Estimations of Flood Potential Risk and Frequency for A Region

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ABSTRACT: The Potential Flood Damage(PFD) is widely used for representing the degree of potential of flood damage in Korea. However, this cannot be connected with the design frequency of river basin and so we have difficulty in the use of water resources field. Therefore in this study we develop the concept of Potential Risk for Flood Damage Occurrence(PRFD) which can be related to the design frequency.

The PRFD has three important elements of hazard, exposure, and vulnerability. The hazard means a probability of occurrence of flood event, the exposure represents the degree that the property is exposed in the flood hazard, and the vulnerability represents the degree of weakness of the measures for flood prevention. The elements also have some sub-elements. Say, the hazard is explained by the frequency based rainfall, the exposure has two sub-elements which are population density and official land price, and the vulnerability has two sub elements which are undevelopedness index and ability of flood defense. Each sub-elements are estimated and the estimated values are rearranged in therange of 0 to 100. the Analytic Hierarchy Process(AHP) is also applied to determine weighting coefficients in the equation of PRFD.

We estimated the PRFD for the Anyang river basin, Korea and also the design frequency by using the maximum rainfall. The exiting design frequency for Anyang river basin is in the range of 50 to 200 years. And the result of this study is in the range of 110 to 130 years. Therefore, we can use the developed method for the estimation of PRFD and the design frequency for the administrative districts and maybe we could apply the method for the watershed and the river channel in the future study.

1. Introduction.

· Korea has been rapidly developed during a last few decades and land use is intensified. Therefore the urbanization and industrialization have been also rapidly proceeded and suffered from natural disaster such as flood. As the result of fast development, the exposure and vulnerability on flood were increased and so the flood damage was also increased every year.

· In two decade, we have done many efforts in decreasing the flood damage through a tree-planting, dam and levee constructions, channel improvement, flood forecasting and warning system, and so on. Nevertheless, the flood damage is continuously increasing. We consider this may be due to abnormal climate variability and we may have the limitation for preventing and decreasing flood damage with structural and nonstructural measures centering around river line. So, 'Watershed Based Integrated Flood Control Plan' is established to overcome this limitation in Korea. The Plan is to distribute the flood discharge into river and watershed which can have pond, flood control channel, river line storage pond, and so on.

· We estimate the Potential Flood Damage(PFD) for defining the vulnerability of a region to the flood but the PFD is not connected with the design frequency of a region or a river. So, this study will provide a concept of Potential Risk for Flood Damage Occurrence(PRFD) which can be estimated in the similar way with PFD and connected with the design frequency of a hydrologic event.

2. Estimation of Potential Risk for Flood Damage Occurrence

2.1 Methodology

We would like to define the Exposure (E) and Vulnerability (V) on the flood and these two words will be used for the estimation of PRFD (Rp). Actually, we borrowed these two words from the work of Kron (2003) and we define the PRFD in Eq.(1) as the function of E and V

$$\mathbf{R_p = f_p(E,V) = \alpha \times E + \beta \times V} \tag{1}$$

R_p: Potential Risk for Flood Damage(PRFD)
P : Hazard (probability which a flood event can occur)
E : Exposure (Degree of loss by flood event which is an element of the Risk)
V : Vulnerability (The lack of flood prevention capability)

In Eq.(1) Exposure shows the degree of damage according to flood event and Vulnerability means the lack of flood prevention capability and shows costs used in structural or nonstructural plan for compensating flood defense shortage. We also define the sub-elements of exposure as regional public land price and population to describe the degree of damage according to flood events. And we define the sub-elements of vulnerability as the degree of undeveloped area in a region and flood prevention capability such as pumping station, dam and resevoir, and channel improvement. Therefore, we can express the E and V with their sub-elements as given as Eq. (2) and (3)

$$\mathbf{E = \alpha_H \times \text{population index} + \beta_H \times \text{public land price}} \tag{2}$$

$$\mathbf{V = \alpha_V \times \text{degree of undeveloped area in a region} + \beta_V \times \text{flood prevention capability}} \tag{3}$$

$$\mathbf{\text{Flood prevention capability} = \alpha_H \times \text{Dam, resevoir} + \beta_H \times \text{pumping station} + \gamma_H \times \text{river improvement}}$$

Here, α , β represent the weighting coefficients and can be estimated by Analytic Hierarchy Process(AHP) technique. The E and V are represented with the indices in the range of 0 to100. So, the sub-elements could be also represented by the proper values to reflect the values of E and V.

2.2 Estimation of Exposure and Vulnerability

2.2.1 Exposure Estimation

The exposure is estimated using public land price and population density. First of all, we investigate the total data of a whole country to present the sub-elements of exposure in the range of 0 to 100, and estimate the indices of study area.

Korean Association of Poverty Appraisers(KAPA) provides the standard table of annual public land. This data is provided in si(or city)-do(or province), si-gun-gu(or city-county-district), or dong(or village) units and also provided for commercial, industrial, inhabitant, crop, and forest areas. We use these data for the estimation of the public land price index. Here, we consider the median value of public land price of standard table as public price index of a region. Population density is simply estimated using the data provided by Korean National Statistical Office.

2.2.2 Vulnerability Estimation

We estimate the vulnerability using its sub-elements. The degree of undeveloped area in a region presented by KDI(Korea Development Institute, 2000) is a relative index describing the development and undevelopment of a study region. Korea has 7-Metropolitan city and 9-Do(or province), and the city and Do are also divided by 170 areas. We estimate the indices using the data which is obtained from 170 areas.

Flood prevention capability is estimated by nonstructural and structural measures such as the channel improvement index, pumping station index, dam and resevoir index which are sub-elements of the capability.

The channel improvement index is represented by the percentage which has the value in the range of 0 to 100. The dam and resevoir index and pumping station index are considered by their existence or not. For example, if the pumping station exists in the study area the index will be 100.

2.3 Analytic Hierarchy Process

The weighting coefficients in the Eqs. of (2) and (3) should be estimated and this study uses the Analytic Hierarchy Process(AHP) for the estimation of coefficients. The AHP is suggested by Saaty in the early of 1970s. The AHP is the decision-making methods capturing knowledge, experience and intuition of an appraiser through judgment by pairwise comparison of the elements and sub-elements.

In general, the AHP can be performed by the following four steps for solving the problems related to the decision-making.

(1) Establish the elements and classify the related elements each other for the decision-making
(2) Collect the judgeable data by Pairwise comparison
(3) Estimate the relative weighting coefficients of decision-making attributes or elements.
(4) Integrate the relative weighting coefficients of the decision-making attributes of elements to get the ranking between many alternatives.

Table 1. General standard of pairwise comparison(Saaty, 1980)

Degree of importance	Definition
1	same
3	a little important

5	important
7	extremely important
9	absolutely important
2, 4, 6, 8 represent the middle importance of 1, 3, 5, 7, 9	

3. Determination of Design Frequency by Recorded Maximum Rainfall.

To determine the design frequency for a region, firstly we estimate the PRFD after the estimation of the exposure and vulnerability of a study area. Also, we estimate the frequency based rainfall for the rainfall gage stations and choose the recorded maximum rainfall from the stations which are around the study area. So, we can determine the frequency from the frequency based rainfall corresponding to the recorded max rainfall.

The determined frequency is corresponding to the maximum value of 100 of PRFD and we obtaine the regression equation of the determined frequency versus PRFD for a study area or a region. So, we can obtain the design frequency corresponding to PRFD in a region from the regression equation.

4. Application

4.1 Study Area

The study area is An Yang river basin and this basin is located in two areas of Seoul city and Gyunggido province in Korea. The basin area is 286 ㎢, main channel length is 32.5 ㎞, and mean width of watershed is 8.8 ㎞. The An Yang river flows several districts of Kangseogu, Gwanakgu, Gurogu, Geumcheongu, Dongjakgu, Yangchoengu, Yeongdeungpo-gu in Seoul and several cities of Gwachonsi, Gwanmyungsi, Gunposi, Bucheonsi, Siheungs , Anyangsi, and Uiwangsi in Gyunggido.

The 70% of study area is urban and forest area. The downstream area of An Yang river is densely populated and the upatream area is urban and residence area. Seoul and Suwon rainfall gage stations are selected to use the rainfall data and the units of determination of PRFD and design frequency is si−gun−gu.

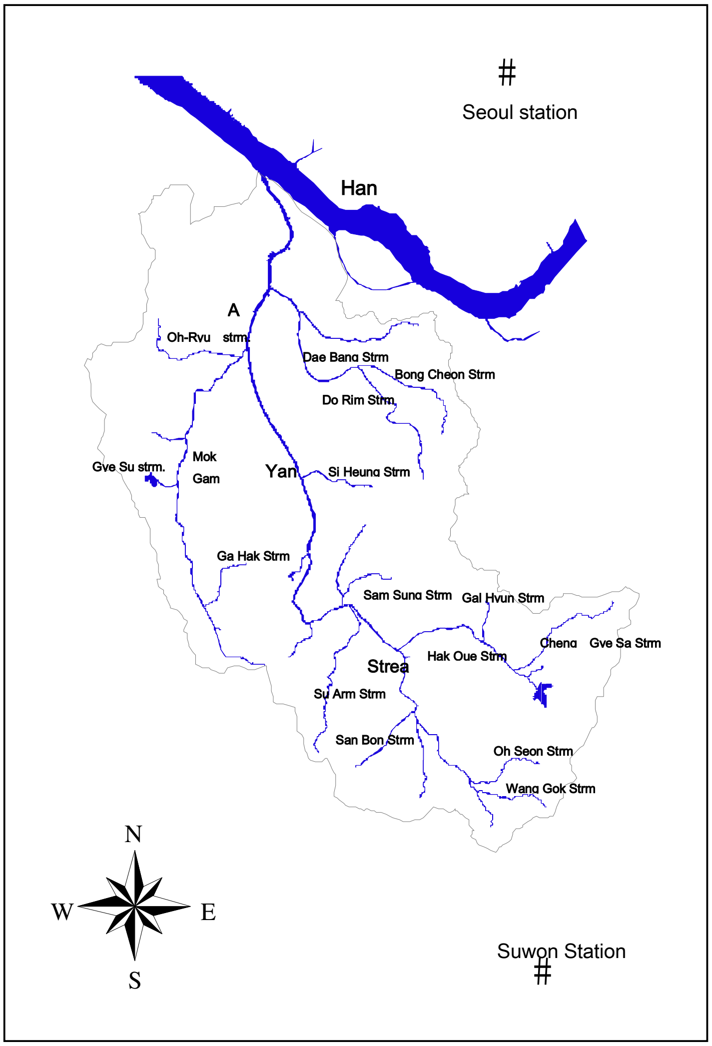

Figure 1. An Yang river basin

4.2 Estimation of Weighting Coefficient

We investigate the questionair survey for pirewise comparision and we analyze the survey by general standard in Table 1. A geometric average is used for the evaluation of the survey. Also, Consistency Index(CI) and Consistency Ratio(CR) are used for the consideration of consistency of the survey. From the analysis of AHP using the survey result, we obtained the weighting coefficients in Table 2.

Table 2. The weighting coefficients by AHP

Classification	Attributes	Weighting coef.
PRFD	Exposure α	0.52
	Vulnerability β	0.48
Exposure	Population density α_E	0.84
	Public land price β_E	0.16
Vulnerability	degree of undeveloped area in a region α_V	0.24

	Flood defence capability β_V	0.76
Flood defence capability	Dam and resevoir α_H	0.54
	Pumping station β_H	0.16
	River improvment γ_H	0.30

4.3 Estimation of PRFD

4.3.1. Exposure Estimation

The sub-elements to calculate the exposure is population density and public land price, and we use the average values of sub-elements for si-gun-gu. The sub-elemensts and the values are represented in Tables 3 and 4. The expousure is shown in Table 5.

Table 3. Public land price index of An Yang river basin

District.		Total area (km^2)	Total land price according to land use (million×100)						Average (won)	Public land price index
			inhabitancy	Commercial	Industry	crop	forest	No designation		
Seoul	Kangseogu	41.40	15,086	155,349	26,550	19,361	8,059	0	5,420	82.14
	Gwanakgu	29.57	8,050	142,311	0	376	15,522	0	56,2258	82.57
	Gurogu	20.12	8,562	74,614	96,870	2,272	1,130	0	911,770	88.28
	Geumcheongu	13.37	3,240	63,288	55,022	339	1,462	0	9,226	88.41
	Dongjakgu	16.35	4,971	177,388	0	0	563	0	1,118,793	90.69
	Yangchoengu	17.41	11,674	134,062	1,838	478	2,552	0	8,650	87.65
	Yeongdeungpogu	24.56	50,748	68,676	145,497	0	0	0	1,078,669	90.26
Gyunggido	Gwachonsi	35.85	78,431	322,470	0	9,934	763	0	7,699	86.28
	Gwanmyungsi	38.51	45,701	185,007	26,967	20,501	1,907	0	4,787	80.67
	Gunposi	36.39	37,550	129,485	29,831	5,011	470	24,426	502	54.05
	Bucheonsi	53.46	5,727	73,883	26,375	13,614	11,791	5,644	199	43.15
	Siheungsi	134.40	3,011	40,441	588	29,225	13,250	1,849	205	43.47
	Anyangsi	58.52	3,842	38,482	11,550	5,201	11,971	0	1,317	65.44
	Uiwangsi	53.96	5,345	101,942	1,285	11,327	5,317	3,579	280	47.17

Table 4. Population density index of An Yang river basin

(Unit : person/km^2)

Si, Do	Si,Gun,GU	Population Density	P.D. index
Seoul	Kangseogu	28,600.11	100.00
	Gwanakgu	25,317.79	98.06
	Gurogu	13,158.50	89.12
	Geumcheongu	21,120.09	95.58
	Dongjakgu	16,933.59	92.56
	Yangchoengu	16,259.36	92.01
	Yeongdeungpogu	20,449.42	95.14
Gyunggido	Gwachonsi	1,970.46	63.18
	Gwanmyungsi	8,764.373	83.57
	Gunposi	7,603.187	81.63
	Bucheonsi	15,948.41	91.75

	Siheungsi	2,831.5	68.13
	Anyangsi	10,396.94	85.90
	Uiwangsi	2,677.131	67.37

Table 5. Exposure of An Yang river basin

District.		Population Density index	Public Land Price index	Exposure
Seoul	Kangseogu	100.00	82.14	91.82
	Gwanakgu	98.06	82.57	85.05
	Gurogu	89.12	88.28	88.41
	Geumcheongu	95.58	88.41	89.56
	Dongjakgu	92.56	90.69	90.99
	Yangchoengu	92.01	87.65	88.35
	Yeongdeungpogu	95.14	90.26	91.04
Gyunggido	Gwachonsi	63.18	86.28	82.58
	Gwanmyungsi	83.57	80.67	81.13
	Gunposi	81.63	54.05	58.46
	Bucheonsi	91.75	43.15	50.93
	Siheungsi	68.13	43.47	47.42
	Anyangsi	85.90	65.44	68.71
	Uiwangsi	67.37	47.17	50.40

4.3.2 Estimation of Vulnerability

The vulnerability can be also estimated by its sub-elements like exposure estimation. The index of degree of undeveloped area in a region is calculated by using the ranking of degree of undeveloped area in a region according to si, gun units**.** A linear regressive equation is determined if we make the first ranking is 0, the final ranking is 100, and then the index of degree of undeveloped area in a region is estimated. The estimation results are shown in Tables of 6, 7, 8, and 9.

Table 6. The index of degree of undeveloped area in a region

District		Degree of undeveloped area in a region	Ranking	Index
Seoul	Kangseogu	2.933	1	0
	Gwanakgu	2.933	1	0
	Gurogu	2.933	1	0
	Geumcheongu	2.933	1	0
	Dongjakgu	2.933	1	0
	Yangchoengu	2.933	1	0
	Yeongdeungpogu	2.933	1	0
Gyunggido	Gwachonsi	1.031	19	10.65
	Gwanmyungsi	0.939	22	12.43
	Gunposi	1.521	9	4.73
	Bucheonsi	2.219	2	0.59
	Siheungsi	1.637	7	3.55
	Anyangsi	1.702	6	2.96
	Uiwangsi	0.715	33	18.93

Table 7. The index of flood defence capability

District		Dam, Resevoir	Pumping station	River Improvement	Flood defence capability index
Seoul	Kangseogu	X	100	100	0
	Gwanakgu	X	0	100	43
	Gurogu	X	100	100	0
	Geumcheongu	X	100	100	0
	Dongjakgu	X	100	100	0
	Yangchoengu	X	100	100	0
	Yeongdeungpogu	X	100	100	0
Gyunggido	Gwachonsi	X	0	100	43
	Gwanmyungsi	100	100	100	0
	Gunposi	X	0	65.34	62.76
	Bucheonsi	X	0	100	43
	Siheungsi	100	0	97.88	16.64
	Anyangsi	X	100	100	0
	Uiwangsi	100	0	68.37	25.49

Table 8. Vulnerability of An Yang river basin

District		degree of undeveloped area in a region	Flood defence capability index	Vulnerability
Seoul	Kangseogu	0	0	0
	Gwanakgu	0	43	32.68
	Gurogu	0	0	0
	Geumcheongu	0	0	0
	Dongjakgu	0	0	0
	Yangchoengu	0	0	0
	Yeongdeungpogu	0	0	0
Gyunggido	Gwachonsi	10.65	43	35.24
	Gwanmyungsi	12.43	0	2.98
	Gunposi	4.73	62.76	48.83
	Bucheonsi	0.59	43	32.82
	Siheungsi	3.55	16.64	13.50
	Anyangsi	2.96	0	0.71
	Uiwangsi	18.93	25.49	23.92

Table 9. The PRFD of An Yang river basin

District		Exposure	Vulnerability	PRFD
Seoul	Kangseogu	91.82	0	47.75
	Gwanakgu	85.05	32.68	59.91
	Gurogu	88.41	0	45.98
	Geumcheongu	89.56	0	46.57
	Dongjakgu	90.99	0	47.31
	Yangchoengu	88.35	0	45.94
	Yeongdeungpogu	91.04	0	47.34
Gyunggido	Gwachonsi	82.58	35.24	59.86
	Gwanmyungsi	81.13	2.98	43.62

	Gunposi	58.46	48.83	53.84
	Bucheonsi	50.93	32.82	42.24
	Siheungsi	47.42	13.50	31.13
	Anyangsi	68.71	0.71	36.07
	Uiwangsi	50.40	23.92	37.69

4.4 Determination of Design Frequency

To analyze the frequency based rainfall according to the duration we collect the data in the period of 1961 to 2001(41 years) in seoul rainfall gage station and 1964 to 2001(38 years) in Suwon rainfall gage station. We obtain the annual maximum rainfall data for six durations. We carried out the frequency based rainfall analysis using the collected data. We used the Gumbel distribution with parameter estimation by probability weighted moments. The results are shown in Tables 10 and 11

Table 10. Frequency based rainfall (Seoul station)

(Unit：mm)

Frerquency (year)	Duration					
	1	2	3	6	12	24
5	65.8	96.7	116.2	150.7	186.4	232
10	77.7	113.5	137.2	177.6	219.2	280.2
20	89.1	129.5	157.2	203.3	250.7	326
30	95.6	138.8	168.7	218.1	268.8	352.5
50	103.9	150.4	183.2	236.6	291.5	385.3
80	111.3	160.9	196.4	253.6	312.2	415.6
100	114.9	165.9	202.6	261.7	322	429.8
150	121.4	175	213.9	276.1	339.9	455.8
200	125.9	181.4	222	286.5	352.5	474.1
500	140.4	201.9	247.6	319.3	392.6	532.6

Table 11. Frequency based rainfall (Suwon station)

(Unit：mm)

Frequency (year)	Duration					
	1	2	3	6	12	24
5	55.43	81.29	102.45	139.64	185.13	233.06
10	64.8	96.07	122	166.36	221.46	281.18
20	73.77	110.25	140.75	192	256.32	327.35
30	78.94	118.4	151.54	206.75	276.37	353.9
50	85.4	128.6	165.03	225.18	301.43	387.1
80	91.31	137.93	177.37	242.05	324.38	417.49
100	94.11	142.35	183.22	250.05	335.24	431.88
150	99.18	150.37	193.82	264.55	354.96	457.99
200	102.78	156.05	201.34	274.82	368.93	476.49
500	114.23	174.12	225.25	307.51	413.37	535.35

Table 12. Recored maximun rainfall according to duration

Duration	Seoul Station		Suwon station	
	year	Max value (mm)	year	Max value (mm)
1	2000	104.4	1965	138.0

2	2000	143.8	2001	154.0
3	1991	185.7	2001	208.0
6	2000	233.0	2001	263.3
12	1990	337.1	1998	365.2
24	1972	453.8	1972	446.8

After the recored max rainfall is determined according to duration in Table 12, the frequency which PRFD equals 100 is obtained by Table 10 and 11**.** That is to say, for the duration of 24hr, the recorded max rainfalls of Seoul and Suwon station are corresponding to the frequency based rainfall of 150 years. So, we determined that the 100 of PRFD is equal to the frequency based rainfall of 150 years. And we obtained the regression equation as shown in Fig. 2. If we use Fig. 2 we can obtain the design frequency corresponding to the PRFD as shown in Table 13.

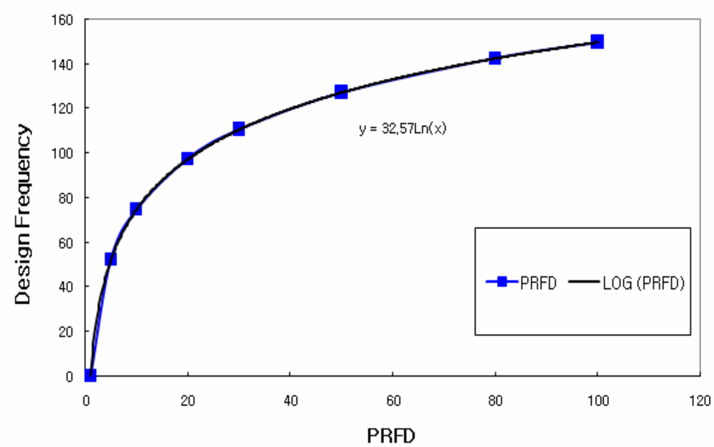

Figure 2. Regression equation of PRFD vs. Frequency

Table 13. Estimated design frequency using PRFD

District.		PRFD	Design frequency (year)
Seoul	Kangseogu	47.75	125.91
	Gwanakgu	59.91	133.30
	Gurogu	45.98	124.68
	Geumcheongu	46.57	125.10
	Dongjakgu	47.31	125.62
	Yangchoengu	45.94	124.66
	Yeongdeungpogu	47.34	125.63
Gyunggido	Gwachonsi	59.86	133.28
	Gwanmyungsi	43.62	122.97
	Gunposi	53.84	129.82
	Bucheonsi	42.24	121.92
	Siheungsi	31.13	111.99
	Anyangsi	36.07	116.78
	Uiwangsi	37.69	118.21

Actually, the PFD and PRFD are similar methods for the estimation of flood potential and so we compare the PRFD estimated in this study and the PFD from the report previously studied(Ministry of Construction and Transportation, 2004).

PRFD estimated in this study is converted to identical index with PFD which is ranged from 0 to 1 as shown in Table 14. If we see Table 14, the PRFD has approximately similar tendency with the PFD. But, we know that the PRFD shows less value than the PFD.

Figure 14. Comparison of PFD and PRFD

The administrative district		Inserting area	Existing PFD	Revised PFD	PRFD
Seoul	Kangseogu	5.18	0.59	0.60	0.48
	Gwanakgu	26.44	0.70	0.70	0.60
	Gurogu	22.74	0.65	0.63	0.46
	Geumcheongu	13.64	0.59	0.59	0.47
	Dongjakgu	6.15	0.59	0.57	0.47
	Yangchoengu	14.82	0.59	0.59	0.46
	Yeongdeungpogu	12.89	0.62	0.63	0.47
Kyung-gi Do	Gwachonsi	6.10	0.37	0.44	0.60
	Gwanmyungsi	39.04	0.57	0.56	0.44
	Gunposi	17.00	0.48	0.41	0.54
	Bucheonsi	8.69	0.65	0.64	0.42
	Siheungsi	14.49	0.42	0.42	0.31
	Anyangsi	56.39	0.55	0.49	0.36
	Uiwangsi	42.44	0.42	0.36	0.38

5. Conclusion

These days, we are considering the watershed based flood control plan instead of the river and the PFD is widely used for the estimation of the flood potential in the watershed. However, the PFD is not connected with the frequency which the river has its frequency according to its degree of importance.

Therefore this study has tried to connect the flood petential in a watershed with the frequency and we have used the PRFD for this purpose. From the study we have obtained the following conclusions

(1) We have defined the concept of the PRFD and suggested the methodology for the estimation of the PRFD by using its elements and sub-elements. And we have used AHP technique for the estimation of weighting coefficients of the elements.

(2) We have connected the PRFD with the freqency of a watershed or a region. Also we have compared the PRFD with the PFD which has similar concept each other. As the results of comparison, two methods have shown the similar results for the flood potential in a region.

(3) Therefore we could compare the frequency for a region by the PRFD with the design frequency of a river which includes a region.

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