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Analysis on flood frequency and water quality variations induced by abnormal climate

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ABSTRACT

Recently, the frequency of severe torrential rain storms has been continuously increasing as an effect of abnormal climate. Annual flood damages and water quality degradation continuously worsen despite the imposition of flood and water quality managements. Hence, suitable analyses should be made to mitigate future flood damages and water quality degradation in riverine systems. In this study, two major analyses were done: analysis on the variation of the flood frequency and water quality. The principal method used to analyze variation of the flood frequency is through the application of flood-frequency analysis in time series on flood discharges. For the flood-frequency analysis, the stream flow data used were gathered from 25 gauging stations located in Geum River Basin. The Log Pearson Type III distribution was used to determine the probability of the flood discharges. The annual maximum series of the flood discharge data from stations was divided into two parts: the historical data and the present data. Flood-frequency analysis was performed to determine the influence of the effects of abnormal climate to the flood discharge in Bugil and Seokhwa stations. For the second part of this study, the water quality data such as BOD, COD, and SS for 24 years were also collected for the analysis of variation patterns of water quality induced by abnormal climate. This study showed that the flood frequency by flood-frequency analysis using the present data was higher compared with the historical data. Further findings showed that, both COD and SS consistently increase while BOD decreases in a yearly basis.

Keywords: Abnormal climate; Flood-frequency analysis; Flood frequency; Non-degradable organic material

1. Introduction

According to the Korea Meteorological Administration, the annual flood damage is continuously increasing, which is caused by the increase in the frequency of locally concentrated rainfall events, one of the known effects of abnormal climate. Furthermore, effects on water quality degradation, such as the increase in water pollution and variation of aquatic ecosystem, were determined as a result of varying

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hydrological cycle process [1]. During the past 20 years, human casualties have decreased while structure damages in the Geum River Basin have increased; moreover, flood-induced damages occurred frequently after year 1995 [2]. Changes in the mean annual precipitation from 1998 to 2008 have increased by 9.1%; while, changes in the temperature from 1971 to 2000, have increased by 6.1℃ [3]. The change in run-off characteristics could result to flooding, and thus, triggers contamination from non-point source pollution. Hence, the destruction of the aquatic ecosystem can be expected [4]. Therefore, the estimation on the precise design flood and analysis on the variation of water quality should be considered to mitigate both the flood damages and water quality degradation in riverine systems.

Previously conducted studies focused on the determination of the hydrological effect and water quality estimation based from varying climate and environmental scenarios [5–9]. In Korea, studies predicting both the hydrologic and water quality characteristics of the riverine system, in relation with abnormal climate, were performed for the last five years [10,11]. However, studies regarding the determination of both the water quality and flood discharge probability, through flood-frequency analysis, were not yet performed.

The most common methods used, for flood frequency, are the synthetic unit hydrograph and the flood-frequency analysis [12]. In drainage areas with extensive flood discharge data, flood-frequency analysis is often performed. However, in basins without observed flood discharge data, rainfall-frequency analyses are performed. For the past 20 years, Korea has been utilizing the probability method with rainfall derived unit hydrograph, which is also applied to ungauged basins. The unit hydrograph of a watershed is defined as the direct run-off hydrograph resulting from a unit volume of excess rainfall of constant intensity and uniformly distributed over the drainage area [13]. Flood-frequency analysis was proven to provide better peak flow estimations in comparison with the use of synthetic unit hydrograph [12]. The principal method used to estimate flood frequency is through the application of flood-frequency analysis in a time series. Time series analysis is a statistical model representing the characteristics of time series data [14].

The Geum River Basin has long-period stream flow data, which is a requisite for performing flood-frequency analysis to determine the flood-frequency variation. However, studies regarding flood-frequency analysis are still inadequate to fully support the implementation of the study into practice. Therefore, to perform the estimation of design flood and analysis on flood-frequency variation through flood-frequency analysis, the use of recent stream flow data is necessary to determine the variation of flood discharges induced by abnormal climate.

This study estimated the best fit of probability distribution at stream flow gauging stations in the Geum River Basin using flood-frequency analysis. Moreover, two unregulated stations located in upstream (i.e. Bugil and Seokhwa stations), stations which are not influenced by run-off of upstream artificially, were subjected to flood-frequency analysis considering the induced effects of abnormal climate. Moreover, four water quality monitoring stations, located within the Geum River and Miho stream, were selected for the analysis of water quality variation, for the past 24 years.

2. Materials and research methods

Fig. 1 shows the schematic diagram that summarizes the procedures of this study. First, the flood discharge by rating curves and water quality data of the Geum River were collected. The preliminary tests were performed to determine which data-sets are most suitable for the analyses. For the third methodology in this study, the goodness of fit was analyzed to

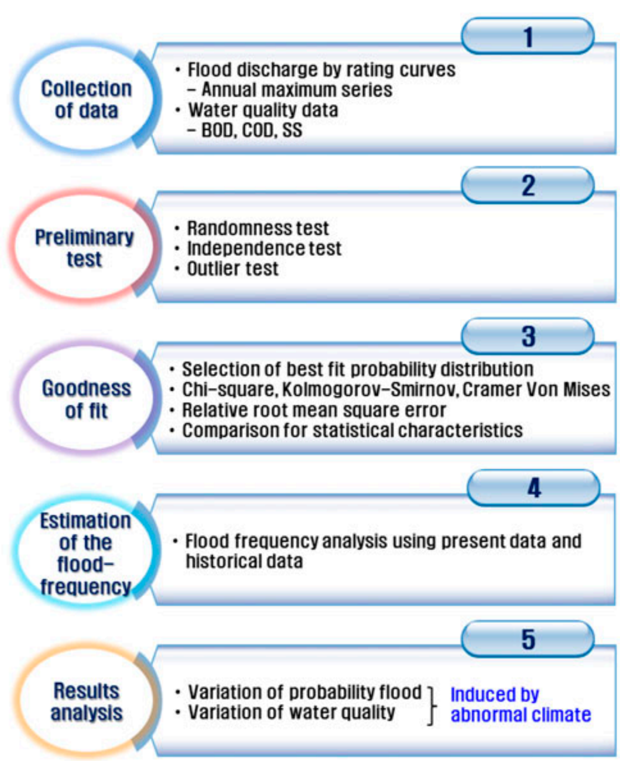


Fig. 1. Flow chart of the research.

determine the optimal probability distribution. And lastly, the estimation and analysis were done to analyze the variation of flood frequency and water quality induced by abnormal climate.

2.1. Study area

The Geum River Basin, the third largest river basin in Korea, has a drainage area of 9,912 km^2; and the main channel has a total length of 397.8 km. Table 1 shows the brief summary of the main characteristics of the Geum River Basin.

Wherein the shape factor is a dimensionless coefficient of the basin, and which is equal to basin length divided by the width of the basin. While, the drainage density is defined as the total stream length divided by drainage area.

Table 2 shows rate of urbanization in the Geum River Basin. The rate of urbanization was calculated through the determination of the ratio of impervious area with total drainage area. According to the Ministry of Land Transport and Maritime Affairs (MLTMA) the increase in the urbanization was insignificant because the ratio of impervious has been increased by 3.0% in the Geum River Basin [2].

2.1.1. Location of stream flow gauging stations and water quality monitoring stations

The stream flow gauging stations in the Geum River Basin has a total count of 92 gauging stations. Wherein, 82 stations are administered by the MLTMA; eight stations by Korea Water Resources Corporation (K-Water); and two stations by Korean Rural Community Corporation. A total of 25 gauging stations were selected as a sample population for the frequency analysis, stations with at least 10 years of flood discharge data. A total of four water quality monitoring stations administered by the Ministry of Environment (ME), were selected for the analysis of water quality variation; the stations selected have at least 24 years of water quality data. Fig. 2 shows the location of all 25 stream flow gauging stations and four water quality monitoring stations in the Geum River basin. The information on each gauging stations is summarized in Tables 3 and 4.

2.2. Determination of hydrologic data series

Flood discharge data are normally subdivided into two types of time series for the flood-frequency analysis; the annual maximum series and the annual exceedance series [15]. The annual exceedance series considers a series of local maxima in a data record in which the number of local maxima is equal to the number of years of record, while the annual maximum series considers a series of data consisting of the largest flow for each year. Annual maximum series is generally used for flood-frequency analysis for the estimation of the design flood [16]. This study was conducted using the annual maximum series of flood-frequency analysis.

2.3. Hypothesis tests of flood discharge data

Preliminary tests were conducted on the sample population. The test is composed of three types: independence test, randomness test, and an outlier test. The Independence test was performed to determine if a significant association between two variables exists, it was conducted with the use of Wald–Wolfitz's test (W–W). The Randomness tests was performed to determine the existence of recognizable patterns and irregularities in the sample population; it was conducted with the use of Anderson correlogram test

Table 1
Characteristics of the Geum River Basin

Drainage area (km^2)	Basin perimeter (km)	Shape factor	Drainage density	Average slope (%)	Main channel length (km)
9,912.0	724.0	1.1	2.5	15.3	397.8

Table 2
Trend of the ratio of impervious areas in Geum River Basin

Year	1975	1980	1985	1990	1995	2000
Ratio (%)	1.30	1.55	2.03	2.53	3.72	4.33

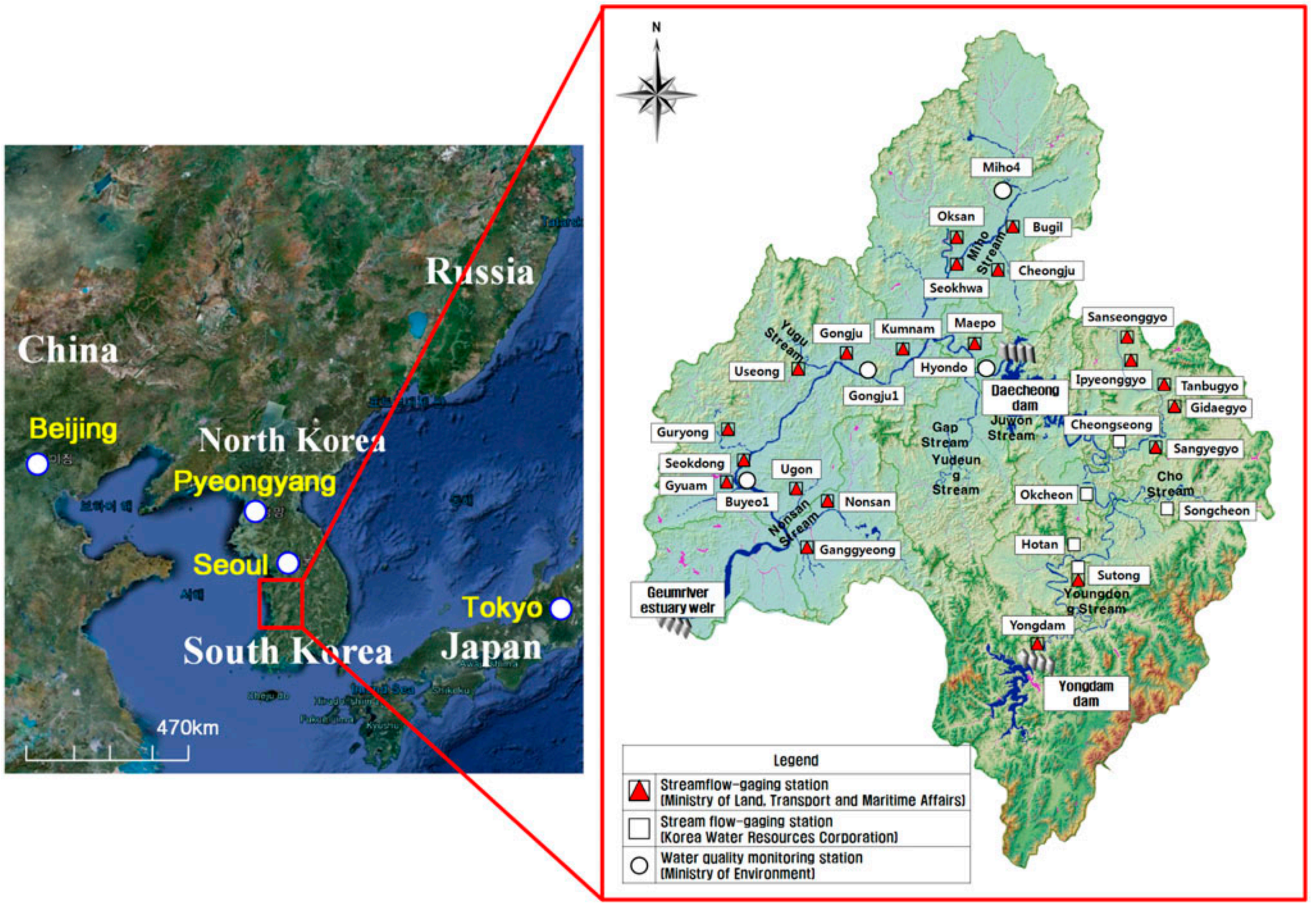


Fig. 2. Location of streamflow gauging stations and water quality monitoring stations in the Geum River Basin.

[17,18], Run test [19], Spearman rank correlation coefficient test [19], and the Turning Point test [20]. Lastly, the Outlier test was performed to determine if the sample population has unexpected high or low values of the sample data which does not represent the sample, and was conducted with the use of Gruss–Beck test (G–B).

2.4. Flood-frequency analysis

2.4.1. Determination of parameter estimation method

The three methods for parameter estimation are the probability weighted moment (PWM), method of moments (MM), and the maximum likelihood method. Short-period data has a higher tendency to be influenced by extreme values due to the limited count of sample population than a long-period data with extreme value. However, [21] conducted the PWM, which decreases the influence effect of extreme values on the sample population [22]. In case of the use of maximum likelihood, it is highly computational and may not yield to any solution [23]. The MM is the simplest method of parameter estimation [24]. Two parameter estimation methods (i.e. PWM and MM) were used in this study to estimate the flood discharge parameters of the sample population since the MM is not accurate with small samples.

2.4.2. Goodness of fit test

The 14 probability distribution selected: Normal (NOR), 2 Parameter Gamma (GAM2), 3 Parameter Gamma (GAM3), Generalized Extreme Value (GEV), Gumbel (GUM), 2 Parameter Log Gumbel (LGU2), 3 Parameter Log Gumbel (LGU3), 2 Parameter Log Normal (LN2), 3 Parameter Log Normal (LN3), Log-Pearson Type III (LPIII), 2 Parameter Weibull (WBU2), 3 Parameter Weibull (WBU3), 4 Parameter Wakeby (WAK4), and 5 Parameter Wakeby (WAK5) distributions.

Table 3
Streamflow gauging stations in the Geum River Basin with at least 10 years of data

Station name	River and streams	Period of peak flow record (years)	Administering agency
Ganggyung	Geum river	18	MLTMA
Gyuam		47	MLTMA
Gongju		45	MLTMA
Kumnam		18	MLTMA
Maepo		20	MLTMA
Okcheon		20	K-Water
Hotan		18	K-Water
Sutong		22	MLTMA
Yongdam		35	MLTMA
Nonsan	Nonsan stream	18	MLTMA
Ugon	Seokseong stream	17	MLTMA
Seokdong	Geum stream	17	MLTMA
Guryong	Ji stream	21	MLTMA
Useong	Yugu stream	16	MLTMA
Oksan	Byeongcheon stream	17	MLTMA
Bugil	Miho stream	18	MLTMA
Seokhwa		41	MLTMA
Cheongju	Musim stream	18	MLTMA
Cheongseong	Bocheong stream	19	K-Water
Sangyegyo		24	MLTMA
Gidaegyo		25	MLTMA
Tanbugyo		22	MLTMA
Ipyeonggyo		17	MLTMA
Sanseonggyo		20	MLTMA
Songcheon	Cho stream	15	K-Water

Table 4
Water quality monitoring gauging stations selected in the Geum River Basin

Station name	River	Water pollution indices (mg/L)	Period (years)	Administering agency
Hyondo	Upstream of Geum river	BOD, COD, SS	24	ME
Miho4	Tributary of Geum river (Miho stream)		24	ME
Gongju1	Midstream of Geum river		24	ME
Buyeo1	Downstream of Geum river		24	ME

All data of the sample population were subjected to the goodness of fit tests: Chi-square, Kolmogorov–Smirnov and the Cramér–von Mises Criterion tests. The highly ranked probability distributions with 5% significance levels were selected (i.e. GAM2, GAM3, GEV, LN2, LN3, LP III).

Relative root mean square error (RRMSE) was used to compare the observed flood discharge with the estimated flood discharge of the selected six probability distribution types. The probability distribution with the least error was selected from comparing the results of the RRMSE and the method of comparison of the statistical characteristics. The probability distribution with the best goodness of fit was selected to best represent the most appropriate probability distribution for the Geum River Basin.

Comparison of statistical characteristics (i.e. coefficient of skewness, coefficient of kurtosis, and coefficient of variation) between the observed flood discharge and the estimated flood discharge, with the use of the six probability distributions was performed for selecting the probability distribution with the best goodness of fit of the sample population.

2.4.3. Probability discharge estimation

Log-Pearson Type III was used for estimating flood discharge in the Geum River Basin; and the MM was used for the parameter estimation, which was suggested by the US Water Resources Council [25].

2.4.4. Probability discharge estimation considering the inducing effects of abnormal climate

The peak flow continuously increases which is primarily induced by abnormal climate. To prevent future flooding, the relationship between the increasing peak flow caused by abnormal climate and the change in the probability discharge should be determined.

In this study, the complete duration of the flood discharge data from Seokhwa and Bugil stations was divided into two parts: the historical data and the present data. The flood-frequency analyses for both historical and present data for Seokhwa and Bugil stations were estimated and compared.

3. Results and discussions

3.1. Collection of flood discharge data

The annual maximum series of the sample population from two gauging stations (i.e. Ganggyung station and Gyuam station) are shown in Fig. 3 Ganggyung station has a maximum, minimum, and a mean flood discharge data of 10,231; 1,968, and 4,721 m^3/s, respectively. While, the Gyuam station was observed with 11,389, 968, and 4,047 m^3/s of maximum, minimum, and mean flood discharges, respectively. The average maximum, minimum, and mean flood discharge of the sample population were observed to be 3,770, 332, and 1,448 m^3/s, respectively. Moreover, the average coefficient of skewness was observed to be 1.23.

3.2. Preliminary tests of flood discharge data

The summary of the preliminary test results is shown in Table 5. In order for the flood discharge data to be accepted in the Independence Test and Randomness Tests, the data for each station should not exceed the 5% level of significance. In Table 5, the test for independence showed that the Sutong station was rejected by failing to meet the boundary condition. The sample population was all accepted for the randomness tests and a total of eight samples failed the outlier test. Both the Guryong and Sanseonggyo stations had high outliers while the Kongju, Okcheon,

Table 5
Summary of the results of preliminary tests of flood discharge data

Station name	IT	RT	OT	Station name	IT	RT	OT
Ganggyung	O	O	O	Useong	O	O	O
Gyuam	O	O	O	Oksan	O	O	O
Kongju	O	O	X	Bugil	O	O	O
Kumnam	O	O	O	Seokhwa	O	O	O
Maepo	O	O	O	Cheongju	O	O	O
Okcheon	O	O	X	Cheongseong	O	O	X
Hotan	O	O	X	Sangyegyo	O	O	O
Sutong	X	O	O	Gidaegyo	O	O	O
Yongdam	O	O	X	Tanbugyo	O	O	O
Nonsan	O	O	O	Ipyeonggyo	O	O	O
Ugon	O	O	O	Sanseonggyo	O	O	X
Seokdong	O	O	X	Songcheon	O	O	O
Guryong	O	O	X				

Note: O: Accepted; X: Rejected; IT: Independence Test; RT: Randomness Test; OT: Outlier Test

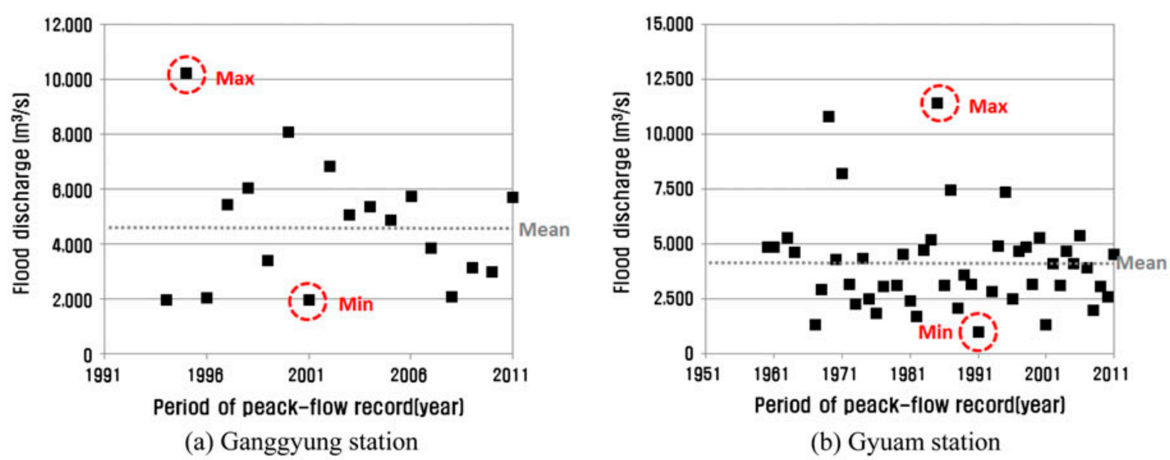


Fig. 3. Annual maximum series of Ganggyung station and Gyuam station.

Hotan, Yongdam, Seokdong, and Cheongseong stations had low outliers. The eight data-set with outlier data was excluded from the flood-frequency analysis. Henceforth, the sample population discussed in this study will disregard the Sutong station.

3.3. Flood-frequency analysis

3.3.1. Goodness of fit test

Table 6 shows the summary of the results of Chi-square, Kolmogorov–Smirnov, and Cramér–von Mises tests for the Ganggyung station. Chi-square (χ^2), Kolmogorov–Smirnov (*K–S*), and Cramér–von Mises (*CVM*) tests were compared simultaneously. The probability distribution with the least value was considered as the best and thus ranked higher for each test. In case of probability distributions yielding to a common value, the probability distribution with the highest rank was selected. Hence, the LN3 and GEV probability distributions were the best fit for the Ganggyung station.

wherein, the χ_n^2 is the calculated chi-square value for each probability distribution, $\chi^2_{\alpha-\alpha,v}$ is the chi-square value for the 5% level of significance; the D_n is critical value for the Kolmogorov–Smirnov and the $D_{0.05}$ is the critical value for the 5% level of significance; the W_n is the calculated Cramér–von Mises critical value for the probability distribution and the $W_{1-\alpha}$ corresponds to the critical value for the 5% level of significance.

3.3.2. Relative root mean square error (RRMSE) test

The six probability distributions were considered for the comparison of the observed flood discharge and the estimated flood discharge of the sample population. The probability distribution with the best goodness of fit was selected and the example results on the use of RRMSE are shown in Table 7.

The probability distribution with the lowest RRMSE corresponds to the probability distribution with the best goodness of fit. For each probability distribution, two methods of parameter estimation (i.e. MM and PWM) were used. The LPIII-MM had the lowest RRMSE having a value of 0.1167; and hence, ranked first and used for calculating Relative Error. The LPIII-MM was used as the basis of comparison with other probability distributions.

Table 7
Summary of the results of the RRMSE for the Ganggyung station

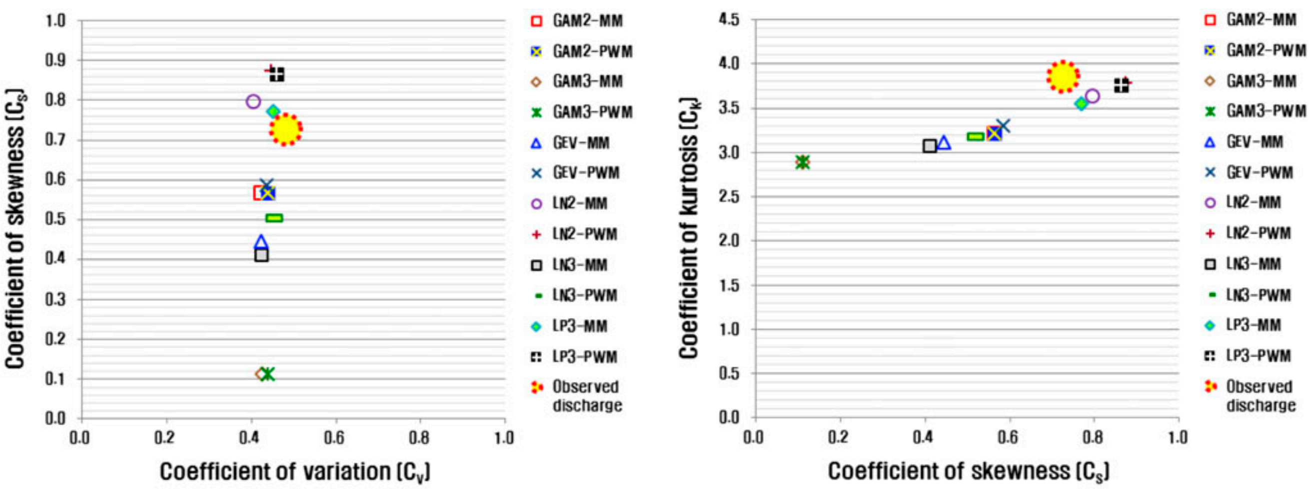
Probability distribution	Method of parameter estimation	RRMSE	Relative error (%)	Rank
GAM2	MM	0.1279	9.61	6
	PWM	0.1192	2.20	3
GAM3	MM	0.1580	35.44	11
	PWM	0.1602	37.32	12
GEV	MM	0.1331	14.09	7
	PWM	0.1245	6.70	4
LN2	MM	0.1515	29.87	10
	PWM	0.1405	20.39	9
LN3	MM	0.1338	14.67	8
	PWM	0.1257	7.70	5
LPIII	MM	0.1167	0.00	1
	PWM	0.1171	0.33	2

Table 6
Summary of the results of Chi-square, Kolmogorov-Smirnov and Cramér–von Mises Tests in Ganggyung station

	χ^2		$K-S$		CVM		
Probability distribution	$\chi_n^2/\chi^2_{\alpha-\alpha,v}$	Rank	$D_n/D_{0.05}$	Rank	$W_n/W_{1-a}(n)$	Rank	Final rank
NOR	0.7980	13	0.6774	13	0.3043	13	13
GAM2	0.4073	7	0.4516	10	0.1087	3	8
GAM3	–	–	–	–	–	–	–
GEV	0.0859	2	0.3226	1	0.1087	3	1
GUM	0.0551	1	0.3871	6	0.0870	1	3
LGU2	0.7045	11	0.4516	10	0.1957	12	12
LGU3	0.0859	2	0.3871	6	0.1087	3	5
LN2	0.1486	5	0.3226	1	0.1087	3	4
LN3	0.0859	2	0.3226	1	0.1087	3	1
LPIII	0.7526	12	0.3548	4	0.1304	8	9
WBU2	0.4274	8	0.5161	12	0.1522	9	11
WBU3	0.5208	9	0.3871	6	0.1522	9	9
WAK4	0.2604	6	0.3548	4	0.1522	9	7
WAK5	0.5781	10	0.3871	6	0.0870	1	6

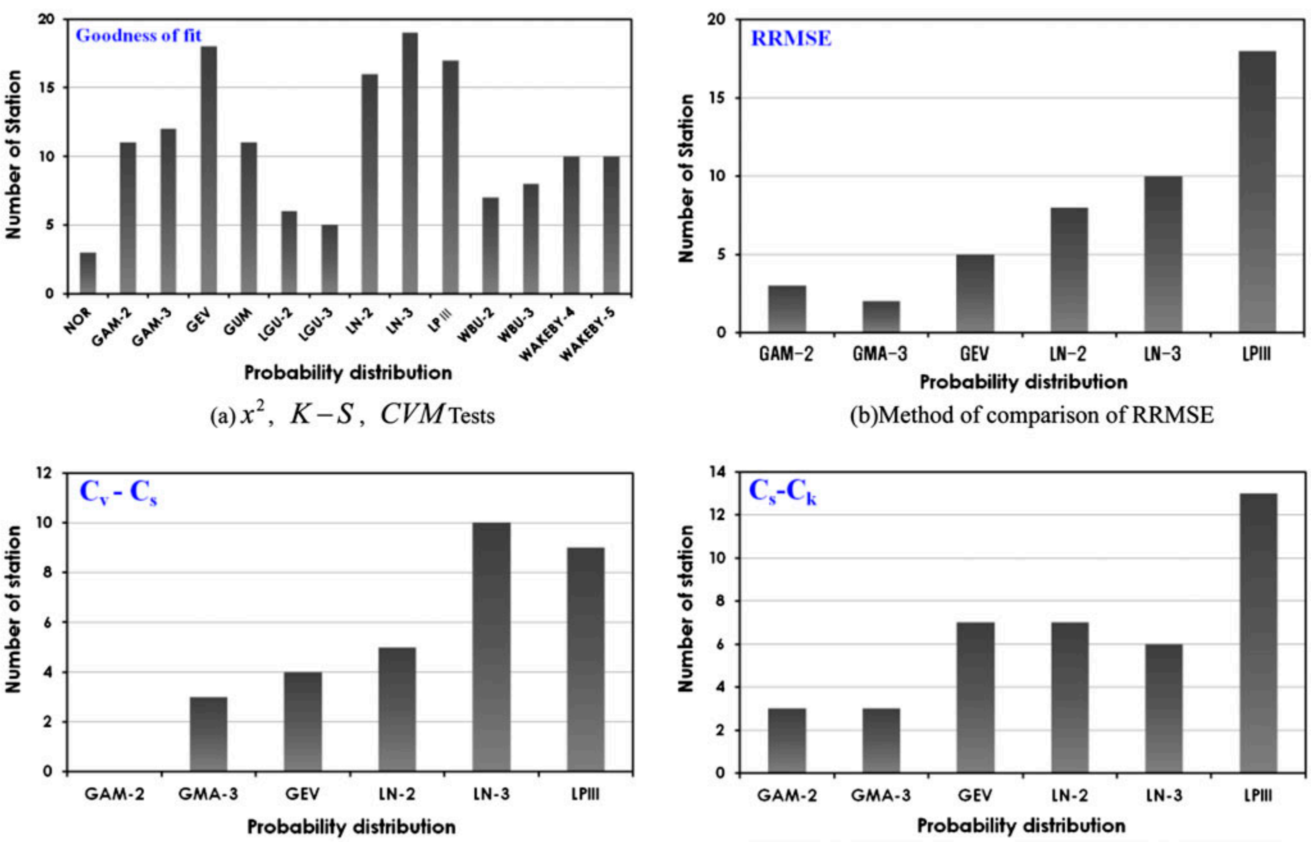
3.3.3. Methods of comparison for statistical characteristics

Fig. 4(a) and (b) show the methods of comparison of the statistical characteristics of the Ganggyung station. Fig. 4(a) shows the relationship between the coefficient of variation and the coefficient of skewness. While Fig. 4(b) shows the relationship between the



(a) Skewness-Variation (b) Kurtosis-Skewness

Fig. 4. Methods of comparison for the statistical characteristics of the Ganggyung station.



(a) x^2, $K-S$, CVM Tests (b)Method of comparison of RRMSE

(c)Method of comparison for the statistical characteristics

Fig. 5. Comprehensive summary of the results of the goodness of fit tests of the sample population in Geum River Basin.

coefficient of skewness and the coefficient of kurtosis. The probability distribution type located nearest to the observed discharge is considered to be the best representation for the Ganggyung station; hence, the LPIII was selected.

3.3.4. Result of the goodness of fit test

Figs. 5 and 6 show the comprehensive summary of the goodness of fit for the sample population in the Geum River Basin. The LPIII distribution was observed to be consistently accurate for all tests in Geum River Basin; thus, the LPIII was selected to represent the probability distribution of the Geum River Basin.

3.4. Flood-frequency estimation

Log-Pearson Type III was used for estimating flood frequency in the Geum River Basin; and the MM was used for the parameter estimation, which was suggested by the US Water Resources Council [25]. The results for the discharge with recurrent intervals are shown in Table 8.

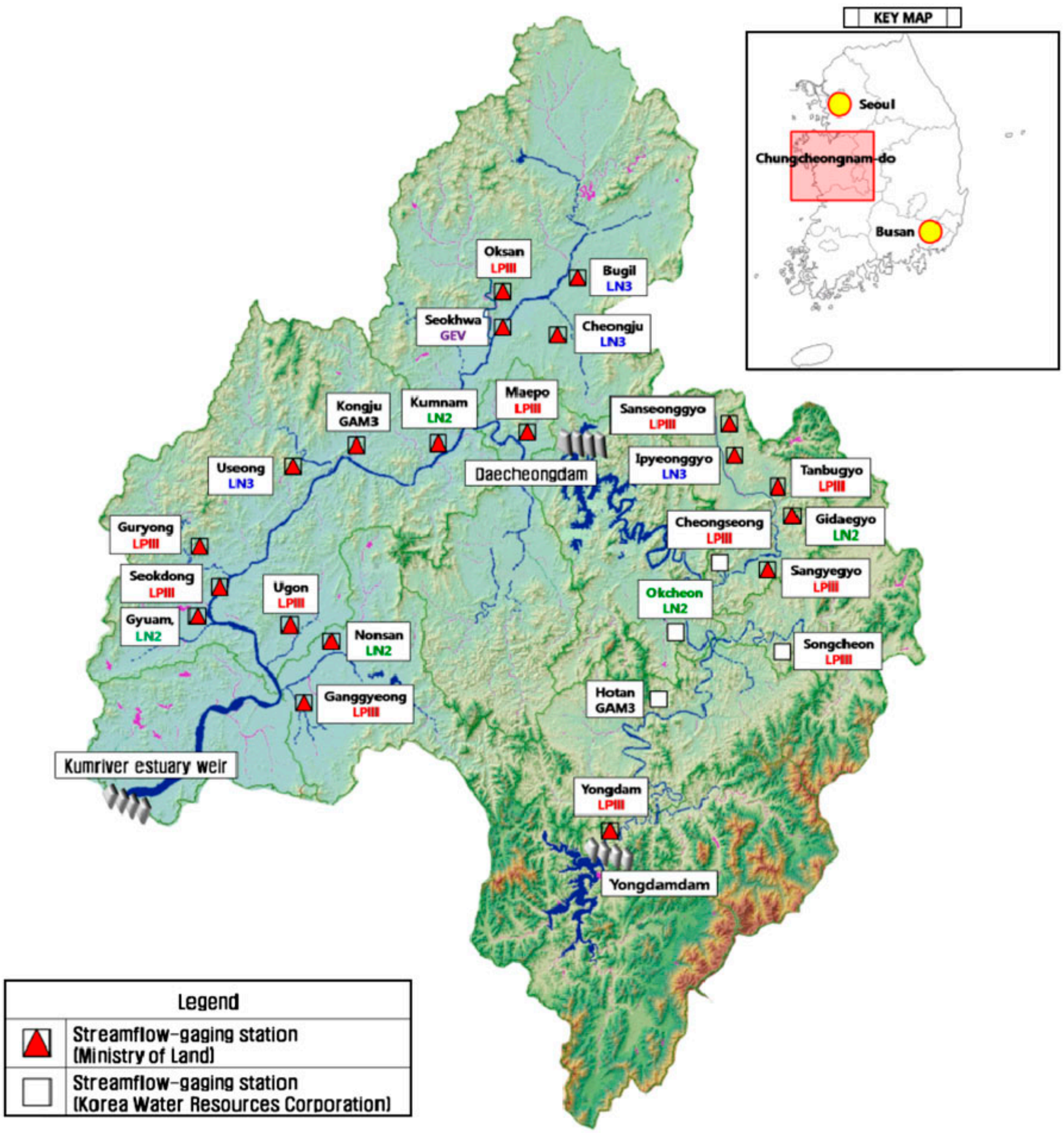


Fig. 6. The Geum River Basin and the corresponding probability distribution type appropriate for each station.

Table 8
Estimated flood discharge for indicated recurrence intervals

	Recurrence intervals (years)						Unit (m^3/s)	
Station name	10	20	30	50	80	100	200	500
Ganggyung	8,196	9,853	10,838	12,101	12,389	13,863	15,688	18,208
Gyuam	6,841	8,113	8,850	9,779	10,635	11,042	12,316	14,021
Kongju	5,919	7,040	7,702	8,548	9,342	9,724	10,938	12,606
Kumnam	6,676	7,688	8,229	8,865	9,411	9,658	10,382	11,247
Maepo	2,947	3,417	3,662	3,944	4,180	4,285	4,583	4,923
Okcheon	6,380	6,996	7,305	7,651	7,934	8,059	8,408	8,797
Hotan	2,837	3,196	3,401	3,657	3,891	4,001	4,345	4,803
Yongdam	1,946	2,327	2,537	2,789	3,010	3,111	3,413	3,782
Nonsan	1,420	1,682	1,828	2,005	2,163	2,236	2,457	2,735
Ugon	864	1,172	1,378	1,667	1,967	2,121	2,654	3,501
Seokdong	727	889	988	1,117	1,240	1,301	1,496	1,774
Guryong	738	893	987	1,108	1,224	1,281	1,463	1,720
Useong	959	1,215	1,392	1,647	1,920	2,064	2,582	3,462
Oksan	1,355	1,808	2,112	2,541	2,986	3,216	4,015	5,297
Bugil	2,795	3,686	4,276	5,102	5,953	6,390	7,898	10,288
Seokhwa	2,968	3,569	3,927	4,387	4,820	5,030	5,697	6,620
Cheongju	765	1,068	1,287	1,616	1,984	2,183	2,925	4,268
Cheongseong	1,369	1,750	1,991	2,317	2,638	2,799	3,333	4,129
Sangyegyo	1,580	2,276	2,739	3,416	4,127	4,497	5,792	7,882
Gidaegyo	951	1,345	1,608	1,978	2,358	2,553	3,219	4,253
Tanbugyo	158	229	278	351	429	471	620	873
Ipyeonggyo	146	181	201	227	251	263	299	349
Sanseonggyo	81	105	120	140	158	168	197	237
Songcheon	2,011	2,477	2,743	3,073	3,370	3,509	3,934	4,477

3.5. Analysis on the variation of the flood frequency considering the induced effects of abnormal climate

The peak flow continuously increases which is primarily induced by abnormal climate. To prevent future flooding, the relationship between the increasing peak flow caused by abnormal climate and the change in the probability discharge should be determined.

In this study, the complete duration of the flood discharge data from two unregulated stations (i.e. Seokhwa and Bugil stations), river storages not

Table 9
Comparison of observed discharge data (i.e. historical and present data) in Bugil station

	Peak flow period record (m^3/s)			
Recurrence frequency (years)	Present data (2002 – 2011)	Historical data (1992 – 2001)	Peak flow deviation (m^3/s, %)	
2	1,453	869	584	▲67%
5	2,557	1,423	1,135	▲80%
10	3,457	1,918	1,539	▲80%
20	4,449	2,511	1,938	▲77%
30	5,079	2,913	2,166	▲74%
50	5,930	3,489	2,442	▲70%
80	6,775	4,095	2,680	▲65%
100	7,198	4,412	2,786	▲63%
200	8,606	5,532	3,074	▲56%
500	10,708	7,386	3,321	▲45%

Note: Design flood frequency: 100 years.

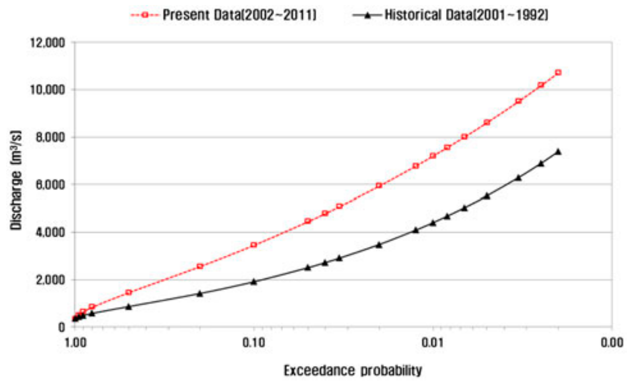


Fig. 7. Results of flood frequency analysis using the historical data and the present data in Bugil station.

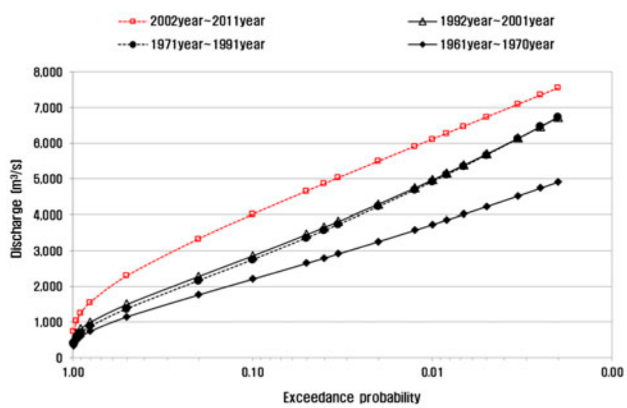


Fig. 8. Results of flood frequency analysis using the three historical data and the present data in Seokhwa station.

releasing downstream; was divided into two parts: the historical data and the present data. The flood-frequency analyses for both parts were estimated and compared. The comparison of the observed discharge data, historical, and present data in Bugil station are shown in Table 9.

Fig. 7 shows that the observed flood discharges in Bugil station using the present data (2002–2011) were higher compared with the historical data (1992–2001). The probability range of flood discharge for 500 to 2 years of recurrence frequency was calculated to be 45–80%. The 100-year design flood has a peak flow deviation of 2,786 m^3/s and the present data had increased by 63% with respect to the historical data.

Fig. 8 shows the comparison of the observed discharge in Seokhwa station using the present data (2002–2011) with the 3rd historical data (1992–2001), 2nd historical data (1971–1991), and 1st historical data (1961–1970). The probability range of flood discharge for 500–2 years of recurrence frequency was calculated to be 12–54% for the 3rd historical data, 12–67% for the 2nd historical data, and 54–101% for the 1st historical data as shown in Table 10. The 100-year design flood has peak flow deviation of 1,148, 1,191, and 2,390 m^3/s for the 3rd, 2nd, and 1st historical data, respectively. For the 100-year design flood, the highest peak flow deviation was from the 3rd historical data, while the 1st and 2nd historical data have peak flow deviations of 23%.

3.6. *Analysis on the variation of water quality considering the induced effects of abnormal climate*

Four water quality monitoring stations, namely: Hyondo, Misho4, Gongju1, and Buyeo1 located in

Table 10
Comparison of observed discharge data (i.e. historical and present data) in Seokhwa station

Recurrence frequency (years)	Peak flow period record (m^3/s)						
	Present data (2002 – 2011)	3rd Historical data (1992 – 2001) Deviation		2nd Historical data (1971 – 1991) Deviation		1st Historical data (1961 – 1970) Deviation	
2	2,302	808	▲54%	924	▲67%	1,157	▲101%
5	3,334	1,057	▲46%	1,168	▲54%	1,573	▲89%
10	4,016	1,161	▲41%	1,261	▲46%	1,813	▲82%
20	4,664	1,211	▲35%	1,297	▲39%	2,017	▲76%
30	5,035	1,219	▲32%	1,295	▲35%	2,123	▲73%
50	5,496	1,206	▲28%	1,269	▲30%	2,245	▲69%
80	5,918	1,172	▲25%	1,222	▲26%	2,346	▲66%
100	6,118	1,148	▲23%	1,191	▲23%	2,390	▲64%
200	6,736	1,043	▲18%	1,064	▲19%	2,513	▲60%
500	7,554	830	▲12%	817	▲12%	2,645	▲54%

Note: Design flood frequency: 100 years.

upstream, tributary, midstream, and downstream of Geum River, respectively, were selected for the evaluation of water quality variation. The water quality indices evaluated were BOD, COD, COD–BOD, and SS. The trend of the water quality was analyzed based on regression analysis, where in the period was divided into two parts. First, is the rainy season from June to September and dry season from October to May, for a period of 24 years.

Fig. 9 shows that the observed BOD data decreased while COD, SS data increased in all of the stations for 24 consecutive years. The results show

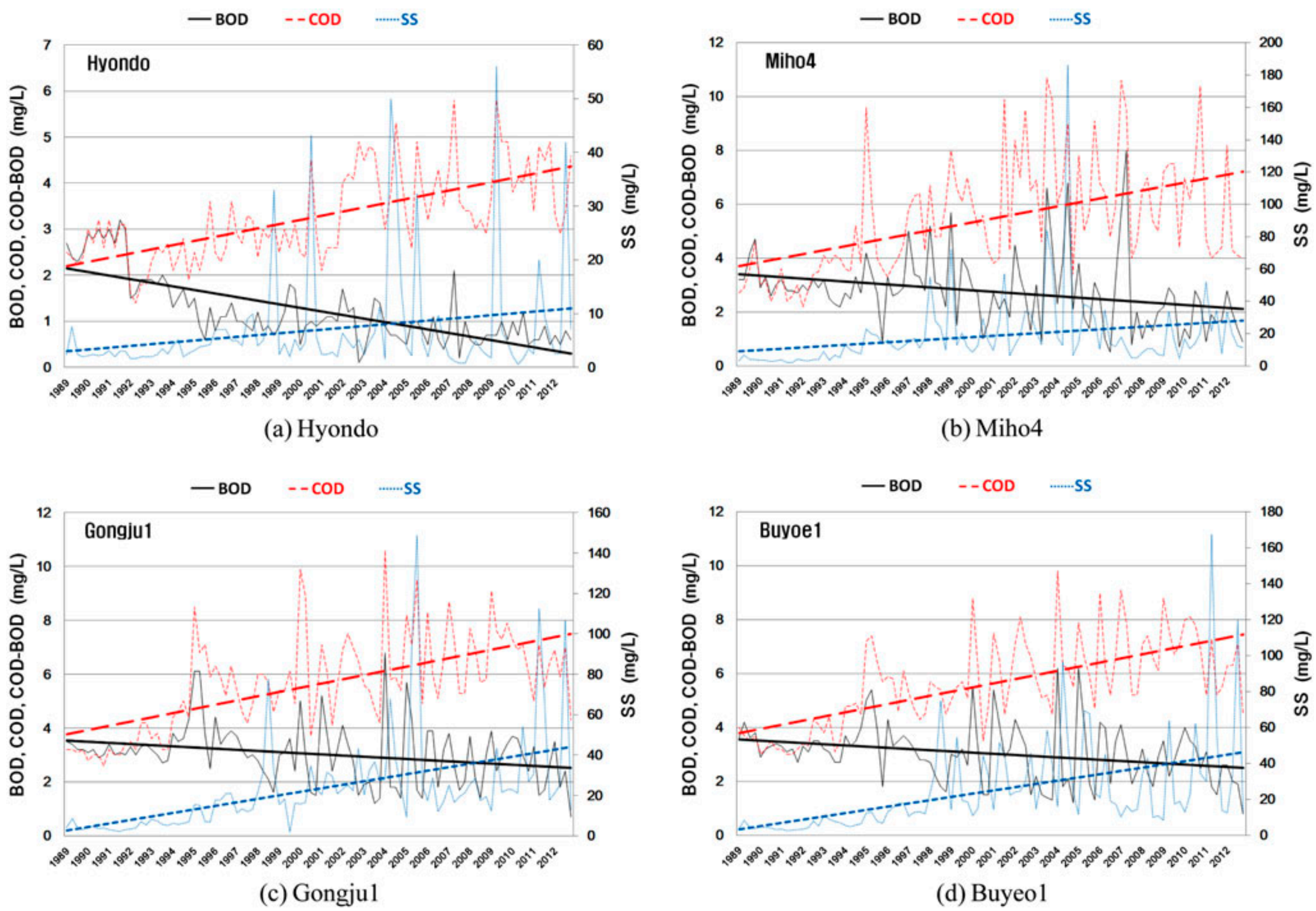


Fig. 9. Regression analysis of the water quality in rainy season during 24 years.

Table 11
Analytical results for variation of water quality in rainy season during 24 years

Water quality indices	Year	Hyondo	Miho4	Gongju1	Buyeo1
BOD (mg/L)	1989	2.17	3.43	3.55	3.57
	2012	0.35	2.18	2.59	2.51
	Variation	−84%	−36%	−27%	−30%
COD (mg/L)	1989	2.18	3.66	3.73	3.75
	2012	4.29	7.12	7.47	7.40
	Variation	97%	94%	100%	97%
SS (mg/L)	1989	2.87	8.90	2.21	2.69
	2012	10.93	28.10	43.78	46.09
	Variation	281%	216%	1,878%	1,611%

that BOD decreased by 27–88% in all of the stations while the COD and SS were increased by 97–100% and 216–1,878%, respectively, as summarized in Table 11.

Fig. 10 shows that the observed BOD data decreased while COD, SS data increased in all of the stations for 24 consecutive years. The results show that BOD decreased by 45–106% in all of the stations while the COD and SS were increased by 45–106% and 70–271%, respectively, as summarized in Table 12.

The result shows that the concentrations of COD and SS during the rainy season are higher as compared with the concentrations during the dry season, and gradually increases as with time. COD and SS

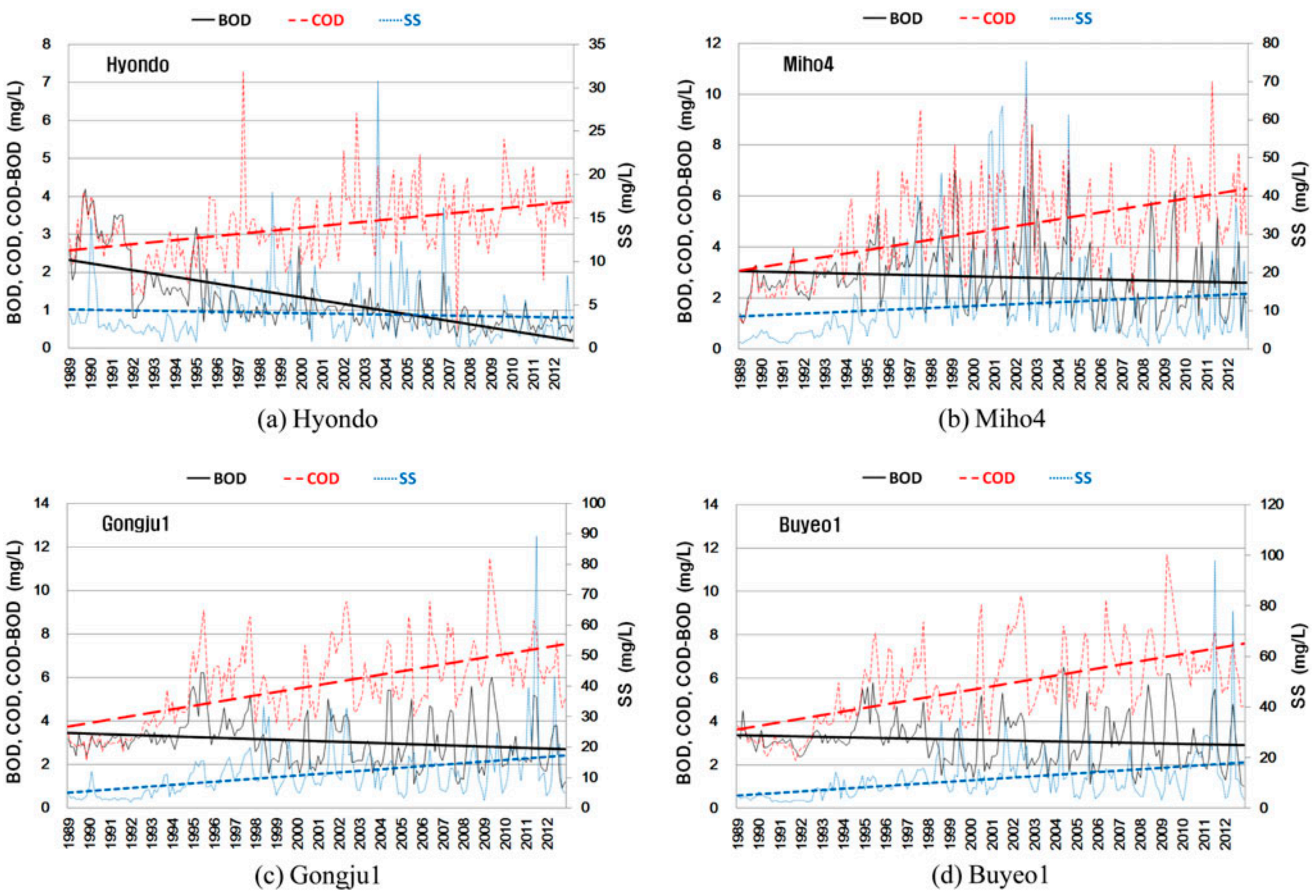


Fig. 10. Regression analysis of the water quality in dry season during 24 years.

Table 12
Analytical results for variation of water quality in dry season during 24 years

Water quality indices	Year	Hyondo	Miho4	Gongju1	Buyeo1
BOD (mg/L)	1989	2.34	3.06	3.45	3.36
	2012	0.23	2.67	2.87	2.97
	Variation	−90%	−13%	−17%	−11%
COD (mg/L)	1989	2.58	3.07	3.73	3.62
	2012	3.73	6.14	7.38	7.46
	Variation	45%	100%	98%	106%
SS (mg/L)	1989	4.47	8.44	4.98	4.89
	2012	3.70	14.40	17.27	18.14
	Variation	−17%	70%	247%	271%

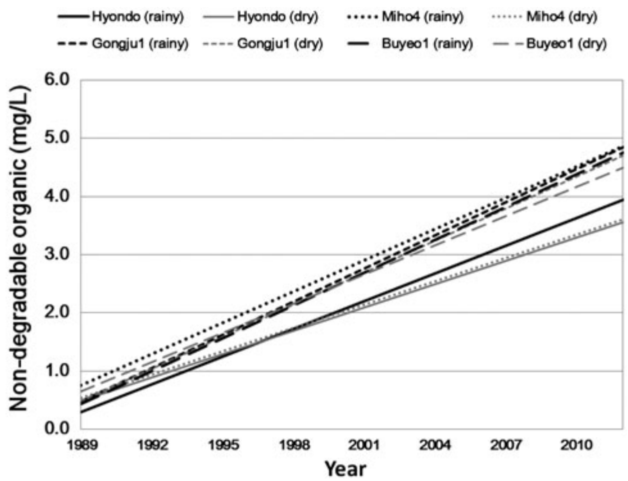


Fig. 11. Regression analysis of COD-BOD for variation of non-degradable organic in rainy and dry seasons during 24 years.

concentrations are dependent with the stormwater run-off. The run-off increased exponentially during the rainy season, while the peak runo-ff continuously increased for the succeeding years.

The non-degradable organic concentration was analyzed based from the regression analysis of COD–BOD in both rainy and dry seasons, during the last 24 years. COD–BOD is an indicator that could represent the emission concentration for non-degradable organics. Results showed that the non-biodegradable organic content in water quality continuously increases with time as shown in Fig. 11. Based from the figure shown, the concentration of non-degradable organic materials in water during the rainy season is greater as compared with the concentration during the dry season. The emission of non-degradable organic materials is also closely associated with the storm water run-off. Lastly, based from the figure shown, it is evident that the run-off increased exponentially during the rainy season and the peak run-off continuously increased for the succeeding years.

4. Conclusions

Flood-frequency analysis for the variation of the flood frequency induced by abnormal climate was performed using the sample population from both historical and present flood data in the Geum River Basin. The appropriate probability distribution type, to estimate the flood frequency, was selected based from the goodness of fit tests performed for each station. Based from the results of the goodness of fit tests performed, the Log-Pearson Type III was best represents the Geum River Basin. Furthermore, the water quality data (i.e. BOD, COD, and SS) were analyzed through regression analysis to determine the recent variations in water quality.

The results show the peak flow deviation of the Bugil station for the 100-year design flood was 2,786 m^3/s; the present data (2002–2011) had increased by 63% with respect to the historical data (1992–2001). Moreover, the 100-year design flood of the Seokhwa station was observed to have the highest peak flow with a 64% deviation from the 3rd historical data (1992–2001); while, the 1st and 2nd historical data (i.e. 1961–1970 and 1971–1991, respectively) have peak flow deviations of 23%. The recurrence frequency was observed to be inversely proportional with the percentage of the peak flow deviation. Therefore, the results of this study showed that the peak flows determined using the present data were greater than using the historical data; which also continuously increases, on a yearly basis, as induced by abnormal climate.

The regression analysis was performed to evaluate the water quality in Geum River Basin using BOD, COD, and SS from the four stations located in upstream, midstream, downstream, and tributary area in the Geum River Basin. Results showed that the BOD gradually decreased, while the COD, COD–BOD, and SS increased for the last 24 years. The decrease in BOD is accredited to the government efforts to reduce non-point source pollution, through the installation of the sewage treatment plants within the river basin. While, the increases in COD and COD–BOD in the stream run-off is due to the increase in the concentration of the non-degradable organic materials, caused by increasing precipitation and seasonal imbalance as induced by abnormal climate. The increase in the concentration of non-degradable organic materials was associated to plant productivity, which has highly decomposition rates triggered by in the increase in the temperature. Increased SS concentration in the stream indicates that the run-off of the particulate matters from basin increased due to the sedimentation within the basin and thus, caused by increasing rain intensity.

As the flood frequency and run-off continuously increases, the water quality such as COD, COD–BOD, and SS has been increased, causing the water degradation in the Geum River Basin. Therefore, efforts to create several countermeasures to mitigate the flood damaged and improve the water quality in the stream should be done.

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