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Relationship between Coliform Bacteria and Water Quality Factors at Weir Stations in the Nakdong River, South Korea

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Received: 8 April 2019; Accepted: 3 June 2019; Published: 4 June 2019

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Abstract: Artificial structures installed in rivers can change the natural physical, physiochemical, and biological characteristics of the rivers. Coliform bacteria are important water quality indicators, related to human health. This study investigated the relationship between coliform bacteria and water quality factors at eight weir stations constructed in the Nakdong River, a major river in South Korea. Fifteen water quality factors were analyzed at these sites from 2012 to 2016 using correlation and multiple regression analyses. The results for all stations confirmed the analytical validity, with high adjusted R^2 values of approximately 0.6 and 0.8 on average for total and fecal coliforms, respectively. The results showed influential water quality factors affecting the concentration of coliform bacteria at weir stations. Specifically, total coliforms were mostly affected by organic matter and fecal coliforms were mostly affected by phosphate phosphorus and suspended solids. Rainfall was the most influential factor affecting both coliforms. Further, both coliforms were negatively affected by organic matter below the Dalseong weir in the mid- to downstream area of the Nakdong River. A positive relationship with phosphate phosphorus was indicated at all weir stations. To the authors' knowledge, this kind of study has never been attempted so far. Thus, the study results can provide important information on influential water quality factors related to coliform bacteria, especially in the Nakdong River, creating a foundation for future water quality management.

Keywords: Nakdong River; weirs; Coliform bacteria; correlation analysis; multiple regression analysis

1. Introduction

The South Korean government constructed weirs in four major rivers from 2009 to early 2012 to mitigate problems relating to water security, water quality improvement, and aquatic ecology restoration [1]. Water level and discharge control by artificial structures can change a river's physical characteristics including riverbed structure, water depth, and stream flow velocity, making some portions resemble a closed water system. These modifications can also result in physiochemical and biological changes in the aquatic environment. Eight weirs were constructed within the Nakdong River in southeastern South Korea. The Nakdong River is the second largest river and an important water resource. Therefore, continuous long-term monitoring is necessary for efficient water quality management with respect to the weirs in the Nakdong River.

Research on water quality management in South Korea has mostly focused on organic matter and nutrients, especially biochemical oxygen demand and total phosphorus, to satisfy water quality standards after the adoption of the Korean Total Maximum Daily Load system. Proper management has also been required for coliform bacteria in water sources such as rivers, lakes, and groundwater because these microorganisms can directly or indirectly impact human health. Coliform bacteria can cause serious illnesses, such as gastroenteritis and diarrhea, through polluted water from untreated sewage, septic tanks, etc. The South Korean government has applied a legal standard for the total and fecal coliforms in rivers as indicator organisms, and has measured them as water quality factors. Total coliforms include all members of the coliform bacteria group, which includes microorganisms from vegetation, soil, and water. Fecal coliforms are the members of the total coliform group that originate in the intestinal gut of warm-blooded animals. Both coliforms are important water quality indicators in rivers because they can determine whether water is available as recreational or drinking purposes.

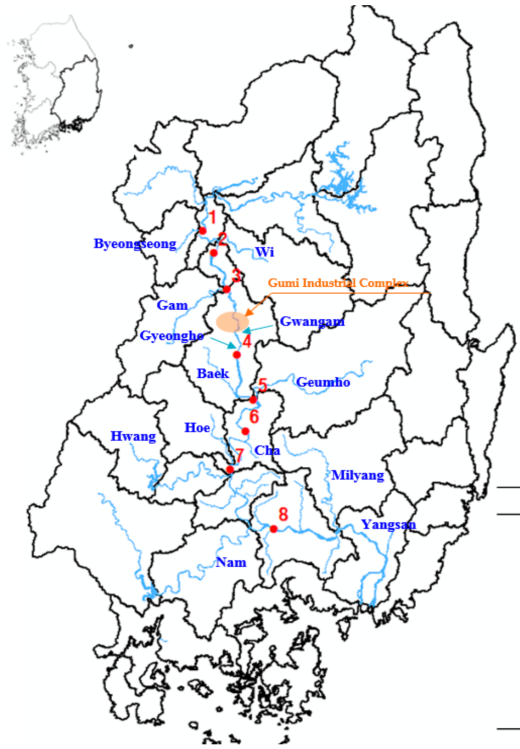
Many studies on coliform bacteria have focused on sanitation or disease [2–4]. Studies treating coliforms as a water quality factor have addressed distribution and detection [5–9], analyses of discharge characteristics [10,11], and model development and simulation [12–17]. Various research topics have been also investigated, such as bacterial source tracking related to the occurrence of coliforms [16], the transport and fate of coliforms [17], and bacterial indicator testing [18]. However, most focused on marine systems [7,13,14,17–23] rather than on rivers [6,9,11], because coastal zones are often used for recreational purposes and are the final repositories of pollutants. Some studies have used regression analyses to determine the relationship between coliform bacteria and water quality factors in rivers [24–27]. Those studies are important because they can help easily predict the concentration of coliform bacteria using water quality factors. However, such studies have been relatively rare in South Korea, and they have mostly focused on groundwater [28] or wastewater treatment discharge [29]. For example, Jung et al. [30] developed regression models of coliform bacteria for Korean rivers that pass through reclaimed land around Hwaong Lake that drains into the Yellow Sea. However, these models were derived from the correlation between total and fecal coliforms and were not based on the relationship between coliform bacteria and water quality factors. Furthermore, to the authors' knowledge, no study has performed regression analyses of the relationship between coliform bacteria and water quality factors at weir stations, and the present study is a first attempt on the topic. Seo et al. [31] analyzed water quality characteristics in the Nakdong River after the construction of weirs using multivariate statistical analyses, and identified a need for coliform bacteria management in the mid- to downstream section in summer. However, they used a total of thirty-eight stations, which included eight weir stations. Several weir-related studies have focused on the prediction and analysis of large algal blooms in stagnant water [32–34], not on the concentration of coliform bacteria.

Therefore, in this study, we aimed (1) to identify the concentration of coliform bacteria at eight weir stations in the Nakdong River using data from 2012 to 2016 and (2) to determine influential water quality factors affecting the concentration of coliform bacteria at weir stations using multiple regression analyses in order to ultimately lay a foundation for efficient future water quality management.

2. Materials and Methods

2.1. Study Area

The Nakdong River is the longest (525 km) of the four major rivers in South Korea; it rises from Hwangji Pond in the Taebaek Mountains, then passes through large cities such as Gumi, Daegu, and Busan (Gyeongsang-do province) before flowing into the southern Korea Strait. The Nakdong River is an important water resource that provides drinking water to approximately 13 million people living in an area of 23,384 km^2; it also supplies water to industrial complexes and large cities along the river. The Nakdong River watershed has an average precipitation of 1156.4 mm, about 54% of which (623.6 mm) is concentrated from July to September. Eight weirs have been constructed over 200 km of the river from Sangju-si to Changnyeong-gun: the Sangju, Nakdan, Gumi, Chilgok, Gangjeong-Goryeong, Dalseong, Hapcheon-Changnyeong, and Changnyeong-Haman weirs (Figure 1). Several important tributaries flow into the mainstream between the weirs: the Byeongseong and Wi streams between the Sangju and Nakdan weirs; the Gam, Bonggok, Han, and Gyeongho streams between the Gumi and Chilgok weirs; the Baek and Habin streams between the Chilgok and Gangjeong-Goryeong weirs; the Geumho River (a second tributary of the Nakdong River) between the Gangjeong-Goryeong and Dalseong weirs; the Cha and Hoe streams between the Dalseong and Hapcheon-Changnyeong weirs; and the Hwang River and Shinban, Topyeong, Changnyeong, Gyeoseong, and Gwangryeo streams, as well as the Nam River (a primary tributary of the Nakdong River) between the Hapcheon-Changnyeong and Changnyeong-Haman weirs.



#	Weir	Station
1	Sangju	Donam
2	Nakdan	Nakdan
3	Gumi	Seonsan
4	Chilgok	Chilgok
5	Gangjeong-Goryeong	Dasa
6	Dalseong	Nongong
7	Hapcheon-Changnyeong	Deokgok
8	Changnyeong-Haman	Haman

Figure 1. Location of weirs in the Nakdong River watershed.

2.2. Data Collection

To identify the water quality factors that affect total and fecal coliforms, a total of 15 factors that are commonly measured in rivers were considered: pH, dissolved oxygen (DO), biochemical oxygen demand (BOD_5), chemical oxygen demand (COD_{Mn}), suspended solids (SS), total nitrogen (TN), total phosphorus (TP), total organic carbon (TOC), water temperature (WT), electric conductivity (EC), ammonia nitrogen (NH_3-N), nitrate nitrogen (NO_3-N), phosphate phosphorus (PO_4-P), chlorophyll-a (Chl-a), and precipitation. These water quality data were collected from the South Korean Water Environment Information System website on a monthly basis from 2012 to 2016. For total and fecal coliforms that increase exponentially, the daily data were collected and geometrically averaged as monthly data. The daily data had a detection limit of 1 for properly calculating the geometric mean. Eight measurement stations representing the eight weirs were used, located 500 m upstream of each weir: Donam (Sangju weir), Nakdan (Nakdan weir), Seonsan (Gumi weir), Chilgok (Chilgok weir), Dasa (Gangjeong-Goryeong weir), Nongong (Dalseong weir), Deokgok (Hapcheon-Changnyeong weir), and Haman (Changnyeong-Haman weir) (Figure 1). Rainfall data were collected on a monthly basis from the Korea Meteorological Administration website for the Sangju, Gumi, Daegu, Hapcheon, and Busan stations.

2.3. Statistical Analysis

To investigate the relationship between total and fecal coliforms and water quality factors, correlation and multiple regression analyses were performed using Statistical Package for the Social Sciences software (SPSS, ver. 12.0; SPSS Inc., Chicago, IL, USA). SPSS is a popular and powerful statistical analysis tool that can help process and analyze large complex data. It has been a lot utilized for multivariate analyses, such as correlation and regression analyses, in various fields of engineering and science [31–34]. Correlation analysis determines whether the relationship between two variables is present or absent, and that two variables are associated to a degree. Multiple regression analysis determines the relationship between independent and dependent variables based on causality. It fits a best line and predicts the impact of two or more independent variables on a dependent variable. The total and fecal coliform values were log-converted to perform the statistical analyses. For correlation analyses, the degree of linearity between two variables was derived from the correlation coefficient (r) through Pearson's correlation analyses, and the significance was based on a p-value of less than 0.05. The correlation coefficient ranged between −1 and +1, and the linearity was ignored when it was −0.1 to +0.1. There was a weak positive/negative linear correlation when the correlation coefficient was between ±0.1 and ±0.3, a moderate positive/negative linear correlation when it was between ±0.3 and ±0.7, and a strong positive/negative linear correlation when it was between ±0.7 and ±1.0.

Multiple regression analyses were performed to investigate the relationship between total and fecal coliforms (dependent variables) and considered water quality factors (independent variables) at the weir stations. All of the water quality values were standardized to eliminate the influence of units. A stepwise method was used, which applied the most influential water quality variables in consecutive order and excluded insignificant variables. The multiple regression analyses were verified by using the p-value, Durbin-Watson (DW), Variance Inflation Factor (VIF), adjusted R^2 value, and p-p plot. When the p-value was smaller than 0.05, the regression model was considered significant and suitable. The adjusted R^2 value indicates that the linearity is high when it approaches 1. The variability of the dependent variables by independent variables could be explained through the adjusted R^2 value. The DW and VIF indices were used for the multicollinearity diagnosis that verified independence among independent variables. The independent variables were independent when DW approached 2, and there were few problems in the multicollinearity when it was between 1 and 3. There was no problem in the multicollinearity when the VIF index was less than 10. The normality test was carried out by the normal p-p plot of residuals. When the standardized residuals were uniformly distributed close to normal distribution, the regression model became more effective.

3. Results and Discussion

3.1. Distribution of Coliform Bacteria

The distribution of total and fecal coliforms at the eight weirs in the Nakdong River are shown in Table 1 and Figure 2. Both coliforms showed a narrow distribution range at Seonsan station, with the lowest mean and standard deviation, and a wide distribution range at Nongong station, with the highest mean and standard deviation. Rapid increases were found for both coliforms at Chilgok and Nongong stations. Chilgok station was considered to be affected by several nearby tributaries, such as the Gyeongho and Gwangam streams. For example, the former, which flows in immediately upstream of Chilgok station, contains high proportions of livestock sheds and agricultural land along its lower reaches; the latter, located near the Gumi Industrial Complex, also carries discharge from a wastewater treatment plant along its downstream reaches. Cho and Um [35] reported the large impacts of livestock, domestic, and industrial wastewater on water quality in the up- to midstream area of the Nakdong River. These conditions could lead to a high concentration of coliforms at Chilgok station. As for the results at Nongong station, the impact of the Geumho River, which enters the Nakdong River 16.2 km upstream from the station, was considered to be most influential. This tributary has the second largest basin in the Nakdong River system and passes through Daegu, a major metropolitan city. More than 40% of its total water quantity is supplied by discharges from many wastewater treatment plants in the Geumho River basin [32,36,37]. Several studies have reported that high pollutant concentrations of the discharges could affect the water quality of the Nakdong River [36,37]. Jung and Kim [32] showed higher nutrient concentrations at Nongong station than at other weir stations for the same reason. Lee et al. [9] also mentioned the impact of polluted tributaries on the Nakdong River mainstream for coliform bacteria. In addition, Yu et al. [38] and Na et al. [39] reported that highly contaminated secondary tributaries, which enter the Geumho River, could affect the water quality of the mid- and downstream section where Nongong station is located. Therefore, the rapid increase in the concentration of coliform bacteria at Nongong station was likely caused by pollutants carried by the Geumho River.

Table 1. Statistics of total and fecal coliforms at each weir station of the Nakdong River (in CFU/100mL).

Station	Total Coliform				Fecal Coliform			
	Avg.	Std.	Max.	Min.	Avg.	Std.	Max.	Min.
Donam	103	290	2117	3	13	49	371	1
Nakdan	98	184	1171	3	12	37	270	1
Seonsan	67	135	893	2	10	31	227	1
Chilgok	233	580	3835	8	39	116	795	1
Dasa	160	425	2664	1	18	50	259	1
Nongong	333	855	4334	5	49	157	841	1
Deokgok	195	523	3082	2	23	74	412	1
Haman	198	677	5049	3	29	130	980	1

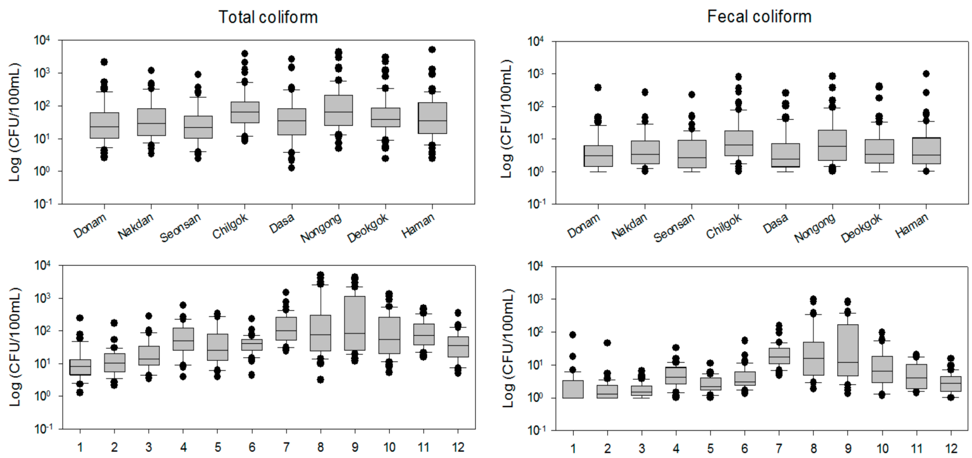


Figure 2. Spatio-temporal distribution of total and fecal coliforms at the weir stations of the Nakdong River. The x-axes of the bottom plots represent months.

Overall, the total and fecal coliform concentrations were low at the upstream stations and gradually increased toward the downstream stations (Table 1 and Figure 2). The Nakdong River watershed is characterized by mountainous terrain in the upstream area, pollution sources such as agricultural land, livestock sheds, and wastewater treatment plants in the midstream area, and influential tributary inflows, such as the Geumho, Nam, and Yangsan Rivers, in the mid- to downstream areas. Such complex influences of point/non-point pollution sources might lead to high coliform concentrations at the downstream stations. The total and fecal coliforms showed high concentrations and wide distribution ranges from July to October, especially in August and September (Figure 2). This likely was due to the impacts of non-point pollution sources caused by rainfall as well as point pollution sources and high water temperature during summer. Lee et al. [9] indicated high concentrations of coliform bacteria during summer and fall seasons in the mid- to downstream section of the Nakdong River because of the inflow of pollutants by rainfall, similar to the present study results. Seo et al. [31]

demonstrated via cluster and factor analyses that influential water quality factors affecting the Nakdong River mainstream from July to October were similar to those over the entire period from January to December, pointing out the need for coliform bacteria management during summer and early fall and further in the mid- to downstream areas. In addition, the impact of water temperature on coliform bacteria was reported by Ramteke et al. [40] and Baek [19].

3.2. Correlation Analysis Results

Analysis of the correlation between coliform bacteria and water quality factors can be seen in Table 2. Total and fecal coliforms showed significant positive correlations with COD, SS, TP, TOC, WT, PO_4-P, and precipitation and significant negative correlations with pH, DO, and EC at the eight weir stations. Significant negative correlations were found between both types of coliforms and TN and NO_3-N, mainly at the mid- and downstream stations. Regarding BOD and Chl-a, significant negative correlations with total coliforms were found mainly at the mid- and downstream stations, whereas no significant correlations with fecal coliforms were found.

Table 2. Pearson correlation coefficients (r) between total (a) and fecal (b) coliforms and water quality components at each weir station. One asterisk (*) and two asterisks (**) mean $p < 0.05$ and $p < 0.01$, respectively.

(a) log TC									
Variable [1]	**Donam**	**Nakdan**	**Seonsan**	**Chilgok**	**Dasa**	**Nongong**	**Deokgok**	**Haman**	**All Stations**
pH	−0.262(*)	−0.492(**)	−0.485(**)	−0.439(**)	−0.374(**)	−0.430(**)	−0.504(**)	−0.493(**)	−0.431(**)
DO	−0.626(**)	−0.511(**)	−0.499(**)	−0.437(**)	−0.592(**)	−0.416(**)	−0.564(**)	−0.653(**)	−0.509(**)
BOD	−0.015	0.004	−0.03	−0.196	−0.043	−0.255(*)	−0.275(*)	−0.259(*)	−0.076
COD	0.512(**)	0.516(**)	0.532(**)	0.387(**)	0.536(**)	0.173	0.358(**)	0.191	0.402(**)
SS	0.545(**)	0.452(**)	0.357(**)	0.481(**)	0.424(**)	0.323(*)	0.308(*)	0.505(**)	0.404(**)
TN	−0.092	−0.019	−0.023	−0.245	−0.435(**)	−0.360(**)	−0.475(**)	−0.487(**)	−0.122(**)
TP	0.466(**)	0.374(**)	0.403(**)	0.515(**)	0.405(**)	0.260(*)	0.242	0.292(*)	0.366(**)
TOC	0.598(**)	0.533(**)	0.559(**)	0.519(**)	0.606(**)	0.361(**)	0.493(**)	0.323(*)	0.484(**)
WT	0.422(**)	0.349(**)	0.331(*)	0.372(**)	0.558(**)	0.344(**)	0.504(**)	0.510(**)	0.414(**)
EC	−0.269(*)	−0.188	−0.332(*)	−0.405(**)	−0.431(**)	−0.494(**)	−0.451(**)	−0.601(**)	−0.175(**)
NH_3-N	−0.073	0.14	0.086	−0.176	0.171	0.042	0.255(*)	0.121	0.156(**)
NO_3-N	−0.115	−0.056	−0.04	−0.15	−0.413(**)	−0.338(**)	−0.462(**)	−0.454(**)	−0.151(**)
PO_4-P	0.614(**)	0.625(**)	0.610(**)	0.615(**)	0.455(**)	0.399(**)	0.469(**)	0.596(**)	0.501(**)
Chl-a	−0.046	−0.153	−0.058	−0.192	−0.16	−0.201	−0.275(*)	−0.322(*)	−0.123(**)
Rain	0.653(**)	0.616(**)	0.570(**)	0.677(**)	0.640(**)	0.667(**)	0.662(**)	0.681(**)	0.620(**)
(b) log FC									
Variable [1]	**Donam**	**Nakdan**	**Seonsan**	**Chilgok**	**Dasa**	**Nongong**	**Deokgok**	**Haman**	**All stations**
pH	−0.213	−0.379(**)	−0.376(**)	−0.360(**)	−0.407(**)	−0.491(**)	−0.467(**)	−0.460(**)	−0.395(**)
DO	−0.643(**)	−0.559(**)	−0.559(**)	−0.493(**)	−0.608(**)	−0.517(**)	−0.535(**)	−0.597(**)	−0.534(**)
BOD	−0.023	0.119	0.077	−0.172	−0.057	−0.323(*)	−0.213	−0.143	−0.069
COD	0.430(**)	0.519(**)	0.528(**)	0.307(*)	0.489(**)	0.092	0.282(*)	0.284(*)	0.340(**)
SS	0.664(**)	0.599(**)	0.524(**)	0.559(**)	0.541(**)	0.467(**)	0.578(**)	0.666(**)	0.531(**)
TN	−0.039	−0.059	−0.07	−0.275(*)	−0.333(**)	−0.418(**)	−0.494(**)	−0.376(**)	−0.152(**)
TP	0.711(**)	0.664(**)	0.665(**)	0.675(**)	0.638(**)	0.365(**)	0.486(**)	0.526(**)	0.519(**)
TOC	0.550(**)	0.574(**)	0.546(**)	0.476(**)	0.580(**)	0.241	0.323(*)	0.395(**)	0.423(**)
WT	0.497(**)	0.493(**)	0.498(**)	0.462(**)	0.630(**)	0.482(**)	0.601(**)	0.537(**)	0.510(**)
EC	−0.478(**)	−0.475(**)	−0.528(**)	−0.514(**)	−0.588(**)	−0.638(**)	−0.669(**)	−0.671(**)	−0.332(**)
NH_3-N	0.028	0.217	0.203	−0.161	0.162	−0.01	0.117	0.065	0.110(*)
NO_3-N	−0.041	−0.092	−0.088	−0.175	−0.334(**)	−0.386(**)	−0.474(**)	−0.361(**)	−0.170(**)
PO_4-P	0.802(**)	0.840(**)	0.774(**)	0.748(**)	0.677(**)	0.495(**)	0.621(**)	0.768(**)	0.634(**)
Chl-a	−0.017	−0.104	−0.066	−0.308(*)	−0.233	−0.243	−0.184	−0.191	−0.135(**)
Rain	0.792(**)	0.794(**)	0.762(**)	0.743(**)	0.833(**)	0.767(**)	0.819(**)	0.773(**)	0.754(**)

[1] Units: DO, BOD, COD, SS, TN, TP, TOC, NH_3-N, NO_3-N, and PO_4-P are in mg/L, WT is in °C, EC is in µmhos/cm, Chl-a is in mg/m^3, and Rain is in mm.

The degree of correlation between total coliforms and water quality factors for all eight weirs ranked in the following order: precipitation > DO > PO_4-P > TOC > pH > WT > SS > COD > TP >

EC > NH_3-N > NO_3-N > Chl-a > TN; that for fecal coliforms and water quality factors ranked as: precipitation > PO_4-P > DO > SS > TP > WT > TOC > pH > COD > EC > NO_3-N > TN > Chl-a > NH_3-N. Moderate negative correlations existed with DO and pH and moderate positive correlations with precipitation, PO_4-P, SS, TP, WT, TOC, and COD. Precipitation exhibited the strongest correlation with both types of coliform bacteria; at each weir station, it also showed high correlation coefficients of > 0.5 with total coliforms and > 0.7 with fecal coliforms. Byeon et al. [10] mentioned the effect of rainfall on coliform concentration. Rainfall can induce increased suspended solids and phosphorus which has strong adsorption ability in rivers; these factors caused positive correlation with the concentration of coliform bacteria. Regarding the influence of organic matter, point pollution sources, distributed along the Nakdong River, affected positive relationships of COD and TOC with coliform bacteria. Many wastewater treatment plants and industrial complexes are distributed over the midstream areas of the Nakdong River. The results demonstrated high correlations between organic matter and coliform bacteria toward the upstream stations based on Dasa station rather than toward the downstream stations. TN and NO_3-N had weak or no correlations of 0.0-0.2 with coliform bacteria at the upstream stations and had moderate negative correlations with coliform bacteria at the mid- and downstream stations. These results seemed reasonable because a previous study, conducted for the Nakdong River and its main tributaries, showed similar results with the present study results [9]. Beck and Sohn [29] also showed that an increase of nitrite nitrogen was inversely proportional to coliform concentration.

3.3. Regression Analysis Results

3.3.1. Validity of Regression Analysis

The validity of the multiple regression models is shown in Appendix A in detail. The variance analysis showed p-values of < 0.05 and no multicollinearity was diagnosed, with VIF values of < 10 and DW values between 1 and 3 at every station. The adjusted R^2 values ranged from 0.474–0.691 for total coliforms and from 0.745–0.810 for fecal coliforms, showing adjusted R^2 values of approximately 60% and 80% on average, respectively. Chilgok and Dasa stations had the highest adjusted R^2 values for total and fecal coliforms, respectively. On the other hand, Nongong station had the lowest adjusted R^2 values for both coliforms. Fecal coliforms generally showed higher adjusted R^2 values than total coliforms. Such results might be explained by the fact that coliform bacteria multiply exponentially in suitable aquatic environments, which were most widely distributed at Nongong station, and total coliforms showed more outliers and influential values compared to fecal coliforms. The normal distribution of residuals was identified through observed and estimated cumulative probability, and the results were close to the normal distribution at all stations (Figure A1).

3.3.2. Results of Regression Analysis

Total coliform concentration for all stations was affected by precipitation, SS, PO_4-P, TOC, BOD, DO, and pH, which explained up to 58.4% of the concentration (Table 3). Total coliforms showed proportional relationships with precipitation, SS, PO_4-P, and TOC, and were inversely proportional to BOD, DO, and pH. The relative influence of the factors ranks as follows: TOC > precipitation > BOD > pH > SS > DO > PO_4-P. As for fecal coliforms, EC was added along with the abovementioned seven water quality factors, and these eight factors explained up to 74.5% of the concentration of fecal coliforms (Table 3). The relationship with water quality factors was identical to that of the total coliforms. EC had an inversely proportional relationship with fecal coliforms. The relative influence of the factors ranked as follows: precipitation > PO_4-P > SS > TOC > BOD > EC > DO > pH. In general, organic matter had a dominant impact on total coliforms, whereas PO_4-P and SS had that impact on fecal coliforms. Precipitation was the most influential factor for the concentration of both types of coliforms.

Table 3. Multiple regression results between total (a) and fecal (b) coliforms and water quality factors at each weir station. Tables A1 and A2 in Appendix A have details for multiple regression results.

	Station	**Variable [1]**	**β**	**Ad.R^2**	**Station**	**Variable [1]**	**β**	**Ad.R^2**
(a) Total coliform	Donam	TOC	0.361	0.663	Nongong	Rain	0.654	0.474
		BOD	−0.238			BOD	−0.216	
		DO	−0.349		Deokgok	Rain	0.529	0.651
		PO_4-P	0.392			TOC	0.405	
		NH_3-N	−0.19			BOD	−0.432	
	Nakdan	DO	−0.396	0.646	Haman	Rain	0.411	0.645
		pH	−0.53			BOD	−0.427	
		SS	0.445			WT	0.331	
	Seonsan	DO	−0.41	0.556		SS	0.217	
		pH	−0.471		All stations	Rain	0.272	0.584
		SS	0.409			pH	−0.164	
	Chilgok	Rain	0.377	0.691		TOC	0.309	
		pH	−0.511			BOD	−0.202	
		SS	0.402			SS	0.163	
		NH_3-N	−0.221			DO	−0.155	
	Dasa	TOC	0.303	0.573		PO_4-P	0.082	
		DO	−0.475					
		SS	0.306					
(b) Fecal coliform	Donam	PO_4-P	0.541	0.807	Nongong	Rain	0.513	0.761
		DO	−0.312			BOD	−0.275	
		Rain	0.231			SS	0.176	
	Nakdan	PO_4-P	0.515	0.807		PO_4-P	0.21	
		DO	−0.236			EC	−0.176	
		Rain	0.253		Deokgok	Rain	0.499	0.801
		pH	−0.146			PO_4-P	0.211	
	Seonsan	PO_4-P	0.375	0.732		EC	−0.242	
		DO	−0.396			pH	−0.241	
		SS	0.322		Haman	Rain	0.427	0.766
		pH	−0.189			EC	−0.26	
	Chilgok	PO_4-P	0.542	0.788		BOD	−0.282	
		Rain	0.381			SS	0.266	
		NH_3-N	−0.15			TOC	0.16	
		DO	−0.181		All stations	Rain	0.364	0.745
	Dasa	Rain	0.468	0.81		PO_4-P	0.21	
		PO_4-P	0.181			DO	−0.124	
		DO	−0.308			SS	0.197	
		SS	0.228			BOD	−0.168	
						TOC	0.182	
						EC	−0.128	
						pH	−0.1	

[1] Units: DO, BOD, SS, TOC, NH_3-N, and PO_4-P are in mg/L, WT is in °C, EC is in µmhos/cm, and Rain is in mm.

The above regression results using all station data reflected the influential water quality factors at each station. At each station, the water quality factors influencing the concentration of coliform bacteria were precipitation, PO_4-P, SS, WT, TOC, BOD, DO, pH, and NH_3-N for total coliforms; this was similar for fecal coliforms except that EC was a factor instead of WT (Table 3). The weir stations generally showed similar water quality factors. However, the water quality factors could be described at the up- and midstream stations and the mid- and downstream stations below Dalseong weir, depending on dominant trends. Seo et al. [31] also spatially classified the Nakdong River as the up- and midstream and mid- and downstream segments at a non-weir station between Dasa (Gangjeong-Goryeong weir) and Nongong (Dalseong weir) stations using cluster analyses. The concentration of total coliforms was especially influenced by decreases in pH and DO and increases in SS at the up- and midstream weir stations and by decreased BOD and increased precipitation at the mid- and downstream weir stations. The concentration of fecal coliforms was mainly affected by decreases in pH and DO and increases in PO_4-P and precipitation at the up- and midstream weir stations and by increased PO_4-P and precipitation and decreased BOD and EC at the mid- and downstream weir stations.

The negative relationship of pH and DO with total and fecal coliforms at the up- and midstream weir stations seemed to be a natural phenomenon, resulting from the consumption of DO due to the proliferation of coliform bacteria and the decrease in pH due to the occurrence of carbon dioxide. Jang and Cheong [21] also showed negative correlations between coliform bacteria and pH. Surface runoff by rainfall seemed to be the main reason for the positive relationship of SS, PO_4-P, and precipitation with total and fecal coliforms. As mentioned above, the Nakdong River basin includes substantial areas of forests and agricultural lands distributed along the river. The inflow of non-point pollutants, such as fertilizer and livestock feces, by rainfall could lead to the occurrence and increase of coliform bacteria in a suitable aquatic environment. Several studies have reported the impact of non-point pollution by rainfall on coliform bacteria [9,31,41]. Jung et al. [30] mentioned that phosphorus could easily be adsorbed onto clay soil and soil organic matter. Therefore, the outflow of such pollutants adsorbed and attached to the soil due to rainfall could cause the positive relationship with total and fecal coliforms. Meanwhile, several studies have reported the impact of suspended and bed sediment on coliform bacteria, showing interaction between sediment and coliform bacteria through deposition, agitation, and resuspension [6,42,43]. Untreated discharge from industrial complexes and wastewater treatment plants, located between the Seonsan and Chilgok stations, could be another reason for the positive relationship.

The positive relationship of PO_4-P and precipitation with total and fecal coliforms at the mid- and downstream weir stations below Dalseong weir could be explained by similar reasons as those expounded above. BOD and EC had negative relationships with total and fecal coliforms. In the case of BOD, the result differed from that of other studies, which found positive relationships between organic matter and coliform bacteria [29,44–48]. Cho and Song [5] stated that coliform bacteria decreased noticeably after three days on average in a river system. It was considered that such natural die-off [11,49] caused the negative relationship at downstream stations rather than at upstream stations. Lee et al. [9] also demonstrated a weak negative correlation between BOD and coliform bacteria in the mainstream of the Nakdong River. In addition, the deposition of organic matter because of the mild gradient downstream could be another reason for this negative relationship. Furthermore, the inflow of pollutants, along with slow flow velocity downstream, could lead to eutrophication and the subsequent propagation of Chl-a, an indicator of algal bloom. The mass propagation of Chl-a as autochthonous organic matter could restrict the occurrence of coliform bacteria. Ahmad et al. [50] also examined the removal of coliform bacteria by a freshwater algal species. Meanwhile, the negative relationship of EC with coliform bacteria could be explained by the dilution of pollutants by rainfall or discharges of tributaries. The Nakdong River has a number of tributaries flowing into the mid- and downstream areas, including the Nam River (a primary tributary) and the Geumho River (a second tributary). Kim et al. [51] indicated negative correlations between pollutants and rainfall and discharges. The dilution of pollutants could cause decreases in electrolytes and the corresponding decrease in EC. Yun et al. [52] reported negative correlations between coliform bacteria and EC.

The study results generally showed that the influential water quality factors in terms of the concentration of coliform bacteria were similar among the weir stations, even though there were commonly major factors at the up- and downstream stations. Seo et al. [31], who studied the spatio-temporal water quality characteristics of the Nakdong River using a total of 38 stations, showed the dominant water quality factors for different spatial sections of the Nakdong River. In addition, their results for the general water quality of the Nakdong River were slightly different from the results of this study. In this regard, it was presumed that present study results might have been affected by the weirs, because weirs can create similar aquatic environments by controlling the flow of rivers and creating a closed water system similar to lakes and dams. However, this is speculative; it is difficult to decide on the impact of weirs without more concrete evidence. To the authors' knowledge, no studies have been found, so far, for the impact of weirs on coliform bacteria. While several studies have addressed water quality factors at weir stations [32–34], they did not elucidate the impacts of the weirs on the water quality factors compared to the results from non-weir stations. Furthermore, in the current situation, it is also difficult to decide on whether the impact of weirs is beneficial or harmful. Lee et al. [33] reported proliferation of harmful algae after weir construction in comparison with that before weir construction in the Nakdong River, while they showed decreases in TP and Chl-a after weir construction at the mid- and downstream stations. Also, in the Lee et al.'s [9] study to analyze coliform bacteria patterns at the Nakdong River mainstream and its tributaries, we could find the trends of lower distribution of total and fecal coliforms at weir stations than at other non-weir stations. Therefore, it would be necessary for studies related to the impact of weirs to consider both temporal (before and after weir construction) and spatial (weir and non-weir stations) conditions along with the interaction of water quality factors. Within the scope of this study, we focused on determining the water quality factors influencing the concentration of coliform bacteria at weir stations. However, weir-related issues, such as the impact of presence and absence and the positive and negative aspects, should be further discussed in the future for effective water quality management.

4. Conclusions

This study investigated the distribution of coliform bacteria and derived the relationship between coliform bacteria and water quality factors through regression analyses in the Nakdong River under altered aquatic environments resulting from weir construction. The influential water quality factors for the concentration of coliform bacteria at weir stations were determined. Specifically, precipitation was the most influential factor for the concentration of coliform bacteria. Total coliforms were dominantly affected by organic matter and fecal coliforms by PO_4-P and SS. In particular, both types of coliforms were negatively affected by pH and DO and positively by SS, PO_4-P, and precipitation at the upstream weir stations. Furthermore, they showed negative relationships with BOD and EC and positive relationships with PO_4-P and precipitation at the weir stations below Dalseong weir. This study lays a foundation for investigating the influential water quality factors related to the occurrence of coliform bacteria in the Nakdong River for future water quality management.

The South Korean government is monitoring the impact of weirs on various aspects of the aquatic environment, and is taking measures to remediate negative issues caused by the artificial conditions by carrying out temporary or regular discharges at some weirs. The concentration of coliform bacteria is variable under the changing aquatic environment. Therefore, continuous monitoring and data collection should be necessarily conducted for future water quality management. Studies related to coliform bacteria at weir stations are yet to be widely studied. This study could be the groundwork for addressing the impact of weirs on coliform bacteria under both temporal and spatial conditions. Continuous research could provide important information on the proper management alternatives of coliform occurrence not only at weir stations, but also on other waterways with dams and other obstructions in the future.

Author Contributions: Conceptualization and methodology design: M.S., H.L., and Y.K. Data analysis and manuscript preparation: M.S. Support of data analysis and manuscript preparation: H.L. and Y.K. Manuscript revision: M.S., H.L., and Y.K.

Funding: This research was funded by the National Institute of Environment Research (NIER) of the Republic of Korea, grant number NIER-2018-05-01-006.

Acknowledgments: We appreciate Ethan Xu for his help for submitting this paper, and anonymous reviewers for their comments improving the manuscript. We also thank members of the Nakdong River Environment Research Center, NIER, for their assistance.

Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Tables and figure below contain details for the validity of the multiple regression models in the 3.3. Regression Analysis Results section.

Table A1. Multiple regression results between total coliforms and water quality factors at each weir station.

Station	Variable [1]	Std. Error	β	t	*p*-Value	Tolerance	VIF	Ad.R^2	DW
Donam	Constant	0.076	-	0.000	1.000			0.663	1.552
	TOC	0.102	0.361	3.536	0.001	0.568	1.761		
	BOD	0.095	−0.238	−2.517	0.015	0.661	1.513		
	DO	0.105	−0.349	−3.324	0.002	0.537	1.861		
	PO_4-P	0.099	0.392	3.952	0.000	0.603	1.659		
	NH_3-N	0.085	−0.190	−2.236	0.030	0.823	1.215		
Nakdan	Constant	0.079	-	0.000	1.000			0.646	1.594
	DO	0.081	−0.396	−4.869	0.000	0.956	1.046		
	pH	0.081	−0.530	−6.582	0.000	0.976	1.025		
	SS	0.082	0.445	5.433	0.000	0.942	1.062		
Seonsan	Constant	0.087	-	0.000	1.000			0.556	1.403
	DO	0.090	−0.410	−4.583	0.000	0.971	1.030		
	pH	0.090	−0.471	−5.220	0.000	0.954	1.048		
	SS	0.089	0.409	4.592	0.000	0.980	1.020		
Chilgok	Constant	0.072	-	0.000	1.000			0.691	1.361
	Rain	0.086	0.377	4.366	0.000	0.702	1.424		
	pH	0.084	−0.511	−6.058	0.000	0.735	1.360		
	SS	0.087	0.402	4.626	0.000	0.692	1.445		
	NH_3-N	0.077	−0.221	−2.857	0.006	0.874	1.144		
Dasa	Constant	0.084	-	0.000	1.000			0.573	1.405
	TOC	0.102	0.303	2.976	0.004	0.698	1.434		
	DO	0.094	−0.475	−5.062	0.000	0.823	1.215		
	SS	0.094	0.306	3.253	0.002	0.820	1.219		
Nongong	Constant	0.094	-	0.000	1.000			0.474	1.161
	Rain	0.095	0.654	6.920	0.000	0.996	1.004		
	BOD	0.095	−0.216	−2.289	0.026	0.996	1.004		
Deokgok	Constant	0.076	-	0.000	1.000			0.651	1.733
	Rain	0.084	0.529	6.281	0.000	0.834	1.199		
	TOC	0.088	0.405	4.614	0.000	0.766	1.306		
	BOD	0.081	−0.432	−5.367	0.000	0.911	1.097		
Haman	Constant	0.077	-	0.000	1.000			0.645	1.419
	Rain	0.113	0.411	3.649	0.001	0.476	2.102		
	BOD	0.082	−0.427	−5.218	0.000	0.898	1.113		
	WT	0.094	0.331	3.531	0.001	0.685	1.459		
	SS	0.103	0.217	2.110	0.039	0.568	1.761		
All stations	Constant	0.030	-	0.000	1.000			0.584	1.333
	Rain	0.044	0.272	6.198	0.000	0.456	2.193		
	pH	0.039	−0.164	−4.169	0.000	0.569	1.758		
	TOC	0.041	0.309	7.496	0.000	0.519	1.926		
	BOD	0.044	−0.202	−4.553	0.000	0.450	2.223		
	SS	0.038	0.163	4.251	0.000	0.601	1.663		
	DO	0.039	−0.155	−3.990	0.000	0.585	1.710		
	PO_4-P	0.040	0.082	2.062	0.040	0.561	1.783		

[1] Units: DO, BOD, SS, TOC, NH_3-N, and PO_4-P are in mg/L, WT is in °C, and Rain is in mm.

Table A2. Multiple regression results between fecal coliforms and water quality factors at each weir station.

Station Name	Variable [1]	Std. Error	β	t	*p*-Value	Tolerance	VIF	Ad.R^2	DW
Donam	Constant	0.058	-	0.000	1.000			0.807	1.601
	PO_4-P	0.079	0.541	6.800	0.000	0.537	1.864		
	DO	0.076	−0.312	−4.080	0.000	0.581	1.721		
	Rain	0.097	0.231	2.384	0.021	0.361	2.771		
Nakdan	Constant	0.058	-	0.000	1.000			0.807	2.347
	PO_4-P	0.096	0.515	5.386	0.000	0.377	2.652		
	DO	0.069	−0.236	−3.405	0.001	0.718	1.393		
	Rain	0.100	0.253	2.521	0.015	0.343	2.915		
	pH	0.063	−0.146	−2.314	0.025	0.867	1.153		
Seonsan	Constant	0.068	-	0.000	1.000			0.732	1.528
	PO_4-P	0.118	0.375	3.184	0.002	0.340	2.943		
	DO	0.075	−0.396	−5.296	0.000	0.841	1.188		
	SS	0.102	0.322	3.153	0.003	0.451	2.218		
	pH	0.091	−0.189	−2.085	0.042	0.573	1.746		
Chilgok	Constant	0.059	-	0.000	1.000			0.788	1.327
	PO_4-P	0.068	0.542	7.950	0.000	0.773	1.294		
	Rain	0.083	0.381	4.572	0.000	0.516	1.937		
	NH_3-N	0.060	−0.150	−2.494	0.016	0.994	1.006		
	DO	0.075	−0.181	−2.412	0.019	0.636	1.572		
Dasa	Constant	0.056	-	0.000	1.000			0.81	1.58
	Rain	0.081	0.468	5.762	0.000	0.489	2.044		
	PO_4-P	0.081	0.181	2.228	0.030	0.491	2.037		
	DO	0.071	−0.308	−4.343	0.000	0.640	1.561		
	SS	0.077	0.228	2.957	0.005	0.543	1.843		
Nongong	Constant	0.063	-	0.000	1.000			0.761	1.777
	Rain	0.079	0.513	6.461	0.000	0.642	1.557		
	BOD	0.068	−0.275	−4.041	0.000	0.875	1.143		
	SS	0.077	0.176	2.305	0.025	0.692	1.444		
	PO_4-P	0.070	0.210	3.004	0.004	0.832	1.201		
	EC	0.084	−0.176	−2.088	0.042	0.573	1.746		
Deokgok	Constant	0.058	-	0.000	1.000			0.801	2.046
	Rain	0.079	0.499	6.340	0.000	0.545	1.834		
	PO_4-P	0.070	0.211	3.001	0.004	0.684	1.462		
	EC	0.072	−0.242	−3.374	0.001	0.656	1.525		
	pH	0.061	−0.241	−3.966	0.000	0.915	1.093		
Haman	Constant	0.062	-	0.000	1.000			0.766	1.686
	Rain	0.089	0.427	4.777	0.000	0.495	2.021		
	EC	0.078	−0.260	−3.346	0.001	0.654	1.530		
	BOD	0.070	−0.282	−4.038	0.000	0.812	1.232		
	SS	0.087	0.266	3.049	0.004	0.519	1.926		
	TOC	0.074	0.160	2.155	0.036	0.715	1.398		
All stations	Constant	0.023	-	0.000	1.000			0.745	1.562
	Rain	0.036	0.364	10.132	0.000	0.419	2.385		
	PO_4-P	0.031	0.210	6.771	0.000	0.561	1.784		
	DO	0.032	−0.124	−3.828	0.000	0.519	1.928		
	SS	0.031	0.197	6.392	0.000	0.567	1.762		
	BOD	0.035	−0.168	−4.778	0.000	0.438	2.284		
	TOC	0.036	0.182	5.067	0.000	0.419	2.388		
	EC	0.031	−0.128	−4.118	0.000	0.561	1.782		
	pH	0.032	−0.100	−3.171	0.002	0.543	1.841		

[1] Units: DO, BOD, SS, TOC, NH_3-N, and PO_4-P are in mg/L, EC is in μmhos/cm, and Rain is in mm.

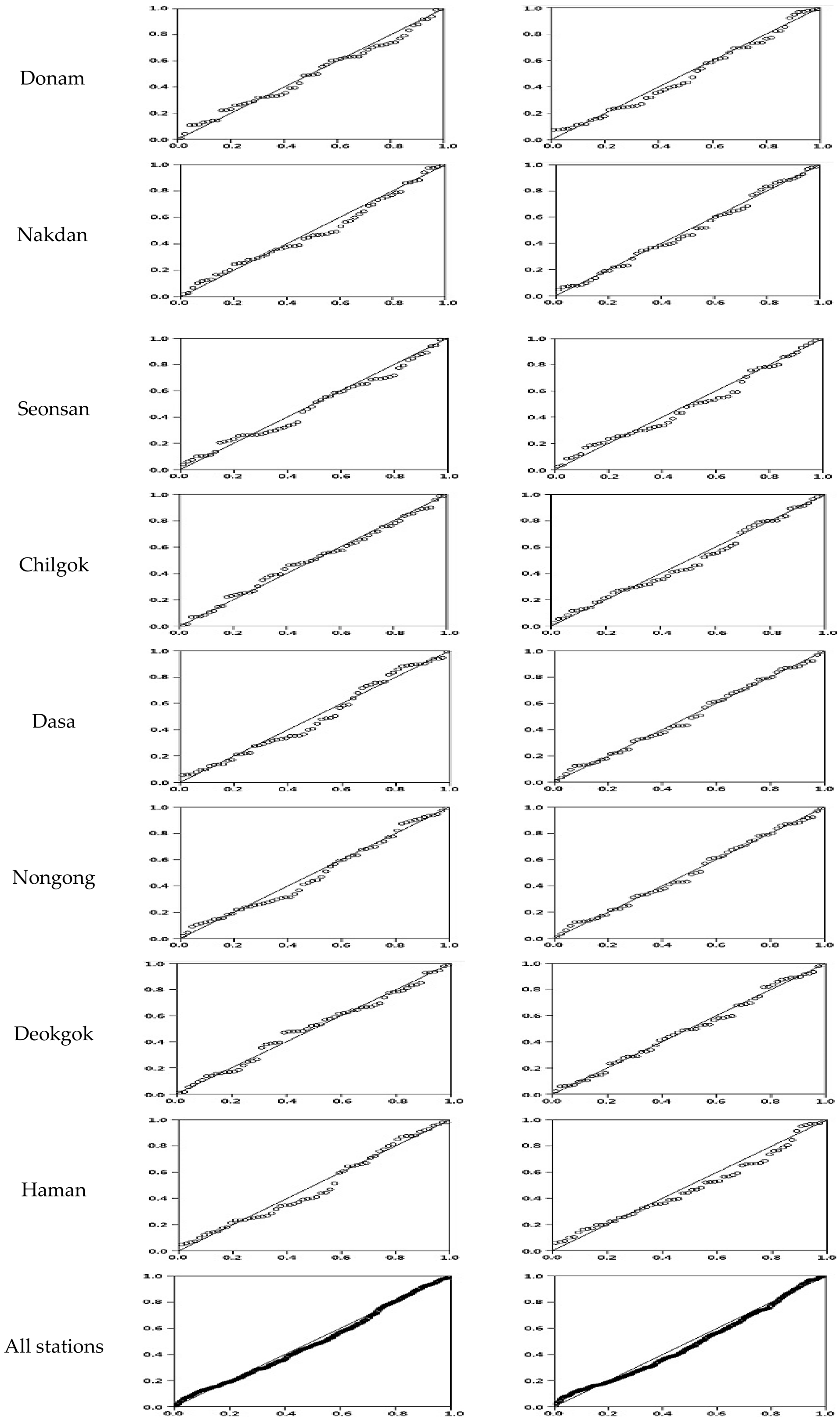


Figure A1. Normal P-P plots of the regression standardized residual between the observed (*x*-axis) and estimated (*y*-axis) cumulative probabilities for the total (left) and fecal (right) coliforms at each weir station.

References

1. National Institute of Environmental Research. *Aquatic Ecosystem Monitoring in Weirs of the Nakdong River*; 4th report; National Institute of Environmental Research, Nadong River Environment Research Center: Dasan-myeon, Goryeong-gun, Korea, 2017. (In Korean)
2. Kim, H.R.; Kim, N.H.; Park, H.S.; Kim, D.H.; Lee, J.H. Survey of fecal coliform contamination in sands of educational facilities and parks in Seoul. *Korean J. Vet. Serv.* **2014**, *37*, 307–312. (In Korean) [CrossRef]
3. Lee, G.C.; Lee, H.S. Total coliforms and fecal coliforms as microbial indicators of waterborne enteric viruses in Korean surface water. *J. Korean Soc. Water Wastew.* **2006**, *20*, 885–892. (In Korean)
4. So, M.H.; Cho, M.H.; Lee, J.Y.; Kim, M.Y. Growth inhibition of coliform bacteria in model system of naengmyon-broth by using dongchimi-juice. *Korean J. Food Nutr.* **1996**, *9*, 29–36. (In Korean)
5. Cho, W.H.; Song, M.H. Effects of Wanggung livestock wastewater on the Mankyung river basin on the coliforms. *J. Korean Soc. Environ. Technol.* **2008**, *9*, 157–164. (In Korean)
6. Crabill, C.; Donald, R.; Snelling, J.; Foust, R.; Southam, G. The impact of sediment fecal coliform reservoirs on seasonal water quality in Oak Creek, Arizona. *Water Res.* **1999**, *33*, 2163–2171. [CrossRef]
7. Frena, M.; Santos, A.P.S.; Souza, M.R.R.; Carvalho, S.S.; Madureira, L.A.S.; Alexandre, M.R. Sterol biomarkers and fecal coliforms in a tropical estuary: Seasonal distribution and sources. *Mar. Pollut. Bull.* **2019**, *139*, 111–116. [CrossRef] [PubMed]
8. Kindiki, S.; Kollenberg, M.; Siamba, D.; Sifuna, A.; Wekesa, C. Analysis of fecal coliform levels at watering points along the upper reaches of river Isiukhu in Kakamega County, Kenya. *J. Adv. Microbiol.* **2018**, *10*, 1–7. [CrossRef]
9. Lee, H.J.; Park, H.K.; Lee, J.H.; Park, A.R.; Cheon, S.U. Coliform pollution status of Nakdong river and tributaries. *J. Korean Soc. Water Environ.* **2016**, *32*, 271–280. (In Korean) [CrossRef]
10. Byeon, S.J.; Choi, G.W.; Jo, H.G. A study on discharged coliform into coastal bathing water after rainfall event. *J. Korean Soc. Hazard Mitig.* **2011**, *11*, 337–343. (In Korean) [CrossRef]
11. Im, S.; Mostaghimi, S. Fecal coliform bacteria loading from the Polecat Creek Watershed in Virginia, USA. *Korean J. Limnol.* **2004**, *37*, 106–111.
12. Choi, S.Y.; Seo, I.W. Prediction of fecal coliform using logistic regression and tree-based classification models in the North Han River, South Korea. *J. Hydro-Environ. Res.* **2018**, *21*, 96–108. [CrossRef]
13. Liu, W.C.; Chan, W.T.; Young, C.C. Modeling fecal coliform contamination in a tidal Danshuei River estuarine system. *Sci. Total Environ.* **2015**, *502*, 632–640. [CrossRef] [PubMed]
14. Liu, W.C.; Liu, H.M. Investigation of the fecal coliform plumes induced by river discharge and wind stress using a three-dimensional model. *Environ. Fluid Mech.* **2019**. [CrossRef]
15. Manache, G.; Melching, C.S.; Lanyon, R. Calibration of a continuous simulation fecal coliform model based on historical data analysis. *J. Environ. Eng.* **2007**, *133*, 681–691. [CrossRef]
16. Sokolova, E.; Pettersson, T.J.R.; Bergstedt, O.; Hermansson, M. Hydrodynamic modelling of the microbial water quality in a drinking water source as input for risk reduction management. *J. Hydrol.* **2013**, *497*, 15–23. [CrossRef]
17. Zhu, X.; Wang, J.D.; Solo-Gabriele, H.M.; Fleming, L.E. A water quality modeling study of non-point sources at recreational marine beaches. *Water Res.* **2011**, *45*, 2985–2995. [CrossRef] [PubMed]
18. Noble, R.T.; Moore, D.F.; Leecaster, M.K.; McGee, C.D.; Weisberg, S.B. Comparison of total coliform, fecal coliform, and enterococcus bacterial indicator response for ocean recreational water quality testing. *Water Res.* **2003**, *37*, 1637–1643. [CrossRef]
19. Baek, S. Distribution characteristics of chemical oxygen demand and *Escherichia coli* based on pollutant sources at Gwangyang Bay of South Sea in Korea. *J. Korea Acad. Ind. Coop. Soc.* **2014**, *15*, 3279–3285. (In Korean) [CrossRef]
20. Choi, J.D.; Kim, J.G. Bacteriological and physicochemical character of sea water and sediments in south western part of Jinhae Bay, Korea. *Korean J. Fish. Aquat. Sci.* **2002**, *35*, 621–626. (In Korean) [CrossRef]
21. Jang, S.G.; Cheong, C.J. Seasonal characteristics of seawater quality in the Suncheon Bay. *J. Wetl. Res.* **2010**, *12*, 47–57. (In Korean)
22. Kim, K.S.; Lee, W.B.; Joo, H.S.; Lee, J.C.; Cho, J.W.; Chun, S.B.; Lee, S.W.; Park, J.C. Physicochemical characteristics and seasonal distribution of microbial population in the Gangjin Bay ecosystem. *Korean J. Microbiol.* **2000**, *36*, 285–291. (In Korean)

23. Son, M.H.; Baek, S.H.; Joo, H.M.; Jang, P.G.; Kim, Y.O. Distributional characteristics of Escherichia coli and water pollution in Gwangyang Bay and Jinhae Bay, Korea. *Korean J. Environ. Biol.* **2011**, *29*, 162–170. (In Korean)
24. Brady, A.M.; Bushon, R.N.; Plona, M.B. *Predicting Recreational Water Quality Using Turbidity in the Cuyahoga River, Cuyahoga Valley National Park, Ohio*; U.S. Geological Survey Scientific Investigations Report 2009-5192; U.S. Geological Survey: Reston, VA, USA, 2009.
25. Christensen, V.G.; Jian, X.; Ziegler, A.C. *Regression Analysis and Real-Time Water-Quality Monitoring to Estimate Constituent Concentrations, Loads, and Yields in the Little Arkansas River, South-Central Kansas*; U.S. Geological Survey Water Resources Investigations Report 00e4126; U.S. Geological Survey: Lawrence, KS, USA, 2000.
26. David, M.M.; Haggard, B.E. Development of regression-based models to predict fecal bacteria numbers at select sites within the Illinois River watershed, Arkansas and Oklahoma, USA. *Water Air Soil Pollut.* **2011**, *215*, 525–547. [CrossRef]
27. Herrig, I.M.; Boer, S.I.; Brennholt, N.; Manz, W. Development of multiple linear regression models as predictive tools for fecal indicator concentrations in a stretch of the lower Lahn River, Germany. *Water Res.* **2015**, *85*, 148–157. [CrossRef]
28. Choi, C.M.; Yun, S.G.; Kim, M.K.; Kim, J.H.; Ko, B.G.; Park, S.J.; Ryu, H.Y. Correlation between ground water quality parameters and total coliforms in livestock farm. *Korean J. Environ. Agric.* **2009**, *28*, 86–91. (In Korean) [CrossRef]
29. Beck, Y.S.; Sohn, J.S. Studies on the effect of water quality parameters on total coliform concentration in sewage effluents. *J. Korean. Soc. Water Qual.* **2006**, *22*, 166–171. (In Korean)
30. Jung, K.W.; Yoon, C.G.; Jang, J.H.; Jeon, J.H. Water quality and correlation analysis between water quality parameters in the Hwaong watershed. *J. Korean Soc. Agric. Eng.* **2006**, *48*, 91–102. (In Korean)
31. Seo, M.J.; Cho, C.D.; Im, T.H.; Kim, S.H.; Yoon, H.J.; Kim, Y.S.; Kim, G.H. Statistical analysis for spatio-temporal water quality characteristics of the Nakdong River. *J. Environ. Sci. Int.* **2019**, *28*, 303–320. (In Korean) [CrossRef]
32. Jung, S.Y.; Kim, I.K. Analysis of water quality factor and correlation between water quality and Chl-a in middle and downstream weir section of Nakdong River. *J. Korean Soc. Environ. Eng.* **2017**, *39*, 89–96. (In Korean) [CrossRef]
33. Lee, H.J.; Park, H.K.; Cheon, S.U. Effects of weir construction on phytoplankton assemblages and water quality in a large river system. *Int. J. Environ. Res. Public Health* **2018**, *15*, 2348. [CrossRef]
34. Oh, S.E.; Ahn, H.K.; Chae, S.K. The study on the prediction of algae occurrence by the multiple regression analysis after weir construction at Namhan River. *J. Environ. Impact Assess.* **2017**, *26*, 470–478. (In Korean)
35. Cho, D.H.; Um, H.S. A study on the water quality management policy based upon the change of water pollution in the upper and middle stream areas of Nakdong River. *Korean Public Adm. Q.* **2005**, *17*, 689–708.
36. Jeon, Y.I. The Assessment of the Quality of Nakdong River and the Analysis of Correlationship According to the Items of Water Quality. Master's Thesis, Department of Environmental Engineering, Graduate School of Yeungnam University, Gyeongsan, Korea, 2012.
37. Jung, K.Y.; Ahn, J.M.; Kim, K.S.; Lee, I.J.; Yang, D.S. Evaluation of water quality characteristics and water quality improvement grade classification of Geumho River tributaries. *J. Environ. Sci. Int.* **2016**, *25*, 767–787. (In Korean) [CrossRef]
38. Yu, J.J.; Lee, K.L.; Lee, H.J.; Hwang, J.W.; Lyu, H.S.; Shin, L.Y.; Park, A.R.; Chen, S.U. Relation of nutrient concentrations on the seasonality of algal community in the Nakdong River, Korea. *J. Korean Soc. Water Environ.* **2015**, *31*, 110–119. (In Korean) [CrossRef]
39. Na, S.M.; Kwon, H.G.; Shin, S.M.; Son, Y.G.; Shin, D.S.; Im, T.H. A study on seasonal pollutant distribution characteristics of contaminated tributaries in Nakdong River basin. *J. Wetl. Res.* **2016**, *18*, 301–312. (In Korean) [CrossRef]
40. Ramteke, P.W.; Bhattacharjee, J.W.; Pathak, S.P.; Kaira, N. Evaluation of coliforms as indicators of water quality in India. *J. Appl. Bacteriol.* **1992**, *72*, 352–356. [CrossRef]
41. Kim, G.H.; Yur, J.H. Effects of the non-point source pollution on the concentration of pathogen indicator organisms in the Geum River Basin, Republic of Korea. *KSCE J. Civ. Eng.* **2004**, *8*, 181–187. [CrossRef]
42. Gannon, J.; Busse, M.K.; Schillinger, J. Faecal coliform disappearance in a river impoundment. *Water Res.* **1983**, *17*, 1595–1601. [CrossRef]

43. Gao, G.; Falconer, R.A.; Lin, B. Numerical modelling of sediment-bacteria interaction processes in surface waters. *Water Res.* **2011**, *45*, 1951–1960. [CrossRef]
44. Arai, T.; Ikejima, N.; Itoh, T.; Sakai, S.; Shimada, T.; Sakazaki, R. A survey of *Plesiomonas shigelloides* from aquatic environments, domestic animals, pets and humans. *J. Hyg.* **1980**, *84*, 203–211. [CrossRef]
45. Araujo, R.M.; Arribas, R.; Lucena, F.; Pares, R. Relation between *Aeromonas* and fecal coliforms in fresh waters. *J. Appl. Microbiol.* **1989**, *67*, 213–217. [CrossRef]
46. Canosa, A.; Pinilla, G. Bacteriological eutrophication indicators in four Colombian water bodies (South America). *Lakes Reserv.* **1999**, *4*, 23–27. [CrossRef]
47. Hiraishi, A.; Saheki, K.; Horie, S. Relationships of total coliform, fecal coliform, and organic pollution levels in the Tamagawa river. *Nippon Suisan Gakkaishi* **1984**, *50*, 991–997. [CrossRef]
48. Kim, G. Discharge characteristics of the indicator microorganisms of combined sewer overflows. *J. Korean Soc. Water Wastew.* **2006**, *20*, 627–635. (In Korean)
49. Van der Steen, P.; Brenner, A.; Shabtai, Y.; Oron, G. The effect of environmental conditions on faecal coliform decay in post-treatment of UASB reactor effluent. *Water Sci. Technol.* **2000**, *42*, 111–118. [CrossRef]
50. Ahmad, F.; Iftikhar, A.; Ali, A.S.; Shabbir, S.A.; Wahid, A.; Mohy-u-Din, N.; Rauf, A. Removal of coliform bacteria from municipal wastewater by algae. *Proc. Pak. Acad. Sci.* **2014**, *51*, 129–138.
51. Kim, K.A.; Kim, Y.J.; Song, M.J.; Ji, K.W.; Yu, P.J.; Kim, C.W. Evaluation of water quality characteristics in the Nakdong River using multivariate analysis. *J. Korean Soc. Water Qual.* **2007**, *23*, 814–821. (In Korean)
52. Yun, B.; Kim, M.K.; Ryu, J.H.; Kim, W.I.; Park, B.Y.; Kim, H.J.; Lee, S.D.; Kim, S.R. Investigation of microbiological and physiochemical quality for irrigation water used in Napa cabbage cultivation. *J. Food Hyg. Saf.* **2017**, *32*, 396–403. (In Korean) [CrossRef]