Supplementary Materials

Table S1. Dates and disaster areas of hazardous extreme rainfall events in the Xindian River watershed from 2012 to 2015.

No.	Disaster Event	Date	Taipei Raingauge (466920)			Disaster Area (District)											
			Duration (hours)	Max Intensity (mm/hr)	Cumulative Rainfall (mm)	Wanhua T01	Zhongzheng T02	Wenshan T03	Banqiao N01	Tucheng N02	Zhonghe N03	Yonghe N04	Xindian N05	Wulai N06	Shenkeng N07	Shiding N08	Pinglin N09
1	0502 Heavy Rainfall	2012/05/02	16	17	42	0	1	0	0	0	0	0	0	0	0	0	0
2	610 Flood	2012/06/10	25	55	338.5	1	0	1	1	1	1	1	1	0	1	0	0
3	Typhoon Saola	2012/08/02	83	23	306.5	0	1	1	1	1	1	1	1	1	1	0	1
4	Typhoon Soulik	2013/07/11	17	18	90	0	0	1	1	0	0	0	1	0	0	0	0
5	0814 Heavy Rainfall	2013/08/14	5	56	74.5	1	0	0	1	0	1	1	0	0	0	0	0
6	Typhoon Trami	2013/08/20	52	39	338	1	0	1	1	1	1	0	1	0	0	0	1
7	0822 Heavy Rainfall	2013/08/22	8	66.5	136	1	1	1	1	1	1	1	1	0	0	0	0
8	Typhoon Kong-Rey	2013/08/28	33	46	147	1	1	1	1	1	1	1	1	0	0	0	0
9	0515 Heavy Rainfall	2014/05/15	10	22	32.5	0	0	0	1	0	0	0	0	0	0	0	0
10	0519 Heavy Rainfall	2014/05/19	40	58	413.5	1	1	1	1	0	1	1	0	0	0	0	0
11	0530 Heavy Rainfall	2014/05/30	18	18	79	0	0	1	0	0	0	0	0	0	0	0	0
12	0605 Heavy Rainfall	2014/06/05	8	35	98	0	0	0	1	0	0	0	0	0	0	0	0
13	0629 Heavy Rainfall	2014/06/29	10	32	72.5	0	0	0	0	1	1	0	0	0	0	0	0
14	Typhoon Fung-Wong	2014/09/21	18	37	165	0	0	0	1	1	0	0	1	0	0	0	0
15	0607 Heavy Rainfall	2015/06/07	2	17.2	29.5	0	0	1	0	0	0	0	1	0	0	0	0
16	0614 Heavy Rainfall	2015/06/14	5	29.8	65.8	0	1	1	0	0	1	1	1	0	0	0	0
17	0623 Heavy Rainfall	2015/06/23	8	33.5	50	0	0	0	1	0	1	0	0	0	0	0	0
18	Typhoon Chan-Hom	2015/07/09	31	12	95.5	0	0	0	1	0	0	0	0	0	0	0	0
19	0718 Heavy Rainfall	2015/07/18	10	23.2	53	0	0	0	0	0	0	0	1	0	0	0	0
20	0723 Heavy Rainfall	2015/07/23	5	50.5	68	0	0	0	1	0	0	0	0	0	0	0	0
21	Typhoon Soudelor	2015/08/07	27	46.3	322.6	1	1	1	1	1	1	1	1	1	0	1	1
22	0813 Heavy Rainfall	2015/08/13	5	12	28	0	0	0	0	0	0	0	1	0	0	0	0
23	0825 Heavy Rainfall	2015/08/25	24	30.5	78.4	0	1	0	0	1	0	0	1	0	0	0	0
24	Typhoon Dujuan	2015/09/28	45	35.1	227.9	0	1	1	0	0	0	0	1	0	0	0	1
Total						7	9	12	15	9	11	8	14	2	2	1	4

Table S2. Profiles of the rain gauges in the Xindian River watershed.

No.	Name	Official ID	District	Location (TWD97)			Time of Set Up	Reference Station of Flood Warning	In the Upstream of a Reservoir	Rainfall Event No. (2012-2015)	Key Event No. (2012-2015)
				Elevation (m)	Lon	Lat					
1	Zhongzheng Bridge	01A410	Zhongzheng	5.0	121.5164	25.0219	1999/06/05	v		515	445
2	Taipei	466920	Zhongzheng	6.3	121.5149	25.0377	1896/01/01	v		639	73
3	Banqiao	466880	Banqiao	9.7	121.4420	24.9976	1972/03/01	v		649	118
4	Gongguan	C1A730	Zhongzheng	22.0	121.5395	25.0144	1987/06/01	v		671	60
5	Xindian	A0A9M0	Xindian	24.1	121.5247	24.9590	2010/08/27	v		534	503
6	Zhonghe	C0AG90	Zhonghe	25.0	121.4904	24.9926	2011/08/23	v		624	51
7	Tucheng	C0AD40	Tucheng	32.0	121.4452	24.9732	2009/11/01	v		649	95
8	Wenshan	C0AC80	Wenshan	40.0	121.5757	25.0024	2009/12/01	v		681	132
9	Shenkeng	C0AD20	Shenkeng	57.0	121.6176	25.0014	2009/11/01	v		687	40
10	Quchi	C0A580	Xindian	70.0	121.5463	24.9224	1987/06/01	v		744	269
11	Shiding	C0A640	Shiding	241.0	121.6629	24.9939	2009/12/01	v		759	40
12	Pinglin	C0A530	Pinglin	300.0	121.7094	24.9382	1987/06/01	v		806	40
13	Tunghou	C0A570	Wulai	360.0	121.5980	24.8482	1987/06/01			878	40
14	Sidu	C0A540	Pinglin	401.0	121.7459	24.8928	1987/06/01		v	-	-
15	Fushan	C0A560	Wulai	405.0	121.5028	24.7762	1987/06/01	v		886	40
16	Sishifen	C1A9N0	Xindian	435.0	121.5933	24.9342	2000/06/01		v	-	-
17	Taiping	C0A550	Shuangxi	460.0	121.8237	24.9712	1987/06/01		v	-	-
18	Fushan(3)	01A430	Wulai	500.0	121.4974	24.7798	1999/06/05	v		345	40
19	Xiapen	C1A630	Wulai	527.0	121.5386	24.7710	1987/06/01			890	40
20	Datungshan	01A440	Wulai	916.0	121.5630	24.8762	1999/06/05	v		322	40

Table S3. The optimal official cumulative rainfall thresholds for the key durations, 1, 3, 6, 12, and 24 hours.

City	District	Reference Rain Gauge	Optimal Official Cumulative Rainfall Threshold of Each Duration					Difference between Current and Optimal Official Rainfall Thresholds				
			1 hr	3 hrs	6 hrs	12 hrs	24 hrs	1 hr	3 hrs	6 hrs	12 hrs	24 hrs
Taipei	Wanhua	Taipei	46	130.5	135	166	322	-24	-9.5	-45	-174	-78
	Zhongzheng	Gongguan	80	90	92	98.5	193	10	-40	-88	-151.5	-157
		Taipei	58	62.5	92	153.5	206.6	-12	-67.5	-88	-96.5	-143.4
		Zhongzheng Bridge	80	87	96	98.5	132	10	-43	-84	-151.5	-218
	Wenshan	Wenshan	72	85	89.5	95	177	12	-35	-80.5	-145	-173
New Taipei	Banqiao	Banqiao	44	68.5	78.5	80.5	84	-6	-51.5	-71.5	-119.5	-216
		Tucheng	57	59	62	88.5	95	7	-61	-88	-111.5	-205
	Tucheng	Banqiao	49.5	63.5	65.5	80.5	122.5	-10.5	-46.5	-84.5	-129.5	-177.5
		Tucheng	74	130.5	136	136.5	142	24	20.5	-14	-73.5	-158
	Zhonghe	Zhonghe	54	105	106.5	110.5	145.5	4	-5	-43.5	-119.5	-154.5
	Yonghe	Zhongzheng Bridge	80	87	96	98.5	132	20	-33	-74	-131.5	-168
	Xindian	Quchi	69	92	111	142	171	19	-38	-69	-108	-179
		Xindian	43	101.5	103	106	185	-7	-28.5	-77	-144	-165
	Wulai	Fushan	95	253.5	273	432	776.5	25	113.5	3	122	326.5
		Tunghou	78	187.5	306	466	536.5	-	-	-	-	-
		Xiapen	65	131	240.5	405	499.5	-	-	-	-	-
		Fushan(3)	83	221	411	620	710	13	81	141	310	260
		Datungshan	69	171	182	269	496	-1	31	-88	-41	46
	Shenkeng	Shenkeng	50	136.5	227.5	368	393	-10	-13.5	-2.5	18	-57
	Shiding	Shiding	56	139.5	251	372	473	-24	-10.5	21	22	23
	Pinglin	Pinglin	54.5	134.5	225	243.5	459	-25.5	-15.5	-5	-86.5	59

Table S4. Optimal cumulative rainfall thresholds of the key durations based on rainfall pattern analysis.

City	District	Reference Rain Gauge	Optimal Cumulative Rainfall Threshold of Each Duration, unit: mm (hour)				
			1-5	6-10	11-15	16-20	21-25
Taipei	Wanhua	Taipei	46 (1)	135.5 (7)	156 (11)	221 (16)	242.5 (25)
	Zhongzheng	Gongguan	80 (1)	92 (7)	96.5 (11)	104.5 (16)	132 (22)
		Taipei	66.5 (1)	102 (7)	116.5 (11)	175.5 (16)	208.1 (25)
		Zhongzheng Bridge	80 (1)	97 (9)	103.5 (11)	107 (16)	115 (22)
	Wenshan	Wenshan	72 (1)	89.5 (6)	90 (11)	132 (17)	174 (23)
New Taipei	Banqiao	Banqiao	44 (1)	78.5 (6)	81 (14)	81.5 (16)	84 (24)
		Tucheng	57 (1)	62 (6)	90 (14)	91.5 (16)	95 (24)
	Tucheng	Banqiao	65 (1)	78.5 (6)	81 (14)	81.5 (16)	84 (24)
		Tucheng	74 (1)	136 (6)	156 (14)	171.5 (16)	194.5 (24)
	Zhonghe	Zhonghe	54 (1)	107 (10)	110.5 (11)	181 (19)	194.5 (21)
	Yonghe	Zhongzheng Bridge	80 (1)	85 (9)	97 (11)	104.5 (16)	132 (22)
	Xindian	Quchi	69 (1)	111 (6)	142 (12)	156.5 (19)	164 (21)
		Xindian	43 (1)	103 (6)	106 (12)	111.5 (17)	117.5 (21)
	Wulai	Fushan	80.5 (1)	595.5 (10)	638 (11)	720.5 (16)	753 (22)
		Tunghou	78 (1)	417.5 (9)	490 (13)	515.5 (16)	520.5 (21)
		Xiapen	65 (1)	362 (10)	386 (11)	440.5 (16)	505.5 (25)
		Fushan(3)	83 (1)	411 (6)	632 (13)	662 (17)	715 (25)
		Datungshan	69 (1)	214 (8)	303 (15)	314 (17)	360 (23)
	Shenkeng	Shenkeng	50 (1)	275 (8)	355 (11)	384 (16)	390.5 (21)
	Shiding	Shiding	56 (1)	329.5 (9)	361 (11)	411 (16)	464 (23)
	Pinglin	Pinglin	54.5 (1)	202.5 (9)	227.5 (11)	261 (16)	284.5 (22)

Table S5. Warning results of 4 models in 12 Taiwanese districts (obtained from the data of 17 rain gauges).

City	District	Reference Rain Gauge	Official Cumulative Rainfall Thresholds for Flood Warning				Optimal Official Cumulative Rainfall Thresholds for Flood Warning				Optimal Cumulative Rainfall Thresholds Based on Rainfall Pattern Analysis				The Data-Driven Probabilistic Rainfall-Iundation Model			
			A	B	C	D	A	B	C	D	A	B	C	D	A	B	C	D
Taipei	Wanhua	Taipei	3	4	0	66	7	0	3	63	7	0	3	63	6	1	2	64
	Zhongzheng	Gongguan	4	5	2	49	8	1	6	45	8	1	6	45	8	1	5	46
		Taipei	3	6	1	63	8	1	10	54	6	3	5	59	5	4	5	59
		Zhongzheng Bridge	3	6	1	435	6	3	7	429	6	3	7	429	5	4	6	430
	Wenshan	Wenshan	5	7	3	117	11	1	9	111	11	1	9	111	11	1	8	112
New Taipei	Banqiao	Banqiao	4	11	2	101	14	1	9	94	14	1	8	95	12	3	9	94
		Tucheng	4	11	3	77	13	2	9	71	13	2	9	71	11	4	8	72
	Tucheng	Banqiao	3	6	1	108	7	2	10	99	7	2	10	99	6	3	9	100
		Tucheng	3	6	4	82	7	2	2	84	6	3	1	85	2	7	0	86
	Zhonghe	Zhonghe	6	5	4	36	10	1	6	34	10	1	6	34	10	1	6	34
	Yonghe	Zhongzheng Bridge	4	4	0	437	6	2	7	430	6	2	7	430	5	3	6	431
	Xindian	Quchi	5	9	7	248	10	4	5	250	10	4	2	253	9	5	2	253
		Xindian	4	10	3	486	10	4	8	481	10	4	9	480	9	5	7	482
	Wulai	Fushan	2	0	2	36	2	0	1	37	2	0	0	38	1	1	0	38
		Tunghou	2	0	1	37	2	0	1	37	2	0	1	37	1	1	1	37
		Xiapen	2	0	1	37	2	0	1	37	2	0	0	38	2	0	0	38
		Fushan(3)	2	0	2	36	2	0	0	38	2	0	0	38	2	0	0	38
		Datungshan	1	1	2	36	2	0	2	36	2	0	2	36	1	1	1	37
	Shenkeng	Shenkeng	1	1	2	36	2	0	7	31	2	0	7	31	2	0	0	38
	Shiding	Shiding	1	0	3	36	1	0	2	37	1	0	1	38	1	0	0	39
	Pinglin	Pinglin	3	1	0	36	4	0	3	33	4	0	3	33	4	0	1	35

A: Hit; B: Miss; C: False alarm; D: Correct negative

Table S6. POD, FAR and CSI performances of the 4 models.

City	District	Reference Rain Gauge	Official Cumulative Rainfall Thresholds for Flood Warning			Optimal Official Cumulative Rainfall Thresholds for Flood Warning			Optimal Cumulative Rainfall Thresholds Based on Rainfall Pattern Analysis			The Data-Driven Probabilistic Rainfall-Iundation Model		
			POD	FAR	CSI	POD	FAR	CSI	POD	FAR	CSI	POD	FAR	CSI
Taipei	Wanhua	Taipei	0.429	0.000	0.429	1.000	0.300	0.700	1.000	0.300	0.700	0.857	0.250	0.667
	Zhongzheng	Gongguan	0.444	0.333	0.364	0.889	0.429	0.533	0.889	0.429	0.533	0.889	0.385	0.571
		Taipei	0.333	0.250	0.300	0.889	0.556	0.421	0.667	0.455	0.429	0.556	0.500	0.357
		Zhongzheng Bridge	0.333	0.250	0.300	0.667	0.538	0.375	0.667	0.538	0.375	0.556	0.545	0.333
	Wenshan	Wenshan	0.417	0.375	0.333	0.917	0.450	0.524	0.917	0.450	0.524	0.917	0.421	0.550
New Taipei	Banqiao	Banqiao	0.267	0.333	0.235	0.933	0.391	0.583	0.933	0.364	0.609	0.800	0.429	0.500
		Tucheng	0.267	0.429	0.222	0.867	0.409	0.542	0.867	0.409	0.542	0.733	0.421	0.478
	Tucheng	Banqiao	0.333	0.250	0.300	0.778	0.588	0.368	0.778	0.588	0.368	0.667	0.600	0.333
		Tucheng	0.333	0.571	0.231	0.778	0.222	0.636	0.667	0.143	0.600	0.222	0.000	0.222
	Zhonghe	Zhonghe	0.545	0.400	0.400	0.909	0.375	0.588	0.909	0.375	0.588	0.909	0.375	0.588
	Yonghe	Zhongzheng Bridge	0.500	0.000	0.500	0.750	0.538	0.400	0.750	0.538	0.400	0.625	0.545	0.357
	Xindian	Quchi	0.357	0.583	0.238	0.714	0.333	0.526	0.714	0.167	0.625	0.643	0.182	0.563
		Xindian	0.286	0.429	0.235	0.714	0.444	0.455	0.714	0.474	0.435	0.643	0.438	0.429
	Wulai	Fushan	1.000	0.500	0.500	1.000	0.333	0.667	1.000	0.000	1.000	0.500	0.000	0.500
		Tunghou	1.000	0.333	0.667	1.000	0.333	0.667	1.000	0.333	0.667	0.500	0.500	0.333
		Xiapen	1.000	0.333	0.667	1.000	0.333	0.667	1.000	0.000	1.000	1.000	0.000	1.000
		Fushan(3)	1.000	0.500	0.500	1.000	0.000	1.000	1.000	0.000	1.000	1.000	0.000	1.000
		Datungshan	0.500	0.667	0.250	1.000	0.500	0.500	1.000	0.500	0.500	0.500	0.500	0.333
	Shenkeng	Shenkeng	0.500	0.667	0.250	1.000	0.778	0.222	1.000	0.778	0.222	1.000	0.000	1.000
	Shiding	Shiding	1.000	0.750	0.250	1.000	0.667	0.333	1.000	0.500	0.500	1.000	0.000	1.000
	Pinglin	Pinglin	0.750	0.000	0.750	1.000	0.429	0.571	1.000	0.429	0.571	1.000	0.200	0.800