

*Full Paper*

## **A case study on estimating the flood severity using flood hydrographs for small ungauged catchments in Korea**

**Eung Seok Kim<sup>1</sup> and Hyun Il Choi<sup>2,\*</sup>**

<sup>1</sup> Department of Civil Engineering, Sunmoon University, 100, Kalsan-ri, Tangeong-myeon, Asan-si, Chungnam-do, 336-708, Korea

<sup>2</sup> Department of Civil Engineering, Yeungnam University, 214-1, Dae-dong, Gyeongsan-si, Gyeongbuk-do, 712-749, Korea

\* Corresponding author, e-mail: [hichoi@ynu.ac.kr](mailto:hichoi@ynu.ac.kr)

*Received: 17 January 2012 / Accepted: 20 February 2013 / Published: 20 February 2013*

---

**Abstract:** Local floods with rapid run-off and debris flow have posed a great potential threat of danger to life and property in recent years. Previous studies have examined the flash flood index determined by the characteristics of observed flood hydrographs such as rising limb, peak discharge and time to peak. To estimate the flood severity for small watersheds in Korea where the observed hydrograph is usually not available, this study proposes a flood hazard index (FHI) based on hydrographs generated from a rainfall run-off model for the annual maximum rainfall series of long-term observed data. The FHI is obtained by summing the relative severity factors measured by the ratios of characteristics of each flood to the highest recorded maximum value and implemented for two selected small ungauged basins in Korea. This study also presents regression equations between FHI and rainfall characteristics to predict the severity of flooding in small catchments. A stronger relation between FHI and maximum rainfall over a short interval demonstrates that heavy or excessive rainfall in a short period of time can cause a serious local flood in small watersheds.

**Keywords:** flood hazard index, flood severity, run-off hydrograph, rainfall run-off model

---

### **INTRODUCTION**

In recent years, heavy rainfall in a short period of time over a small area often caused sudden local flooding leading to significant loss of life and property. Most watersheds in the Korean Peninsula are exposed to flood hazards due to both climatic and geomorphic vulnerability by convective storms of short duration and high intensity over small, steep slope regions. As a result,

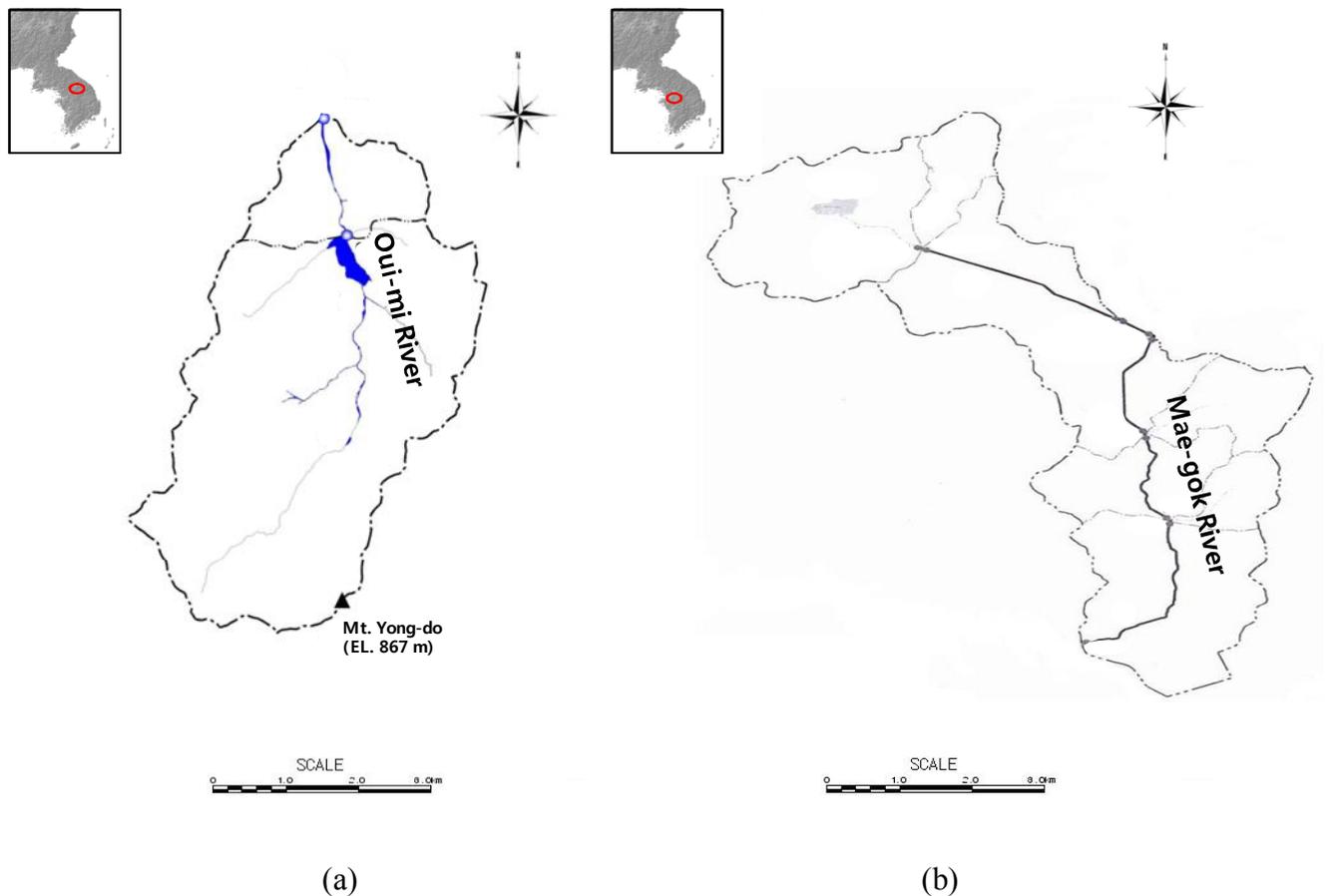
the rapid run-off associated with debris flow inundated some watershed areas and caused bank erosion and bridge collapse as reported by the Korea National Emergency Management Agency (KNEMA) [1]. Although such flood damage is a common natural disaster in Korea, it is considered almost infeasible to cope with flash flooding rising quite quickly with little or no advance flood warning in small watersheds. The present flood forecasting systems based on a rainfall run-off model places a limit on predicting flash flooding in small watersheds with short flood response time [2-4].

While flash floods were considered mainly from a climatological perspective with special focus on the temporal and spatial characteristics of rainfall [5-7], Kyiamah [8] initially characterised flash floods from a run-off perspective using run-off hydrographs. To distinguish flash floods from other floods, Bhaskar et al. [9] presented a flash flood index using run-off hydrograph characteristics such as rising curve gradient, flood magnitude ratio and flood response time, evaluated directly from observed run-off hydrographs of 30 flood events from four watersheds in eastern Kentucky. Jung [10] estimated the flash flood index for several flood events of the Bo-chung River basin in the Korean Peninsula following Bhaskar et al. [9]. In these studies, the flash flood index was determined by the sum of three relative severity factors using each different ordinal scale where class intervals were to some extent arbitrary. Although each relative severity factor was applied systematically to all flood events, the flash flood index was often subjected to a certain factor with a greater scale value than other factors. Kim and Kim [3] estimated the flash flood index to investigate the relative severity of flash floods in the Han River basin with 101 flood events and quantified the flash flood severity for some flood events caused by heavy rainfall in July of 2006.

In previous studies the flash flood index was computed directly from the observed flood hydrographs. Since most small watersheds in Korea usually do not have a local flood observation and warning system, in this study the flash flood index by Bhaskar et al. [9] is modified and a flood hazard index (FHI) is presented, which is determined by summing each relative severity factor such as the rising curve gradient, flood magnitude ratio and flood response time measured at different scales and units, normalised to the highest recorded maximum value. The FHI can be used to estimate the relative severity of flood hazards for a flood event to the highest recorded maximum flood level. However, the FHI based on the characteristics of flood run-off hydrographs does not incorporate any vulnerability feature. Although a flood disaster is the result of a flood hazard, the resulting loss depends on the ability of the affected population to resist the hazard. Thus, the proposed flood index is designated as FHI. In order to understand the hydrologic behaviour of local flooding in small ungauged catchments, FHI is obtained by quantifying the characteristics of flood run-off hydrographs generated from a rainfall run-off model, viz. the hydrologic engineering centre-hydrologic modelling system (HEC-HMS), for the annual maximum rainfall series of long-term observed data. FHI is implemented in two selected small ungauged basins in the Korean Peninsula: the Oui-mi River basin (OM) located in a mountainous region and the Mae-gok River basin (MG) with a relatively flat drainage area. This study also examines the relationship between FHI and rainfall characteristics in the two basins in order to provide a basic database for forecasting a local flood directly from rainfall pattern.

## STUDY CATCHMENTS

OM and MG, selected as the study catchments, are surrounded by rainfall gauge stations from which long-term hourly rainfall data are collected. A hilly 16.74 km<sup>2</sup> natural basin 7.52 km long, OM is located between 128°10'35"-128°11'37"E and 37°14'39"-37°15'29"N [11]. The annual maximum rainfall series during 1973-2008 was collected for OM from the Jae-chun gauge station managed by KNEMA. The annual mean rainfall volume was 1,322.5 mm over the same period and the highest recorded maximum depth of a single rainfall event was 228.5 mm on September 11, 1990. MG has a flat natural drainage area of 35.48 km<sup>2</sup> and a basin length of 11.25 km. It is located between 127°01'56"-127°07'29"E and 36°46'44"-36°51'48"N [12]. The annual maximum rainfall series during 1973-2008 was collected for MG from Chun-an gauge station managed by KNEMA. The annual mean rainfall volume was 1,235.9 mm over the same period and the recorded maximum depth of a single rainfall event was 262.5 mm on August 9, 1995. Figure 1 depicts the basin maps and Table 1 summarizes the basin characteristics of the two catchments under study.



**Figure 1.** Basin maps for (a) the Oui-mi River (OM) and (b) the Mae-gok River (MG)

**Table 1.** Characteristics of the two study basins

Basin	Basin area: A(km <sup>2</sup> )	Basin length: L(km)	Basin width: A/L(km)	Shape factor: A/L <sup>2</sup>	Average elevation (m)	Average slope (%)
OM	16.74	7.52	2.23	0.30	544.9	53.4
MG	35.48	11.25	3.15	0.28	65.0	9.6

## RUN-OFF SIMULATIONS

### Flood Run-off Hydrographs

Flood run-off hydrographs were generated from the rainfall run-off model, i.e. HEC-HMS [13], using the annual maximum precipitation series of the Jae-chun gauge station for OM and the Chun-an gauge station for MG for 36 years from 1973-2008. The Natural Resources Conservation Service curve number method [14] was used for the loss rate and the Clark unit hydrograph [15] was used as the transform method. Table 2 shows parameter values required for HEC-HMS run-off simulations in the two basins. All parameter values suggested in the basic plan reports [11, 12] were used for OM and MG. The 36-year annual maximum flood run-off simulation results are summarised in Tables 4 and 5 for OM and MG respectively.

**Table 2.** Parameter values for the flood run-off generation by HEC-HMS in the two basins

Basin	NRCS curve number	Storage coefficient (hr)
OM	70.10	1.18
MG	87.92	2.02

### Long-term Run-off Simulations

As shown in Table 3, the basic plan reports for OM [11] and MG [12] maintenance works have presented the monthly run-off simulated by the Kajiyama equation and the daily watershed streamflow model respectively, the latter being a daily streamflow model based on soil water storage [16].

**Table 3.** Simulated monthly run-off in the two basins

Basin	Monthly run-off (m <sup>3</sup> /sec)												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean
OM	0.07	0.09	0.12	0.29	0.22	0.43	1.31	1.10	0.55	0.17	0.11	0.08	0.40
MG	0.19	0.20	0.25	0.38	0.41	0.70	1.74	2.46	1.19	0.38	0.24	0.24	0.70

## ESTIMATION OF FLOOD HAZARD INDEX (FHI)

This study quantifies the severity of floods in small ungauged catchments by estimating FHI from flood hydrographs simulated by a rainfall run-off model for the annual maximum precipitation series of long-term observations. Bhaskar et al. [9] characterised the flash flood severity by defining a flash flood index  $RF$  evaluated from the observed flood hydrograph characteristics such as the rising curve gradient  $K$ , flood magnitude ratio  $M$  and flood response time  $T$ . These characteristics were quantified by the relative severity factors at each different ordinal scale of assignment, where the choice of class intervals was to some extent arbitrary. The flash flood index  $RF$  determined by the sum of the three severity factors is often subjected to a certain factor among the three with a greater scale of measurement than other factors. Hence this study presents FHI integrated from each relative severity factor normalised to the highest recorded maximum value.

### Rising Curve Gradient

The rising limb of hydrographs can be described by an exponential function as Equation (1) and then the rising curve gradient  $K$  can be computed by Equation (2):

$$Q_t = Q_0 e^{Kt} \quad (1)$$

$$K = \frac{\ln(Q_t / Q_0)}{t} \quad (2)$$

where  $Q_0$  is the specified initial discharge, and  $Q_t$  and  $K_t$  are the discharge and the rising curve gradient respectively, at a later time  $t$  close to the time to peak. Because the rising curve gradient represents the steepness of the rising limb of a flood hydrograph, a large value of parameter  $K$  can be associated with a rapid local flood. The rising curve gradient  $K$  ranges between 3.79-24.67/day for OM as shown in column 4 of Table 4, and between 3.17-36.81/day for MG as shown in column 4 of Table 5. To quantify the relative severity for the rising curve gradient  $K$  as a dimensionless index  $RK$ , the ratio of  $K_i$  of each flood to the highest recorded maximum value  $K_{max}$  is computed from the 36-year long-term flood data:

$$RK = \frac{K_i}{K_{max}} \quad (3)$$

### Flood Magnitude Ratio

The flood magnitude ratio  $M$  means a ratio of the peak flood discharge to the long-term average discharge, as defined in Equation (4):

$$M = Q_p / Q_a \quad (4)$$

where  $Q_p$  is the flood peak discharge and  $Q_a$  is the long-term average discharge ( $0.4\text{m}^3/\text{s}$  for OM and  $0.7\text{m}^3/\text{s}$  for MG) as shown in Table 3. The flood magnitude ratio  $M$  varies between 36.17-458.15 for OM as shown in column 5 of Table 4, and between 46.60-504.04 for MG as shown in column 5 of Table 5. The relative severity factor  $RM$  is also computed by the ratio of each flood event's  $M_i$  to the highest recorded maximum value  $M_{max}$  from the 36-year long-term flood data:

$$RM = \frac{M_i}{M_{max}} \quad (5)$$

### Flood Response Time

The flood response time  $T$  is defined as the time duration between the start of a flood event and the time of peak flow, which can be measured directly from flood hydrographs.  $T$  varies between 3-24 hr for OM as shown in column 6 of Table 4, and between 3-25 hr for MG as shown in column 6 of Table 5. Because a low  $T$  is readily associated to a high run-off velocity causing sudden local flooding, the relative severity factor  $RT$  is computed by the ratio of the inverse value of  $T_i$  of each flood event to the inverse value of the recorded minimum value  $T_{min}$  from the 36-year long-term flood data:

$$RT = \frac{T_{min}}{T_i} \quad (6)$$

### Flood Hazard Index (FHI)

We can define more relative severity factors  $RS_j$  representing the flood hydrograph characteristics, aside from the rising curve gradient  $K$ , the flood magnitude ratio  $M$  and the flash flood response time  $T$  mentioned above. These relative severity factors need to be summed for an overall value to evaluate the flood severity for each flood event. If the number of relative severity factors is  $n$ , the relative flood severity  $RF_n$  is given in the general form as:

$$RF_n = \sum_{j=1}^n RS_j \quad (7)$$

where the relative severity factors  $RS_j$  may comprise  $RK$ ,  $RM$ ,  $RT$  and any other possible severity factors. A high value of  $RF_n$  is expected to indicate a sudden local flood of great volume. While Bhaskar et al. [9] presented  $RF_3$ , which is the sum of the three relative severity factors on different scale values such as  $RK = 1-7$ ,  $RM = 1-16$ , and  $RT = 1-10$ ,  $RF_3$  from the same scale relative severity factors is computed in this study.

The rising curve gradient  $K$  and the flood response time  $T$  may represent similar characteristics of a flood hydrograph because a low value of  $T$  can be associated with a high run-off velocity leading to a steep rising limb of flood hydrographs. The correlation coefficients between  $RK$  and  $RT$  are very high at 0.948 for OM and 0.973 for MG as shown in Table 6. It is therefore required to avoid double-counting of similar severity factors in the relative flood severity  $RF_n$ , the sum of relative severity factors. Therefore, this study presents another relative flood severity  $RF_2$ , the sum of the two relative severity factors, i.e. the rising curve gradient  $K$  and the flood magnitude ratio  $M$ , and then compares  $RF_2$  with  $RF_3$ . Also, this study presents  $FHI_n$ , a ratio of each flood event  $(RF_n)_i$  to the maximum  $(RF_n)_{max}$  in order to evaluate the severity of each flood event relative to the extreme flood situation:

$$FHI_n = \frac{(RF_n)_i}{(RF_n)_{max}} \times 100 \text{ (\%)} \quad (8)$$

Tables 4 and 5 show  $FHI_3$  for  $RF_3$  and  $FHI_2$  for  $RF_2$  in Equation (8), along with the rainfall characteristics for the two basins, OM and MG.

**Table 4.** Summary of run-off and flood hazard indexing characteristics, along with rainfall data for the Oui-mi River basin (OM)

No	Flood Run-off Characteristics				Flood Indexing Parameters									Rainfall Characteristics								
	Flood event date	Flood peak discharge $Q_p$ (m <sup>3</sup> /s)	Time to peak discharge $T$ (hr)	Rising curve gradient $K$ (day <sup>-1</sup> )	Flood magnitude $M$	Flood response time $T$ (hr)	Relative severity factor			Flood index			Average rainfall intensity $I_a$ (mm/hr)	Maximum 1-hour rainfall $R_{1h}$ (mm)	Maximum 2-hour rainfall $R_{2h}$ (mm)	Maximum 3-hour rainfall $R_{3h}$ (mm)	Maximum 4-hour rainfall $R_{4h}$ (mm)	Maximum 5-hour rainfall $R_{5h}$ (mm)	Maximum 6-hour rainfall $R_{6h}$ (mm)	Total rainfall depth $R_t$ (mm)	Rainfall duration time $D$ (hr)	
	(1)	(2)	(3)	(4)	(5)	(6)	$RK$ (7)	$RM$ (8)	$RT$ (9)	$RF_3^{a)}$ (10)	$FHI_3^{b)}$ (11)	$RF_2^{c)}$ (12)	$FHI_2^{d)}$ (13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)	(21)	(22)
1	06/29/73	20.5	8.0	8.51	51.18	8.00	0.34	0.11	0.38	0.83	38.81	0.46	26.88	5.06	14	25	32	36	37.5	40	40.5	8
2	08/23/74	14.5	4.0	14.94	36.17	4.00	0.61	0.08	0.75	1.43	66.94	0.68	40.29	4.47	22.3	27.5	29.6	35.3	42.3	46.5	67	15
3	09/15/75	30.7	19.0	4.10	76.81	19.00	0.17	0.17	0.16	0.49	22.94	0.33	19.64	4.39	13	23	27	36.5	40	51	101	23
4	08/14/76	28.0	11.0	6.87	69.95	11.00	0.28	0.15	0.27	0.70	32.85	0.43	25.38	4.26	15	23.5	26	36	39	39	81	19
5	09/06/77	39.6	16.0	5.24	98.97	16.00	0.21	0.22	0.19	0.62	28.75	0.43	25.23	5.37	21.5	42	46.5	67	83.5	84.4	107.4	20
6	08/19/78	44.9	18.0	4.83	112.35	18.00	0.20	0.25	0.17	0.61	28.36	0.44	25.96	6.44	29.5	37	46	54.5	66.5	79	122.3	19
7	08/04/79	59.2	11.0	8.51	147.97	11.00	0.34	0.32	0.27	0.94	43.89	0.67	39.31	9.39	29.5	45.5	57	78	94.5	106	112.7	12
8	07/22/80	71.7	17.0	5.78	179.35	17.00	0.23	0.39	0.18	0.80	37.43	0.63	36.82	6.63	43	53.2	75.4	85.6	91.1	95.9	132.6	20
9	07/01/81	31.9	15.0	5.25	79.69	15.00	0.21	0.17	0.20	0.59	27.38	0.39	22.76	5.59	15	25.5	31	37.5	47	53	95	17
10	08/21/82	26.2	3.0	24.67	65.51	3.00	1.00	0.14	1.00	2.14	100.00	1.14	67.28	6.05	32	38	42	43.5	49.5	51.5	60.5	10
11	07/19/83	24.7	7.0	10.37	61.73	7.00	0.42	0.13	0.43	0.98	45.90	0.56	32.67	6.11	17	28.5	36.5	43.5	48.5	50.5	55	9
12	09/02/84	24.0	17.0	4.23	59.99	17.00	0.17	0.13	0.18	0.48	22.34	0.30	17.80	4.83	10.5	16	24	29	36	43	96.5	20
13	07/17/85	57.8	5.0	18.60	144.49	5.00	0.75	0.32	0.60	1.67	77.90	1.07	62.94	14.92	29	45	65	78	89	89.5	89.5	6
14	07/19/86	80.5	7.0	14.42	201.33	7.00	0.58	0.44	0.43	1.45	67.78	1.02	60.28	6.39	32	58	69	78.5	86	97	134.2	21
15	07/22/87	70.0	4.0	24.40	175.04	4.00	0.99	0.38	0.75	2.12	98.98	1.37	80.71	8.15	41.5	57.5	67.5	82	92	101.5	187.5	23
16	07/14/88	111.5	12.0	9.06	278.70	12.00	0.37	0.61	0.25	1.23	57.20	0.98	57.43	13.97	33	57	75.5	99.5	118	134	223.5	16
17	07/26/89	77.4	7.0	14.28	193.40	7.00	0.58	0.42	0.43	1.43	66.72	1.00	58.93	6.22	34	67.5	85.5	89.5	95	99	143	23
18	09/11/90	92.8	24.0	4.35	232.09	24.00	0.18	0.51	0.13	0.81	37.70	0.68	40.19	9.52	38.5	72	88	93.5	94.5	102	228.5	24
19	07/20/91	58.3	12.0	7.77	145.64	12.00	0.31	0.32	0.25	0.88	41.19	0.63	37.24	10.58	32	38	47.5	61.5	65	74	137.5	13
20	09/24/92	35.6	15.0	5.42	88.91	15.00	0.22	0.19	0.20	0.61	28.65	0.41	24.36	5.44	13.5	25.5	36.5	49	56.5	64	98	18
21	07/13/93	70.4	13.0	7.52	176.02	13.00	0.30	0.38	0.23	0.92	42.92	0.69	40.55	7.55	30.5	42	52.5	63.5	69	75	158.5	21
22	06/30/94	123.6	20.0	5.56	309.10	20.00	0.23	0.67	0.15	1.05	49.00	0.90	52.98	8.54	37	68.5	90.5	94	100	102.5	196.5	23
23	08/25/95	40.7	8.0	10.57	101.83	8.00	0.43	0.22	0.38	1.03	47.87	0.65	38.31	5.71	22.5	29	36.5	43	61.5	69.5	120	21
24	07/28/96	55.0	4.0	22.95	137.50	4.00	0.93	0.30	0.75	1.98	92.41	1.23	72.43	12.33	35	53	68.5	72.5	73.5	74	74	6
25	07/01/97	98.7	18.0	5.88	246.82	18.00	0.24	0.54	0.17	0.94	44.04	0.78	45.74	7.24	49.5	56.5	63.5	69.5	73.5	79	166.5	23
26	08/08/98	50.7	15.0	5.99	126.73	15.00	0.24	0.28	0.20	0.72	33.57	0.52	30.57	4.75	19.5	38.5	41	41.5	43	48	95	20
27	08/02/99	57.8	22.0	4.23	144.51	22.00	0.17	0.32	0.14	0.62	29.08	0.49	28.65	5.61	27.5	40.5	51	57.5	65	73.5	123.5	22
28	07/22/00	64.2	11.0	8.68	160.45	11.00	0.35	0.35	0.27	0.97	45.49	0.70	41.33	7.42	36	50	54.5	63.5	66	78.5	96.5	13
29	06/30/01	98.3	5.0	21.15	245.79	5.00	0.86	0.54	0.60	1.99	93.04	1.39	82.04	17.75	41	72	87	93.5	104	106.5	106.5	6
30	08/31/02	62.1	23.0	4.12	155.22	23.00	0.17	0.34	0.13	0.64	29.69	0.51	29.77	8.61	22.5	40.5	54	68.5	82	85.5	198	23
31	06/27/03	46.8	9.0	9.77	117.07	9.00	0.40	0.26	0.33	0.98	45.96	0.65	38.35	8.17	15	30	42.5	52	61.5	75	122.5	15
32	08/18/04	33.0	21.0	3.79	82.43	21.00	0.15	0.18	0.14	0.48	22.22	0.33	19.63	3.73	12.5	23	31	40.5	51	59.5	89.5	24
33	07/11/05	33.6	10.0	8.00	83.97	10.00	0.32	0.18	0.30	0.81	37.68	0.51	29.87	5.74	23	33	44	55	67.5	73.5	109	19
34	07/16/06	67.5	15.0	6.45	168.65	15.00	0.26	0.37	0.20	0.83	38.70	0.63	37.05	8.46	22.5	42	54.5	71	86	91	203	24
35	08/05/07	183.3	7.0	17.24	458.15	7.00	0.70	1.00	0.43	2.13	99.28	1.70	100.00	18.65	68	122.5	149	161	171.5	180.5	186.5	10
36	07/24/08	70.6	19.0	5.15	176.43	19.00	0.21	0.39	0.16	0.75	35.07	0.59	34.95	4.02	49	63	68	69.5	74	77.5	96.5	24
average		59.9	12.6	9.68	149.72	12.56	0.39	0.33	0.33	1.05	48.83	0.72	42.34	7.72	28.52	44.70	55.43	64.72	72.79	79.16	123.76	17.50
maximum		183.3	24.0	24.67	458.15	24.00	1.00	1.00	1.00	2.14	100.00	1.70	100.00	18.65	68.00	122.50	149.00	161.00	171.50	180.50	228.50	24.00
minimum		14.5	3.0	3.79	36.17	3.00	0.15	0.08	0.13	0.48	22.22	0.30	17.80	3.73	10.50	16.00	24.00	29.00	36.00	39.00	40.50	6.00

Note: a)  $RF_3 = RK + RM + RT$ , b)  $FHI_3 = \frac{(RF_3)_i}{(RF_3)_{max}} \times 100$ , c)  $RF_2 = RK + RM$ , d)  $FHI_2 = \frac{(RF_2)_i}{(RF_2)_{max}} \times 100$

**Table 5.** Summary of run-off and flood hazard indexing characteristics, along with rainfall data for the Mae-gok River basin (MG)

No	Flood Run-off Characteristics				Flood Indexing Parameters									Rainfall Characteristics								
	Flood event date	Flood peak discharge $Q_p$ (m <sup>3</sup> /s)	Time to peak discharge $T$ (hr)	Rising curve gradient $K$ (day <sup>-1</sup> )	Flood magnitude ratio $M$	Flood response time $T$ (hr)	Relative severity factor			Flood index			Average rainfall intensity $I_a$ (mm/hr)	Maximum 1-hour rainfall $R_{1h}$ (mm)	Maximum 2-hour rainfall $R_{2h}$ (mm)	Maximum 3-hour rainfall $R_{3h}$ (mm)	Maximum 4-hour rainfall $R_{4h}$ (mm)	Maximum 5-hour rainfall $R_{5h}$ (mm)	Maximum 6-hour rainfall $R_{6h}$ (mm)	Total rainfall depth $R_t$ (mm)	Rainfall duration time $D$ (hr)	
	(1)	(2)	(3)	(4)	(5)	(6)	$RK$	$RM$	$RT$	$RF_3^{(a)}$	$FHI_3^{(b)}$	$RF_2^{(c)}$	$FHI_2^{(d)}$	(14)	(15)	(16)	(17)	(18)	(19)	(20)	(21)	(22)
1	08/23/73	135.22	15.0	6.66	193.17	15.00	0.18	0.38	0.20	0.76	29.48	0.56	35.42	4.69	42.5	57.4	65.9	68.4	75.9	84.4	93.7	20
2	07/09/74	135.23	6.0	16.66	193.19	6.00	0.45	0.38	0.50	1.34	51.52	0.84	52.47	7.22	25	42.5	54	78.5	89.5	99.5	101.1	14
3	07/28/75	57.11	9.0	8.81	81.58	9.00	0.24	0.16	0.33	0.73	28.33	0.40	25.18	6.05	12.5	20	25.5	30	36.5	45.5	66.5	11
4	08/14/76	209.21	3.0	36.81	298.87	3.00	1.00	0.59	1.00	2.59	100.00	1.59	100.00	10.47	49.5	94.5	107.5	115.4	115.4	115.4	125.6	12
5	09/06/77	180.72	8.0	13.37	258.17	8.00	0.36	0.51	0.38	1.25	48.22	0.88	54.95	7.39	37	73.5	84.5	91	100.6	104.6	147.7	20
6	08/16/78	189.15	9.0	12.00	270.21	9.00	0.33	0.54	0.33	1.20	46.10	0.86	54.12	13.67	27.5	54	76	101.5	117	119	123	9
7	06/26/79	101.30	3.0	31.01	144.71	3.00	0.84	0.29	1.00	2.13	82.13	1.13	70.91	10.94	29.5	46	61.5	69.5	78	81.5	87.5	8
8	07/14/80	198.50	5.0	21.83	283.57	5.00	0.59	0.56	0.60	1.76	67.71	1.16	72.55	15.50	46	73	96.5	104.5	107.5	108	108.5	7
9	07/12/81	73.64	5.0	17.07	105.20	5.00	0.46	0.21	0.60	1.27	49.08	0.67	42.22	6.25	16	30.5	43.5	53.5	61.5	66	81.2	13
10	07/28/82	180.74	8.0	13.37	258.20	8.00	0.36	0.51	0.38	1.25	48.22	0.88	54.95	8.30	44.5	61	86.5	95	104	116	166	20
11	07/19/83	75.74	11.0	7.82	108.21	11.00	0.21	0.21	0.27	0.70	26.99	0.43	26.82	5.30	18	28	33.5	37	42	49	74.2	14
12	07/04/84	210.61	8.0	13.82	300.87	8.00	0.38	0.60	0.38	1.35	51.97	0.97	61.05	7.52	39.5	58	75	91	114.5	133	158	21
13	08/10/85	38.78	13.0	5.38	55.40	13.00	0.15	0.11	0.23	0.49	18.78	0.26	16.08	2.45	11	15.5	18.5	21	23	25.5	49	20
14	07/19/86	171.31	5.0	21.13	244.73	5.00	0.57	0.49	0.60	1.66	64.00	1.06	66.51	13.36	34	57	83	106	111	114	120.2	9
15	07/21/87	174.96	18.0	5.90	249.94	18.00	0.16	0.50	0.17	0.82	31.73	0.66	41.19	7.84	31.5	53.5	79.5	85.5	88.5	89	149	19
16	07/11/88	46.11	12.0	6.18	65.88	12.00	0.17	0.13	0.25	0.55	21.15	0.30	18.74	4.54	12	21	24	29	35	38	63.5	14
17	09/14/89	74.73	15.0	5.72	106.75	15.00	0.16	0.21	0.20	0.57	21.87	0.37	23.04	4.36	16.5	31	39.5	47	57.5	66	96	22
18	06/19/90	104.34	8.0	11.72	149.06	8.00	0.32	0.30	0.38	0.99	38.14	0.61	38.55	5.92	25.5	32	41	56	67	72.5	112.5	19
19	05/26/91	60.02	5.0	16.09	85.74	5.00	0.44	0.17	0.60	1.21	46.56	0.61	38.12	3.08	15.5	26	30	37.5	48	52	61.5	20
20	08/27/92	179.12	11.0	9.70	255.89	11.00	0.26	0.51	0.27	1.04	40.26	0.77	48.41	7.60	29.5	49.5	61	90.5	107.5	119.5	159.5	21
21	07/13/93	66.09	4.0	20.69	94.42	4.00	0.56	0.19	0.75	1.50	57.83	0.75	47.05	5.25	20.5	33.5	48	51	55.5	62	115.5	22
22	06/30/94	110.73	23.0	4.14	158.19	23.00	0.11	0.31	0.13	0.56	21.47	0.43	26.76	5.84	32.5	38.5	48	51	55.5	55.5	128.5	22
23	08/09/95	352.83	6.0	20.50	504.04	6.00	0.56	1.00	0.50	2.06	79.32	1.56	97.73	23.86	67.5	103.5	132.5	156.5	175.5	200.5	262.5	11
24	06/17/96	79.28	21.0	4.15	113.26	21.00	0.11	0.22	0.14	0.48	18.52	0.34	21.18	4.61	21.5	25.5	32.5	37.5	41.5	51	101.5	22
25	07/01/97	209.74	13.0	8.50	299.63	13.00	0.23	0.59	0.23	1.06	40.73	0.83	51.81	7.97	33	62.5	86	99.5	108.5	113.5	151.5	19
26	09/30/98	72.26	17.0	5.00	103.22	17.00	0.14	0.20	0.18	0.52	19.94	0.34	21.37	7.20	11.5	18	26	33	39.5	48	165.5	23
27	08/02/99	107.51	4.0	23.61	153.59	4.00	0.64	0.30	0.75	1.70	65.42	0.95	59.40	12.32	32.5	57.5	65.5	79.5	81.5	88.5	135.5	11
28	08/20/00	116.47	9.0	10.71	166.39	9.00	0.29	0.33	0.33	0.95	36.81	0.62	38.98	7.61	25	41.5	44	50	53.5	67.5	106.5	14
29	08/07/01	200.53	7.0	15.63	286.47	7.00	0.42	0.57	0.43	1.42	54.82	0.99	62.34	18.36	35.5	65.5	80.5	91	113	128	128.5	7
30	08/07/02	240.13	13.0	8.75	343.04	13.00	0.24	0.68	0.23	1.15	44.31	0.92	57.65	14.94	37.5	64	86	105	133	161	239	16
31	06/27/03	103.84	10.0	9.36	148.34	10.00	0.25	0.29	0.30	0.85	32.73	0.55	34.44	7.29	16.5	31.5	45	52.5	59.5	70.5	124	17
32	06/16/04	56.95	25.0	3.17	81.36	25.00	0.09	0.16	0.12	0.37	14.17	0.25	15.54	4.06	15.5	29.5	39.5	49.5	57	66.5	97.5	24
33	09/17/05	164.66	10.0	10.47	235.23	10.00	0.28	0.47	0.30	1.05	40.54	0.75	47.15	10.18	33.5	56.5	81	89	99.5	103	112	11
34	07/16/06	83.36	12.0	7.36	119.09	12.00	0.20	0.24	0.25	0.69	26.47	0.44	27.39	8.09	22.5	34	55.5	67	79.5	90	137.5	17
35	08/04/07	90.39	9.0	10.03	129.13	9.00	0.27	0.26	0.33	0.86	33.25	0.53	33.19	8.50	45	66.5	71	75	100.5	122	144.5	17
36	06/18/08	32.62	16.0	4.11	46.60	16.00	0.11	0.09	0.19	0.39	15.11	0.20	12.82	4.03	18.5	24	27	29.5	35.5	39	68.5	17
average		130.1	10.4	12.42	185.87	10.44	0.34	0.37	0.38	1.09	42.05	0.71	44.34	8.40	28.65	46.55	59.84	70.12	79.68	87.91	121.19	16.19
maximum		352.8	25.0	36.81	504.04	25.00	1.00	1.00	1.00	2.59	100.00	1.59	100.00	23.86	67.50	103.50	132.50	156.50	175.50	200.50	262.50	24.00
minimum		32.6	3.0	3.17	46.60	3.00	0.09	0.09	0.12	0.37	14.17	0.20	12.82	2.45	11.00	15.50	18.50	21.00	23.00	25.50	49.00	7.00

Note: a)  $RF_3 = RK + RM + RT$ , b)  $FHI_3 = \frac{(RF_3)_i}{(RF_3)_{max}} \times 100$ , c)  $RF_2 = RK + RM$ , d)  $FHI_2 = \frac{(RF_2)_i}{(RF_2)_{max}} \times 100$

**Table 6.** Correlation coefficients between two relative severity factors

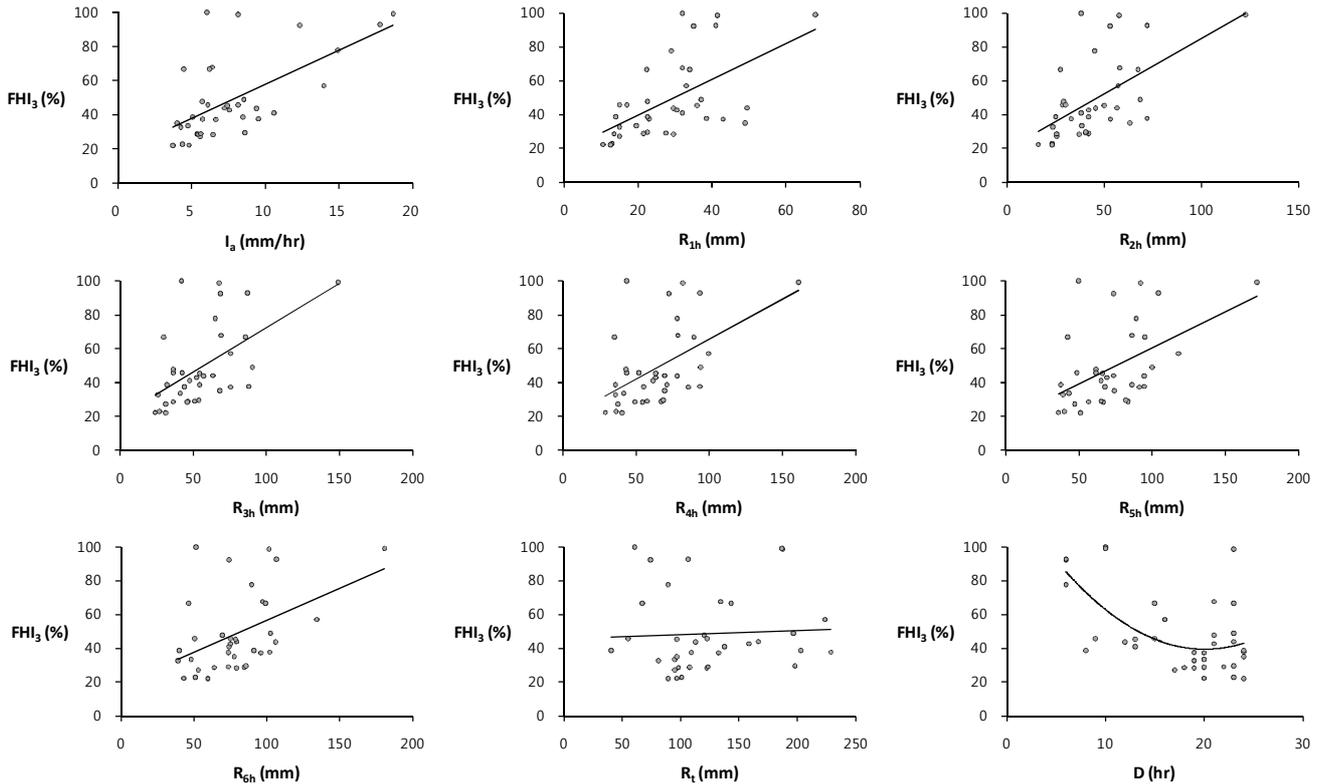
Basin	Correlation coefficient		
	<i>RK</i> and <i>RM</i>	<i>RM</i> and <i>RT</i>	<i>RK</i> and <i>RT</i>
OM	0.162	-0.089	0.948
MG	0.371	0.174	0.973

## RESULTS AND DISCUSSION

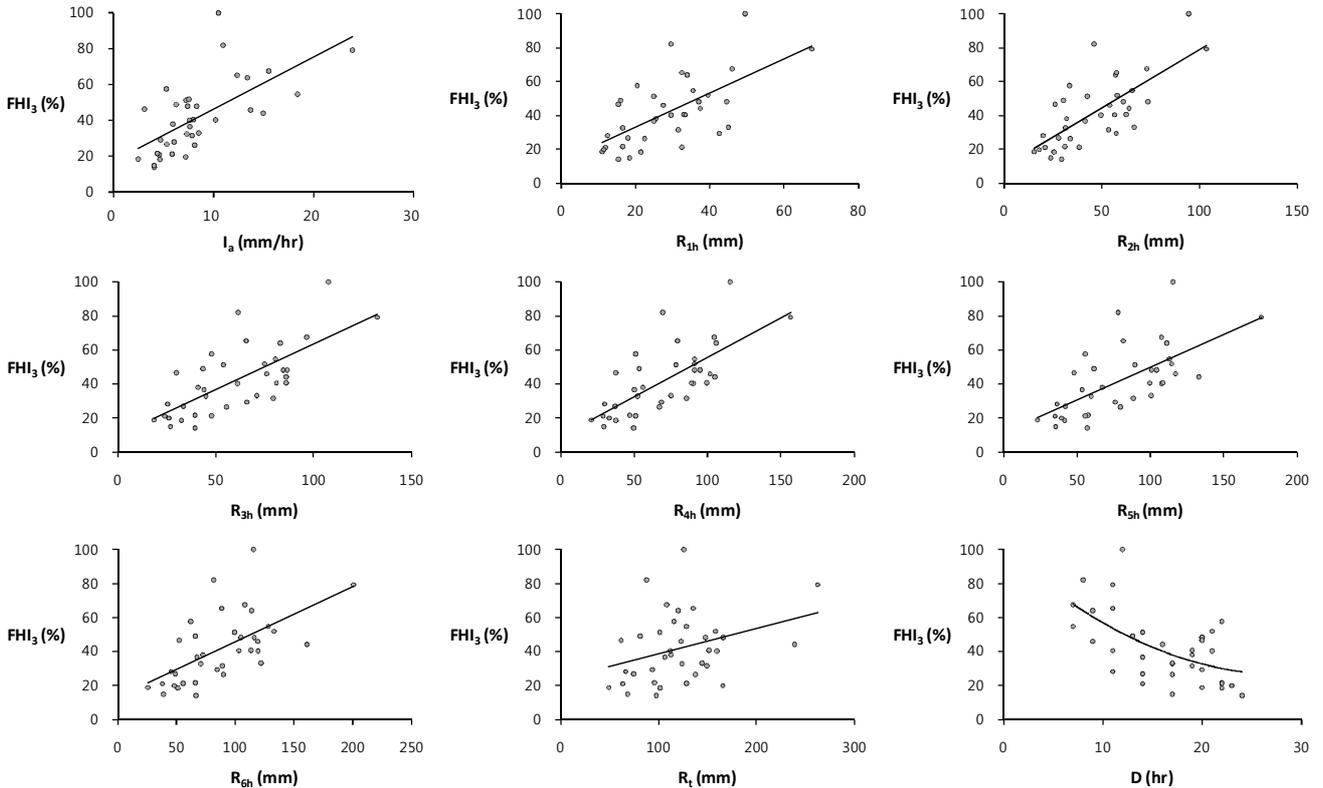
Analysis of the relationship between rainfall and run-off is important for understanding the characteristics of sudden local flooding in a short period of time over a small area. This study examines the relationship between FHI and the rainfall characteristics of the 36-year annual maximum rainfall series in two study basins. This analysis is accomplished using regression equations and scatter plots between FHI and the rainfall characteristics, viz. the average rainfall intensity  $I_a$ , the maximum rainfall depths for 1-, 2-, 3-, 4-, 5- and 6-hour durations,  $R_{1h}$ ,  $R_{2h}$ ,  $R_{3h}$ ,  $R_{4h}$ ,  $R_{5h}$  and  $R_{6h}$  respectively, the total rainfall depth  $R_t$  and the rainfall duration  $D$ . The average rainfall intensity means the total amount of rainfall for a storm event divided by the duration of the storm. The scatter plots of  $FHI_3$  and  $FHI_2$  versus each rainfall data in the two basins are illustrated in Figures 2 and 3. Table 7 summarises the regression analysis results for the relations between  $FHI_n$  and rainfall data in the two basins.

$FHI_2$  shows a much stronger relation to some rainfall data with relatively high coefficients of determination  $R^2$  for both basins as compared with the relationship between  $FHI_3$  and the rainfall characteristics. This suggests that  $FHI_2$ , which prevents double-counting of relative severity factors with similar characteristics, is more suited for estimating the relative flood severity directly from rainfall patterns in small watersheds. OM has a relatively high linear relation between  $FHI_2$  and the 2-hour maximum rainfall depth  $R_{2h}$  with coefficient of determination  $R^2$  of 0.605, as shown in Figure 3 (a). The trend between  $FHI_2$  and the 4-hour maximum rainfall depth  $R_{4h}$  shows the best-fit line with  $R^2$  of 0.765 for MG, as illustrated in Figure 3 (b). This demonstrates that the flood behaviour of OM located in the mountainous region with a smaller area is strongly influenced by the excessive rainfall in a shorter period of time as compared with the result from MG, a relatively larger flat watershed. The total rainfall amount  $R_t$  and the duration  $D$  show a weak and limited relationship to  $FHI_3$  and  $FHI_2$  in both basins (Figures 2 and 3). This result suggests that a local flood in small watersheds is mainly caused by excessive rainfall in a short period of time rather than the total rainfall amount. Furthermore,  $R^2$  in MG are much higher than those in OM for most of the regression equations as summarised in Table 7. This is partially due to the use of point rainfall data measured by a gauge station around the basin, which might not have adequately captured the spatial variation of rainfall over the hilly region of OM compared to a more accurate representation in the flat region of MG.

Although the current relation results between FHI and the rainfall characteristics are not conclusive and more tests are required for the damage reported from past floods of real severity in a large number of watersheds, the proposed FHI methodology is expected to provide the basic database for forecasting a local flood directly from rainfall patterns.

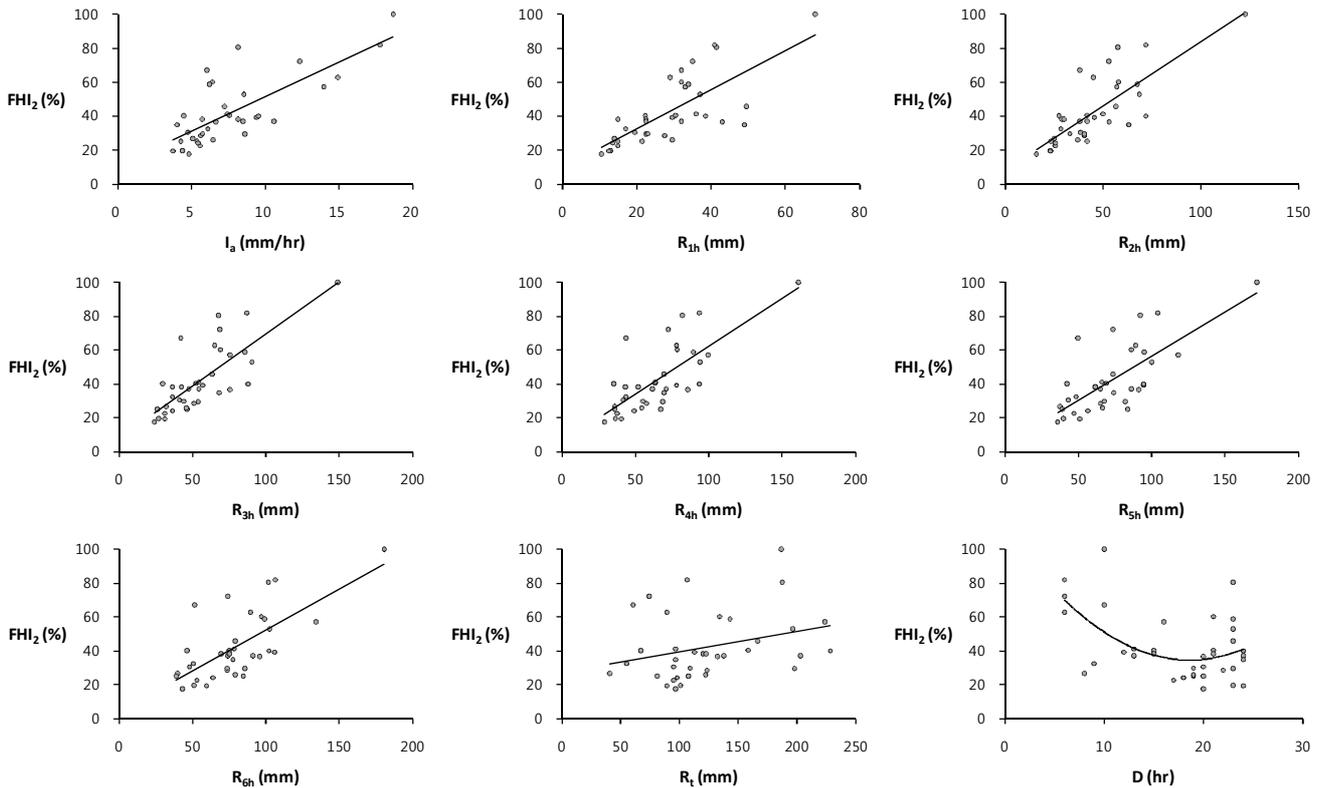


(a) Oui-mi River basin (OM)

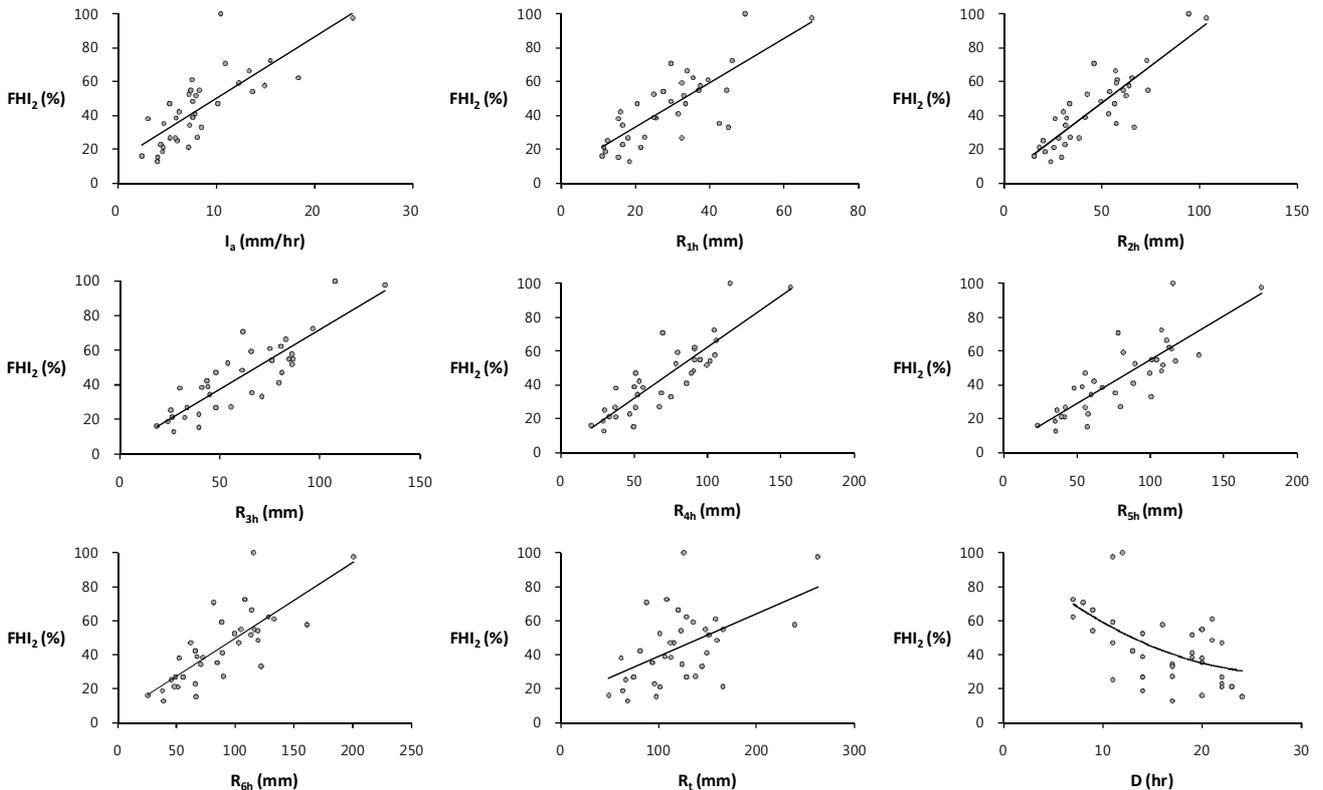


(b) Mae-gok River basin (MG)

**Figure 2.** Plots for trends between  $FHI_3$  and rainfall characteristics (average rainfall intensity  $I_a$ , 1-hour maximum rainfall depth  $R_{1h}$ , 2-hour maximum rainfall depth  $R_{2h}$ , 3-hour maximum rainfall depth  $R_{3h}$ , 4-hour maximum rainfall depth  $R_{4h}$ , 5-hour maximum rainfall depth  $R_{5h}$ , 6-hour maximum rainfall depth  $R_{6h}$ , total rainfall depth  $R_t$ , and rainfall duration  $D$ ) in (a) OM and (b) MG



(a) Oui-mi River basin (OM)



(b) Mae-gok River basin (MG)

**Figure 3.** Plots for trends between  $FHI_2$  and rainfall characteristics (average rainfall intensity  $I_a$ , 1-hour maximum rainfall depth  $R_{1h}$ , 2-hour maximum rainfall depth  $R_{2h}$ , 3-hour maximum rainfall depth  $R_{3h}$ , 4-hour maximum rainfall depth  $R_{4h}$ , 5-hour maximum rainfall depth  $R_{5h}$ , 6-hour maximum rainfall depth  $R_{6h}$ , total rainfall depth  $R_t$ , and rainfall duration  $D$ ) in (a) OM and (b) MG

**Table 7.** Regression analysis results for the relations between FHI<sub>n</sub> and rainfall data

Rainfall data	OM		MG	
	Regression Equation	$R^2$	Regression Equation	$R^2$
$I_a$	$FHI_3 = 4.000I_a + 17.928$	0.393	$FHI_3 = 2.893I_a + 17.737$	0.424
	$FHI_2 = 4.064I_a + 10.956$	0.577	$FHI_2 = 3.633I_a + 13.807$	0.601
$R_{1h}$	$FHI_3 = 1.058R_{1h} + 18.643$	0.321	$FHI_3 = 1.005R_{1h} + 13.238$	0.405
	$FHI_2 = 1.152R_{1h} + 9.484$	0.542	$FHI_2 = 1.311R_{1h} + 6.774$	0.619
$R_{2h}$	$FHI_3 = 0.659R_{2h} + 19.371$	0.325	$FHI_3 = 0.692R_{2h} + 9.854$	0.525
	$FHI_2 = 0.754R_{2h} + 8.635$	0.605	$FHI_2 = 0.871R_{2h} + 3.769$	0.750
$R_{3h}$	$FHI_3 = 0.528R_{3h} + 19.555$	0.311	$FHI_3 = 0.538R_{3h} + 9.855$	0.507
	$FHI_2 = 0.614R_{3h} + 8.311$	0.599	$FHI_2 = 0.692R_{3h} + 2.918$	0.754
$R_{4h}$	$FHI_3 = 0.473R_{4h} + 18.190$	0.272	$FHI_3 = 0.468R_{4h} + 9.257$	0.505
	$FHI_2 = 0.568R_{4h} + 5.593$	0.557	$FHI_2 = 0.607R_{4h} + 1.779$	0.765
$R_{5h}$	$FHI_3 = 0.429R_{5h} + 17.621$	0.247	$FHI_3 = 0.388R_{5h} + 11.156$	0.428
	$FHI_2 = 0.519R_{5h} + 4.581$	0.516	$FHI_2 = 0.519R_{5h} + 3.016$	0.688
$R_{6h}$	$FHI_3 = 0.382R_{6h} + 18.611$	0.211	$FHI_3 = 0.323R_{6h} + 13.634$	0.359
	$FHI_2 = 0.479R_{6h} + 4.420$	0.472	$FHI_2 = 0.445R_{6h} + 5.218$	0.612
$R_t$	$FHI_3 = 0.026R_t + 45.589$	0.003	$FHI_3 = 0.147R_t + 24.198$	0.107
	$FHI_2 = 0.119R_t + 27.628$	0.084	$FHI_2 = 0.253R_t + 13.739$	0.282
$D$	$FHI_3 = 0.232D^2 - 9.325D + 133.130$	0.360	$FHI_3 = 0.092D^2 - 5.175D + 99.582$	0.352
	$FHI_2 = 0.223D^2 - 8.304D + 111.980$	0.277	$FHI_2 = 0.091D^2 - 5.133D + 101.340$	0.309

## CONCLUSIONS

This study has presented a new flood hazard index (FHI) to characterise local flooding by run-off hydrographs generated from the annual maximum rainfall series of long-term observations for small ungauged watersheds. The stronger relation between FHI and the maximum rainfall over a short interval illustrates that excessive rainfall in a short period of time mainly causes the local flooding in small watersheds. The availability of higher spatial-resolution rainfall data is expected to significantly improve the flood predictability in order to cope with the consistent threat of flood hazards in small ungauged watersheds. The conditions for effective implementation of FHI are improvements in the accuracy of rainfall run-off model predictability and precipitation forecasting. The best-fit regression equation between FHI and the rainfall data can provide the basic database for forecasting the local flood severity directly from rainfall patterns in small ungauged catchments, where the flood response time is quite short. For practical use of the regression analysis results of this study in a flash flood forecasting

and warning system, further research is needed to determine a threshold of FHI to be linked with the threshold run-off in GIS-based, flash flood guidance.

#### ACKNOWLEDGEMENTS

This research was supported by the Yeungnam University research grant (211A380025) in 2011.

#### REFERENCES

1. Korea National Emergency Management Agency (KNEMA), *The Annual Natural Disaster Bulletin*, **2010**, pp.100-107.
2. H. S. Shin, H. T. Kim and M. J. Park, "The study of the fitness on calculation of the flood warning trigger rainfall using GIS and GCUH", *J. Korea Water Resour. Assoc.*, **2004**, 37, 407-424.
3. B. S. Kim and H. S. Kim, "Estimation of the flash flood severity using runoff hydrograph and flash flood index", *J. Korea Water Resour. Assoc.*, **2008**, 41, 185-196.
4. L. Marchi, M. Borga, E. Preciso and E. Gaume, "Characterisation of selected extreme flash floods in Europe and implications for flood risk management", *J. Hydrol.*, **2010**, 394, 118-133.
5. J. A. Smith, M. L. Baeck, Y. Zhang and C. A. Doswell, "Extreme rainfall and flooding from supercell thunderstorms", *J. Hydrometeorol.*, **2001**, 2, 469-489.
6. J. A. Rogash and J. Racy, "Some meteorological characteristics of significant tornado events occurring in proximity to flash flooding", *Weather Forecast.*, **2002**, 17, 155-159.
7. E. R. Vivoni, D. Entekhabi, R. L. Bras, V. Y. Ivanov, M. P. Van Horne, C. Grassott and R. N. Hoffman, "Extending the predictability of hydrometeorological flood events using radar rainfall nowcasting", *J. Hydrometeorol.*, **2006**, 7, 660-677.
8. G. K. A. Kyiamah, "Monitoring and characterization of flash flood", *MS Thesis*, **1996**, University of Louisville, USA.
9. N. R. Bhaskar, M. N. French and G. K. Kyiamah, "Characterization of flash floods in Eastern Kentucky", *J. Hydrol. Eng.*, **2000**, 5, 327-331.
10. J. C. Jung, "The study on estimation of the flash flood index for the Bo-chun River basin", *MS Thesis*, **2000**, Suwon University, Korea.
11. "The basic plan report for the Oui-mi River maintenance works", Wonju City, Gangwon Province, Korea, **2007**.
12. "The basic plan report for the Mae-gok River maintenance works", Chungcheongnam Province, Korea, **2004**.
13. U. S. Army Corps of Engineers, "Hydrologic Modeling System: Technical Reference Manual", Hydrologic Engineering Center, Davis (CA), **2000**.
14. Natural Resources Conservation Service (NRCS), "Urban Hydrology for Small Watersheds", Technical Release 55, U.S. Department of Agriculture, **1986**.
15. C. O. Clark, "Storage and the unit hydrograph", *Trans. ASCE*, **1945**, 110, 1419-1446.
16. J. Noh, "A conceptual watershed model for daily streamflow based on soil water storage", *PhD Thesis*, **1991**, Seoul National University, Korea.