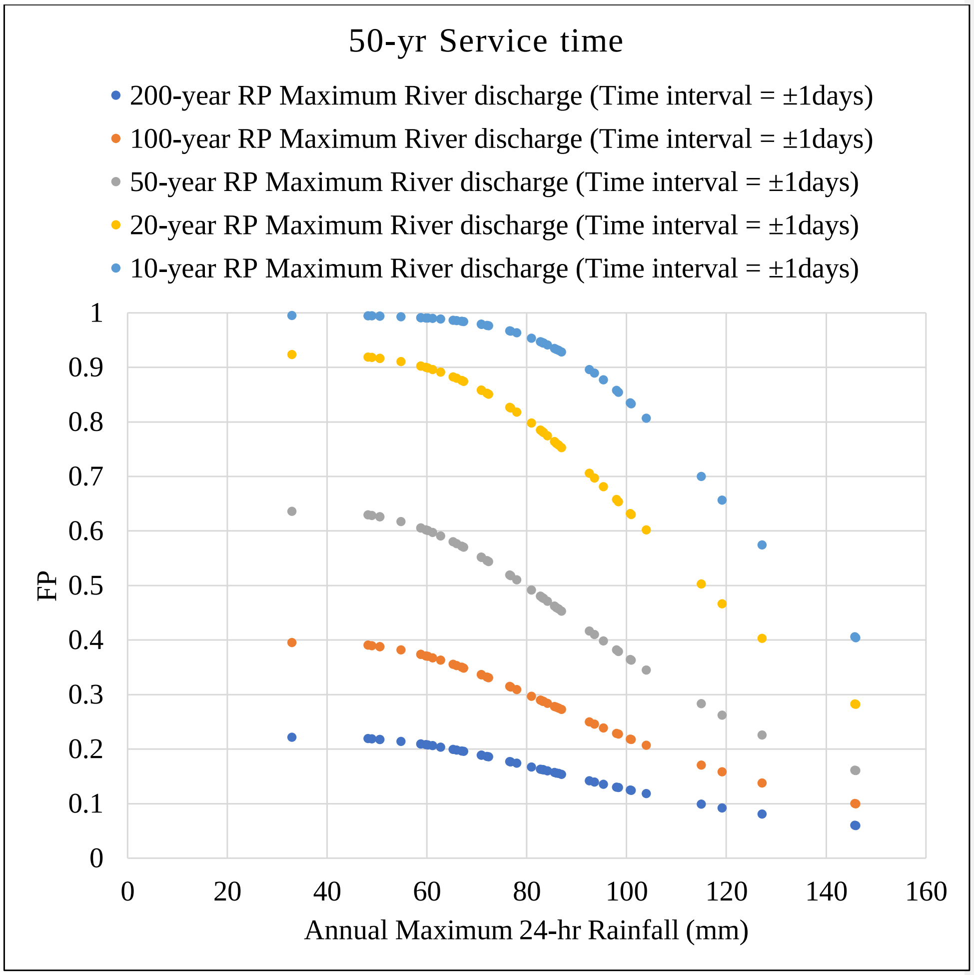


(c)

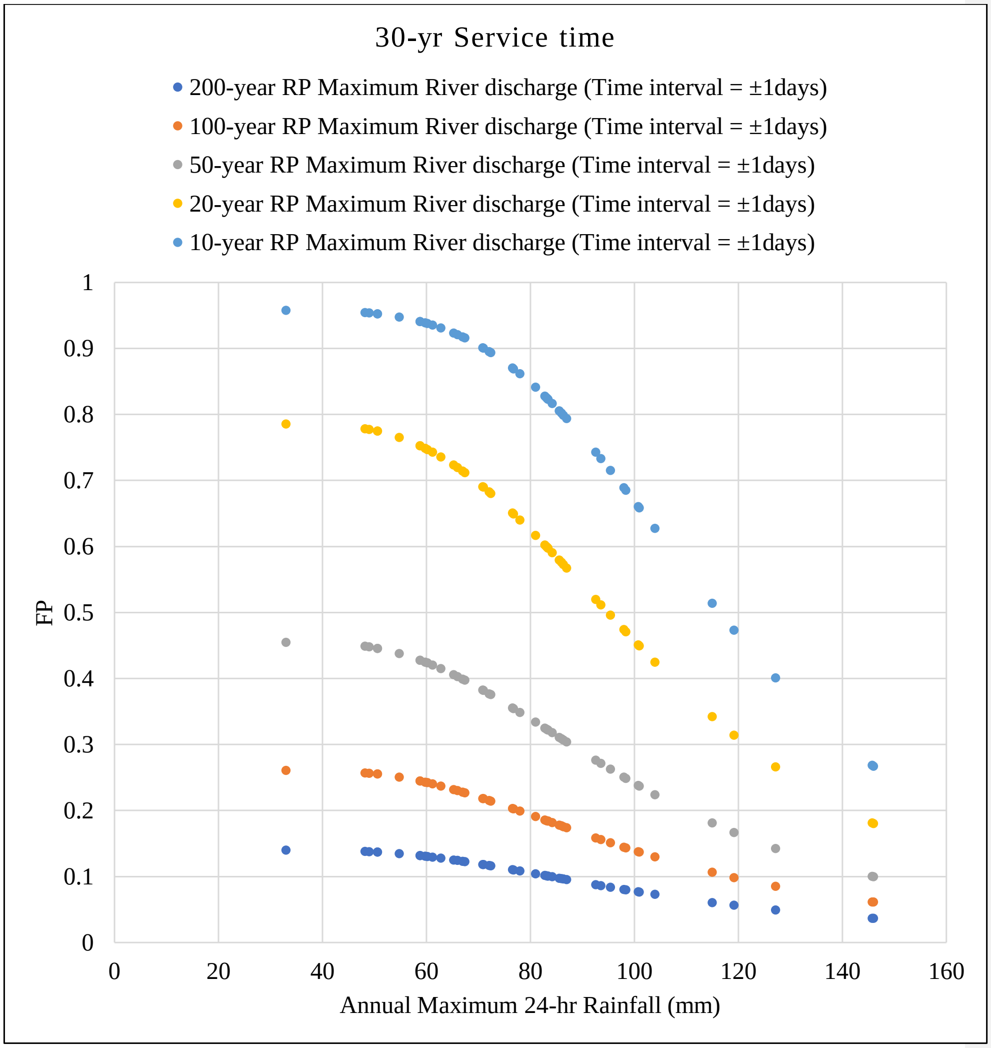
SF 14. Variation in the bivariate hydrologic risk for flood pair rainfall-storm surge for (a) service time = 100-years (b) Service time = 50-years (c) Service time = 30-years


100-yr Service time
200-year RP Maximum River discharge (Time interval = ±1days)
100-year RP Maximum River discharge (Time interval = ±1days)
50-year RP Maximum River discharge (Time interval = ±1days)
20-year RP Maximum River discharge (Time interval = ±1days)
10-year RP Maximum River discharge (Time interval = ±1days)
FP
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
20
40
60
80
100
120
140
160
Annual Maximum 24-hr Rainfall (mm)

(a)


50-yr Service time
200-year RP Maximum River discharge (Time interval = ±1days)
100-year RP Maximum River discharge (Time interval = ±1days)
50-year RP Maximum River discharge (Time interval = ±1days)
20-year RP Maximum River discharge (Time interval = ±1days)
10-year RP Maximum River discharge (Time interval = ±1days)
FP
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
20
40
60
80
100
120
140
160
Annual Maximum 24-hr Rainfall (mm)

(b)



(c)

SF 15. Variation in the bivariate hydrologic risk for flood pair rainfall-river discharge for (a) service time = 100-years (b) Service time = 50-years (c) Service time = 30-years