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Analysis of Water Quality Characteristics in Unit Watersheds in the Hangang Basin with Respect to TMDL Implementation

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Abstract: Spatiotemporal water quality tendencies before and after total maximum daily load (TMDL) implementation in the Hangang basin were analyzed to determine the water quality improvement resulting from the TMDL policy. The periodicities of water quality indicators were also analyzed and water quality characteristics corresponding to different unit watershed units were identified in terms of pollution source. Considering five water quality indicators, including biochemical oxygen demand and total phosphorus, it was observed that water quality indicator concentrations were low in the upstream areas of the Bukhangang and Namhangang watersheds. However, they were high between the downstream areas of the Namhangang watershed and the Imjingang watershed and in the Hangang downstream and Jinwicheon watersheds. Additionally, the concentrations of water quality indicators in most of the unit watersheds where TMDL had been implemented decreased after TMDL implementation. However, increasing tendencies in the concentrations of water quality indicators continued to be observed in some of the watershed units in the upstream areas of the Bukhangang and Namhangang watersheds, possibly because these watersheds are affected by nonpoint source pollution owing to rainfall. Therefore, in the future, it would be necessary to implement policies that take these findings into consideration.

Keywords: spatiotemporal analysis; water quality indicators; Mann–Kendall test; autocorrelation function; nonpoint source pollution

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1. Introduction

In South Korea, there has been deterioration in river water quality over the last 30 years owing to increased discharge of wastewater resulting from population growth, rapid industrialization, and rapid urbanization [1]. To address this problem, pollutant concentrations have been regulated by implementing emission limits; however, the water quality criteria specified by these emission limits are being exceeded, indicating that water quality management systems that are based on pollutant concentration regulation are limited. In this regard, the Korean government introduced the total maximum daily load (TMDL) strategy, which enables the regulation and management of the total amount of pollutants to overcome the limitations associated with strategies that limit emissions [2].

Specifically, the TMDL strategy was introduced to ensure the improvement of water quality in watersheds by regulating pollutant loads rather than by emission control [3]. For the implementation of this strategy, a TMDL watershed unit is established by combining drainage watersheds and administrative districts based on topography. Thereafter, the target water quality is set considering the watershed at the end of the unit, as well as the current water quality, level of development, and the reduction capacity of the unit watershed. Under the reference flow conditions, the allowable pollutant amount, i.e., the pollutant load that is in compliance with the target water quality, is allocated; thus, mandatory management is performed, such that the expected pollutant emission amount in the corresponding unit watershed does not exceed the pollutant load allocated to it [4]. This makes it possible to preserve public water environments, minimizes disputes between local governments related to water resource use in a given watershed, and promotes environmental equity as well as coexistence in the watershed community [5].

In the United States, during the implementation of the TMDL strategy, the pollutants to be managed and the corresponding criteria for polluted rivers are determined considering the purpose and uniqueness of the waterbody. In Korea, the TMDL strategy has been extensively implemented; however, its implementation is still pending in some areas. Additionally, given that biochemical oxygen demand (BOD) and total phosphorus (TP) are used as water quality indicators in TMDL implementation [6] and because these same indicators are monitored nationwide, it is necessary to investigate whether the effective application of TMDL results in actual improvements in overall water quality.

Korea primarily consists of four basins, namely the Hangang, Nakdonggang, Geumgang, and Yeongsangang or Seomjingang basins. In the Nakdonggang, Geumgang, and Yeongsangang or Seomjingang basins, the mandatory implementation of the TMDL strategy has been in effect since 2004; however, in the Hangang basin, which serves as a major source of drinking water for the Seoul metropolitan area and accounts for 27% of the total area of Korea, an agreement regarding the establishment of target water quality standards could not be reached owing to disagreements between local governments. As such, in 2013, the TMDL strategy was implemented only in some of the unit watersheds in this basin (e.g., Seoul). Despite this, it is expected that the strategy will be implemented in all of the other unit watersheds in this basin by 2021.

The analysis of water quality and time series tendencies serves as an important basic data source for future policy implementation; therefore, studies on tendency analysis have been actively conducted using the Mann–Kendall test and the seasonal Mann–Kendall test. Birsan et al. [7] analyzed Switzerland's seasonal discharge trends from 1930 using the Mann–Kendall test and identified the increased outflow in summer and the effects of climate change. In addition, the Mann–Kendall test and the seasonal Mann–Kendall test were used for the 33-year precipitation trend in the Pieria Region (Greece) by Karpouzos et al. [8]; for the point source pollutants in the Delaware basin (USA), as well as stream water and water quality trends by Kauffman et al. [9]; for water quality parameters selected from Eymir lake (Turkey), as well as volume and precipitation trends by Yenilmez et al. [10]; and for the long-term temporal and spatial variability trends of five water quality indicators in Nakdonggang basin (Korea) by Kim et al. [11]. Specifically, Chang [12] analyzed the water quality in the Hangang basin, while Kim et al. [13] analyzed the effects of policies related to the special water preservation area around Lake Paldang based on the current pollution sources and water quality.

Chang reported that identifying spatiotemporal changes in the water quality of a watershed is important for evaluating the effectiveness of TMDL policies and water resource management strategies [12]; thus, in this study, the spatiotemporal tendencies of water quality in the Hangang basin before and after the implementation of the TMDL strategy were analyzed to evaluate the water quality improvement resulting from the TMDL policy. Further, to identify the characteristics of each unit watershed with respect to the pollution source, the periodicities of water quality indicators were also determined. The purpose of this study is to identify the current water quality status and assist in managing water quality and establishing policies in the future.

2. Data and Methods

2.1. Study Area

The site for this study was the Hangang River basin. It extends from the Taebaeksan Mountain to the outlet of river into the West Sea. It covers 28,645.6 km^2, representing 27%

of the total area of Korea [14], and its river length is 5417 km. Further, its main tributaries, the Bukhangang and Namhangang Rivers, enter Lake Paldang, which is the largest water supply source in Korea, and flow into the West Sea via Seoul, the capital city of Korea. Furthermore, Lake Paldang serves as the major drinking water source for the 25 million inhabitants of Seoul. Additionally, the Hangang basin, including Lake Paldang, is primarily divided into the Bukhangang, Namhangang, Gyeongancheon, Hangang downstream, and Imjingang watersheds, which together consists of 49 unit watersheds. In this study, these 49 unit watersheds, including the Jinwicheon watershed, where large cities are located, were considered. Only the HG-J watershed, which is located at the end of this river basin, was excluded because it is influenced by the tides at the West Sea. As shown in the area demarcated by the red line in Figure 1, except for some unit watersheds in the upstream area of Hangang, the TMDL system has been implemented in 33 out of the 49 unit watersheds in Hangang River basin since June 2013 and since 2012 for the JW_A unit watershed.

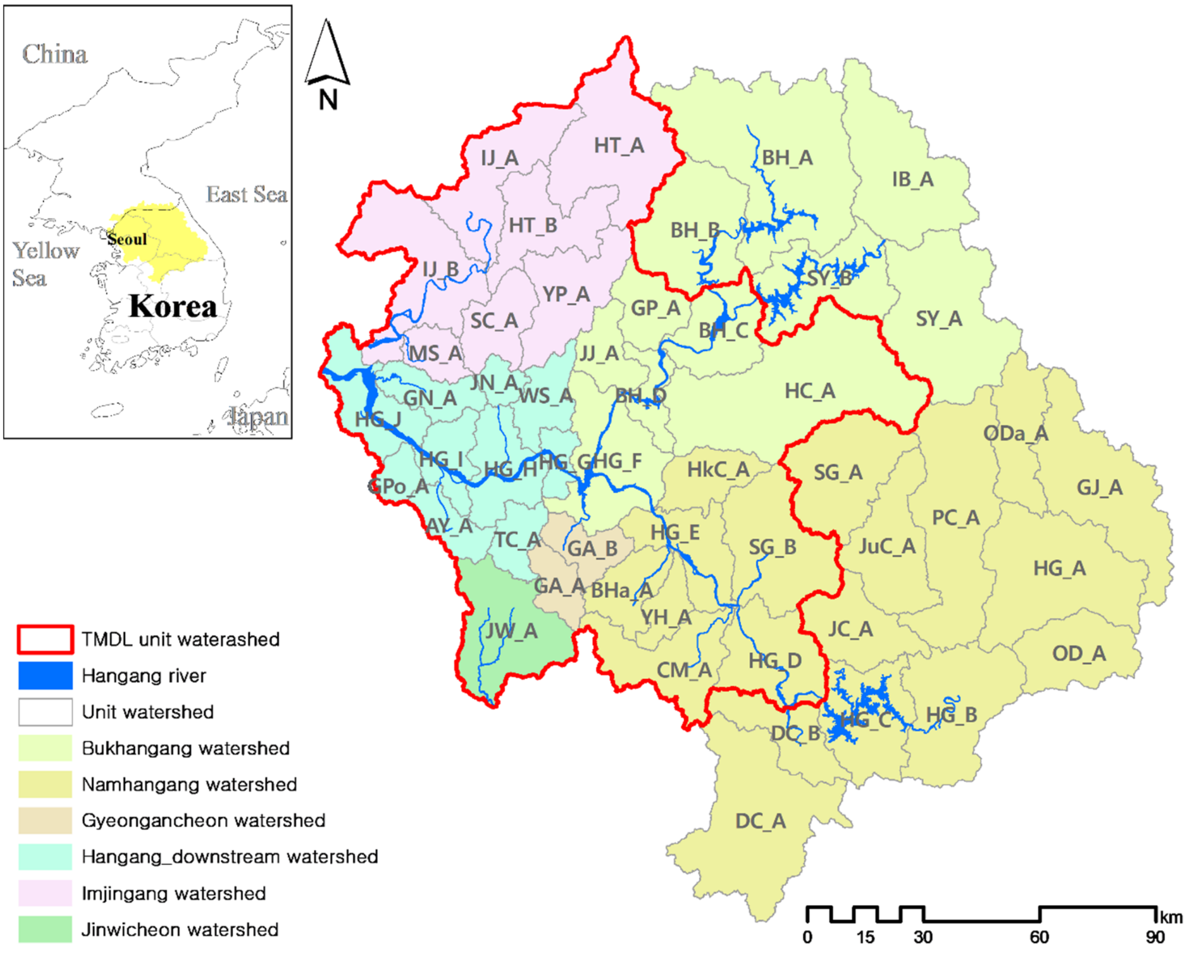

Figure 1. Target area.

From Figure 2, which shows the land-use characteristics corresponding to each watershed, urban and agricultural areas accounted for 76.3% of the total area of this river basin. The JW-A unit watershed exhibited the highest proportion of the used area (53.2%), whereas the CM-A unit watershed showed the highest proportion of the agricultural area (61.2%).

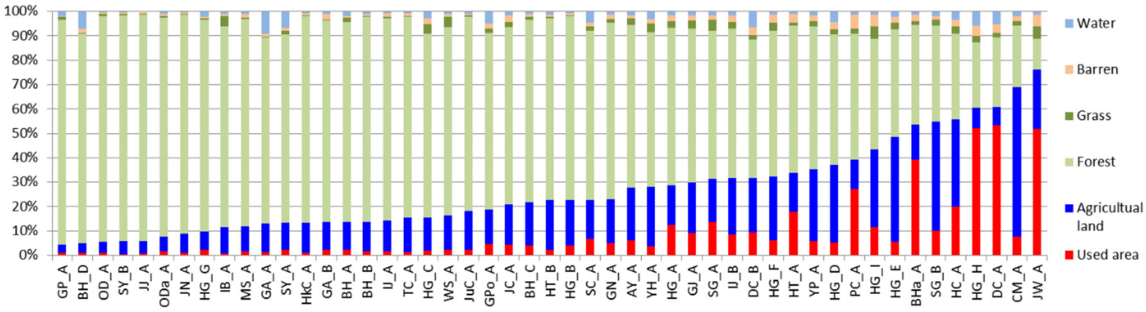

Figure 2. Proportions of land-use type in each watershed unit.

2.2. Statistical Analysis

To perform statistical analysis, R, a language-based analysis software program, was used. After the Mann–Kendall test was first reported by Mann [15] and Kendall [16], Dietz and Killeen [17] proposed a multivariate version of the Mann–Kendall test, which accounts for covariance between variables. The test was improved by Hirsch and Slack [18] to produce the seasonal Mann–Kendall test, which calculates for correlation between seasons. The seasonal Mann–Kendall test is the non-parametric statistical method used for the identification of a tendency using monthly data [19].

The test statistic S_g for g (season) = 1, 2, . . . , p is calculated as follows:

$$S_g = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} sgn(x_{jg} - x_{ig})$$

The Kendall rank correlation coefficient (Kendall's tau) is computed as:

$$\tau = \frac{S_g}{n(n-1)/2}$$

where x_i and x_j are the data values at times i and j, n is the length of the data, and p the number of seasons in a year. The distribution of S_g is asymptotically normal with null mean and variance as:

$$\sigma^2 = \frac{n(n-1)(2n+5)}{18}$$

The variable S' is derived as the sum of the single seasonal statistics:

$$S' = \sum_{g=1}^{p} S_g$$

Hirsch et al. (1982) derived its expected and approximated variance:

$$E[S'] = 0$$

$$var[S'] \cong \sum_{g=1}^{p} \sigma_g^2$$

the seasonal statistic S is standardized and compared with a standard normal distribution at the required significance level [20]. When $p > 0.05$ showed validity with respect to the significance level ($\alpha = 0.05$) and 95% confidence level on both sides, the null hypothesis that there is no tendency was accepted. Conversely, when $p < 0.05$ showed validity, the null hypothesis was rejected and the alternative hypothesis that a tendency exists was accepted [21].

The autocorrelation function (ACF) is an important tool in the analysis of time series data [22]. The autocorrelation reflects the degree of correlation between different values of the same variable at different times. It was used to examine the randomness or periodicity of the data [23]. The ACF at lag k is as follows:

$$\rho_k = \frac{\sum_{t=1}^{N-k} (X_t - \overline{X})(X_{t+k} - \overline{X})}{\sum_{t=1}^{N} (X_t - \overline{X})^2}$$

Autocorrelation plots (correlograms), which are graphical representations of autocorrelation, were drawn with the autocorrelation coefficient on the vertical axis and the lag value on the horizontal axis. Notably, in a correlation, autocorrelation at each lag is expressed as the upper and lower limits based on the confidence interval, while ACFs that exceed the limits indicate autocorrelation at the given lag and significance level [24–26].

2.3. Water Quality Data

Weekly water quality data for the period 2008–2018 (11 years) corresponding to 49 unit watersheds in the Hangang River basin from the Water Environment Information System [27] were used for analysis in this study basin (some data corresponding to the winter season were excluded). These data consisted of five water quality indicators (BOD, chemical oxygen demand (COD), suspended solids (SS), total nitrogen (TN), and TP). The average number of data points for each unit watershed was 475, except for the JW-A unit, for which there were 259.

3. Results and Discussion

3.1. Water Quality in Each Unit Watershed

The water quality status for each unit basin is as shown in Figure 3. The SY-B unit, located in the upstream area of the Bukhangang watershed, showed the lowest median BOD value (0.3 mg/L), while the SC-A unit, located in the Imjingang watershed, showed the highest value (10.6 mg/L). Additionally, the SY-B unit showed the lowest TP and SS values (0.008 and 1.2 mg/L, respectively), while the SC_A unit showed the highest COD value (12.7 mg/L). The OD-A unit, located in the upstream area of the Namhangang watershed, showed the lowest COD value (0.949 mg/L), while the lowest TN value (0.948 mg/L) was observed at the IJ-A unit, located in the Imjingang watershed. The highest TN value (12.680 mg/L) was observed at the AY_A unit, which is located in the Hangang downstream watershed. In particular, the MS_A and GPo_A units exhibited very high SS and TP concentrations compared with the other units. It was found that the high SS value observed at the MS-A unit resulted from the reverse flow of turbid water from the West Sea and the downstream area of Hangang owing to the tides. The GPo_A unit exhibited water quality characteristics that were different from those common to rivers. This could be attributed to the presence of stagnant waters owing to the nature of the river in this unit.

When all the five water quality indicators were considered, as shown in Figures 3 and 4, the JW_A unit exhibited the highest concentrations for all of these indicators, followed by the GPo_A, SC_A, AY_A, and GN_A units. This observation could be explained by the fact that JW_A has the highest proportion of used and agricultural areas (76.3%) among all of the unit watershed shown in Figure 2. Further, a number of sewage treatment plants, factory sites, and agricultural lands are distributed in this unit. Industrial complexes are located in the SC_A unit, while in the AY_A unit, which harbors large cities, several sewage treatment plants are present. Further, in the GN_A unit, a number of sewage treatment plants are present (e.g., the Paju Geumchon Sewage Treatment Plant).

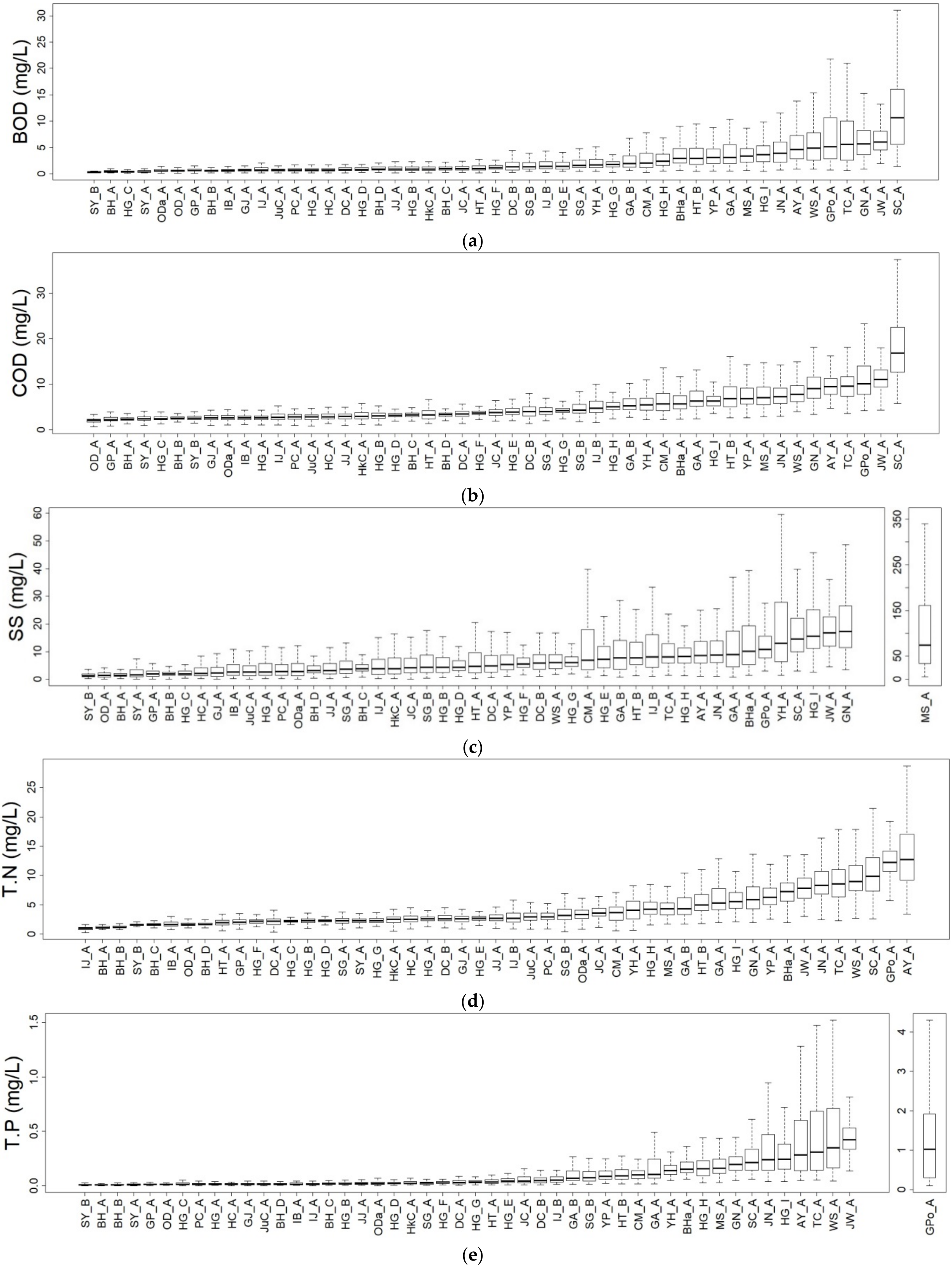

Figure 3. Boxplots corresponding to the different watershed units: (**a**) BOD; (**b**) COD; (**c**) SS; (**d**) TN; (**e**) TP.

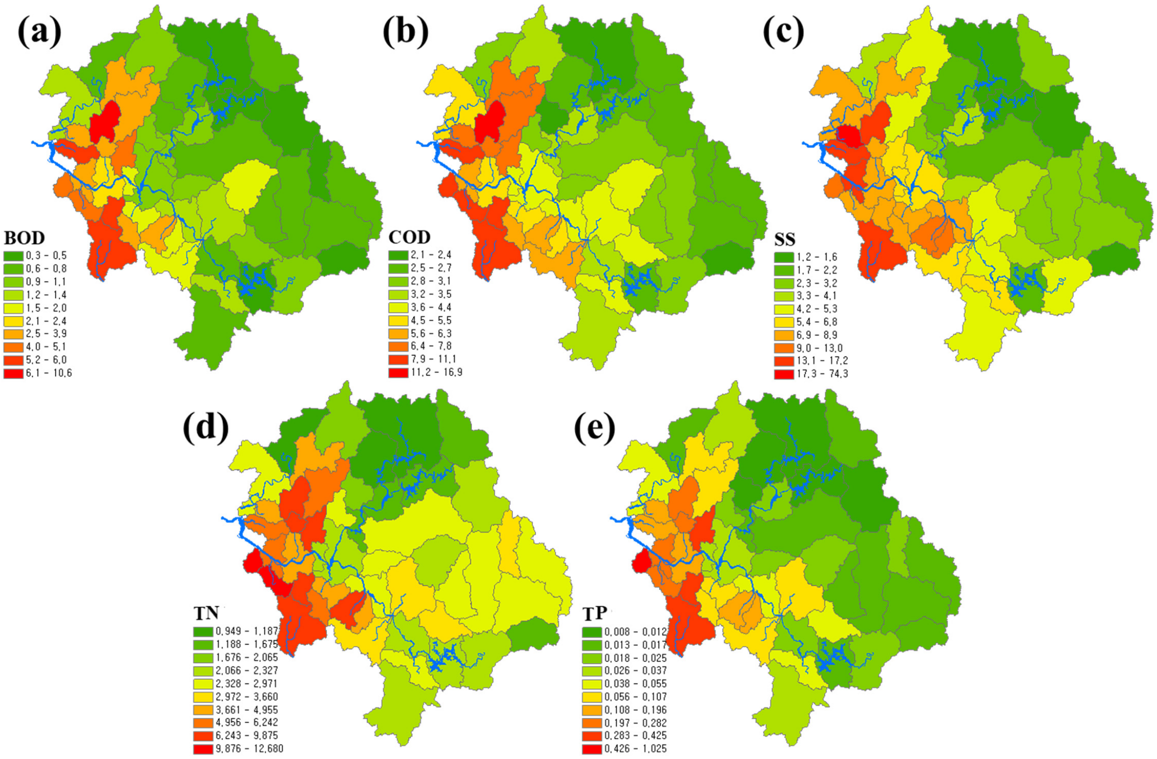

Figure 4. Median water quality indicator values for each watershed unit: (**a**) BOD; (**b**) COD; (**c**) SS; (**d**) TN; (**e**) TP.

The upstream areas of the Bukhangang and Namhangang watersheds showed low concentrations for the considered water quality indicators, while the region between the downstream area of the Namhangang watershed to the Imjingang watershed, along with the Hangang downstream and Jinwicheon watersheds, showed high concentrations. In most of these areas, TMDL was implemented, while Figure 5 shows the attainment of the target water quality in each watershed unit considering the existing emission loads. Additionally, distributions similar to the current status of the water quality were observed, given that the existing loads were considered.

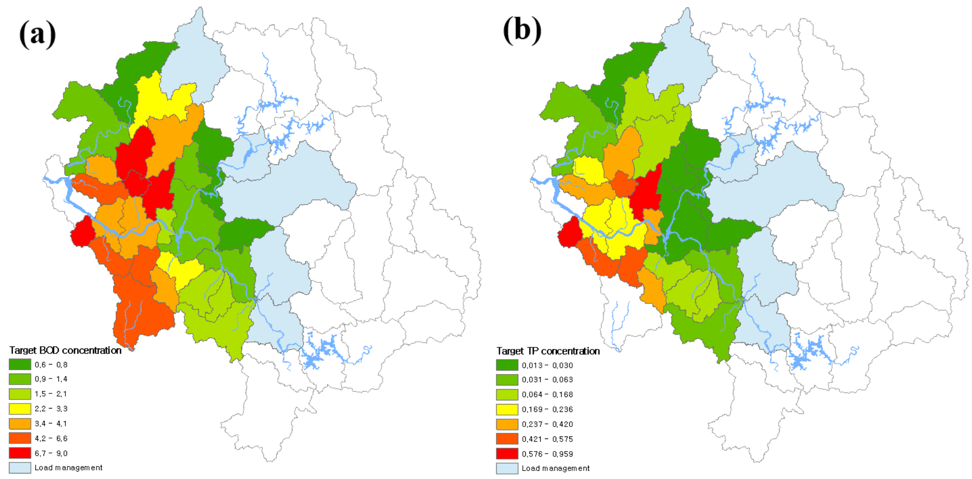

Figure 5. TMDL target water quality: (**a**) BOD; (**b**) TP.

3.2. *Tendency Analysis Results*

The results of the tendency analysis performed using the seasonal Mann–Kendall's test are shown in Figures 6 and 7 (Appendix A, Table A1). Specifically, Figure 6 shows the water quality trends within 2008–2018, while Figure 7 shows the increasing and decreasing trends from 2013 onward, when TMDL was implemented, to 2018; thus, it was observed that BOD, a TMDL management index, decreased and increased by 41 and two units, respectively, and exhibited no tendency in six watershed units within the 2008–2018 period. Further, from 2013 onward, BOD decreased, increased, and showed no tendency in 31, 3, and 9 unit watersheds, respectively. Overall, the BOD concentrations decreased in most of the watersheds, although showed an increasing trend in the SY_B and BH_A units, where TMDL was not implemented from 2008 onward, as well as in the HG_C unit, where TMDL was not implemented until 2013. The SY_B, BH_A, and HG_C units exhibited the lowest BOD concentrations among all of the unit watersheds. Furthermore, it appeared that they responded to even slight increases in pollutant concentrations, and considering datasets from the two periods, TP showed a tendency to increase in the SY_B, BH_A, BH_B, HG_C, and HG_D units. In the BH_C and BH_D units, it showed a tendency to increase after 2013. Additionally, it was observed that low TP concentrations appeared immediately after phosphorus treatment facilities were installed at the sewage treatment plants in these areas from the end of 2011 [28]. TP concentrations decreased in 20 units from 2008 onward, showing a tendency to decrease in 11 units from 2013 onward. In most of the units where a decrease was observed, TMDL had been implemented. Additionally, TMDL had been implemented in all of the units that exhibited a decrease in TP from 2013 onward.

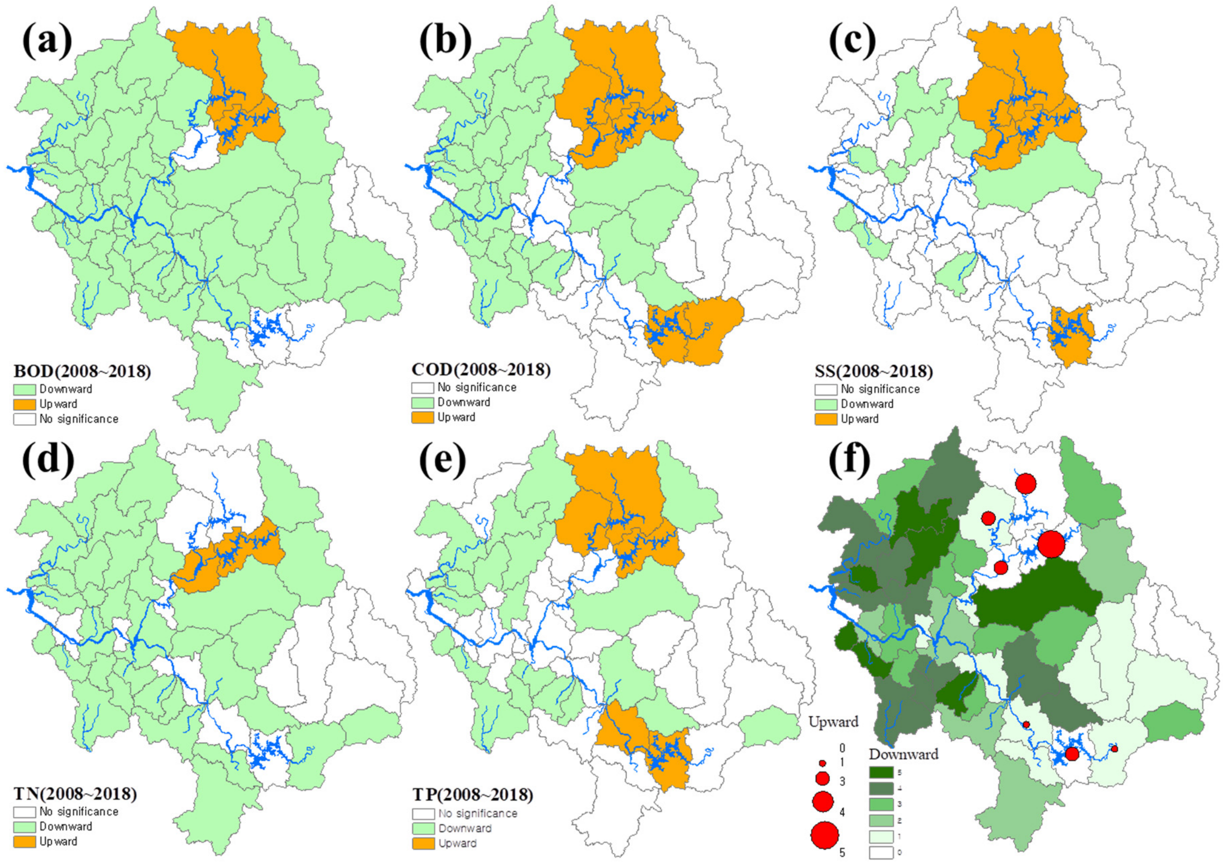

Figure 6. Water quality indicator trend analysis for each watershed unit within the 2008–2018 period: (**a**) BOD; (**b**) COD; (**c**) SS; (**d**) TN; (**e**) TP. (**f**) Numbers of water quality indicators that showed increased and decreased trends.

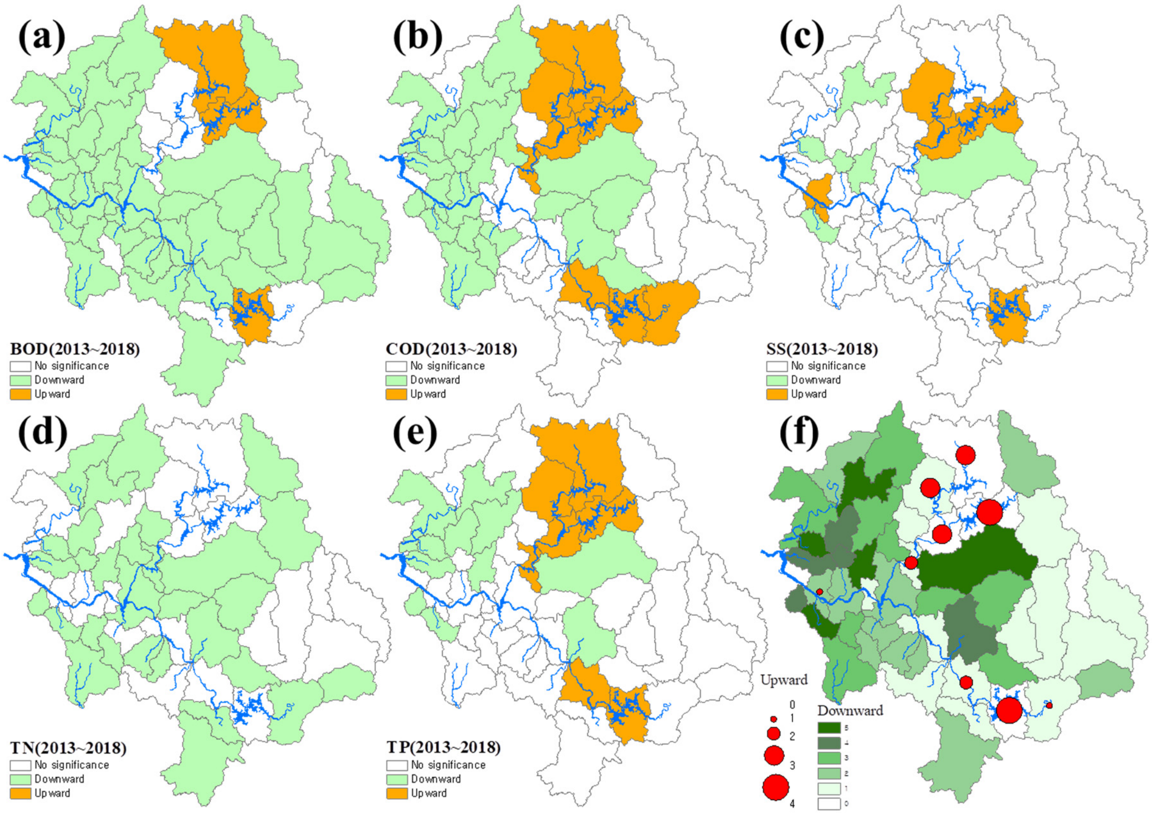

Figure 7. Water quality indicator trend analysis for each watershed unit within the 2013–2018 period: (**a**) BOD; (**b**) COD; (**c**) SS; (**d**) TN; (**e**) TP. (**f**) Numbers of watershed units that showed downward and upward trends.

COD, which is not a typical TMDL management index, showed a tendency to increase in the upstream areas of the Bukhangang and Namhangang dams. After 2013, it also showed a tendency to increase in the downstream units. SS showed no tendency in most of the watersheds; however, in the upstream areas of the Bukhangang and Namhangang dams and in the HG_I unit after 2013, it showed a tendency to increase. Additionally, TN showed a tendency to increase in the SY_B and BH_C units after 2008 but decreased or showed no tendency in all unit watersheds after 2013.

When the five water quality indicators were considered, it was observed that most of them showed a decreasing tendency in the unit watersheds where TMDL had been implemented from 2008 onward. Further, a comparison of the periods after 2008 and 2013 showed that no unit exhibited any increasing or decreasing tendencies before TMDL implementation; however, after 2013, when TMDL was actually implemented, the concentrations of the water quality indicators increased in the BH_C, BH_D, and HG_D units. This was because in these areas, water was stagnant in the upstream areas of the dams; thus, it appeared that the management of water quality indicators, including BOD, is required. Among the watersheds where TMDL had not yet been implemented, the Bukhangang upstream watershed showed an increasing trend in the concentrations of the water quality indicators; however, given that the concentrations of the water quality indicators were low, it appeared that discussion with the local government is required when TMDL is actually implemented from 2021 onward.

3.3. Periodicity Analysis Results

The periodicities of water quality indicators in the unit watersheds where TMDL had been implemented were analyzed using autocorrelation analysis. This enabled the identification of major pollution sources and tendencies according to the characteristics of the pollution sources. In Korea, 50–60% of annual rainfall is concentrated in summer owing to the influence of the monsoon climate [29]; therefore, we reasoned that the seasonal periodicity of the water quality would be evident when the influence of nonpoint sources was significant. Figure 8 shows the autocorrelation plot and spatial distribution of the different water quality indicators for each unit. Given that weekly water quality data were used, seasonal periodicity could be confirmed when the ACF was above the 95% confidence interval (blue dotted lines) for a period of 52 weeks (i.e., one year).

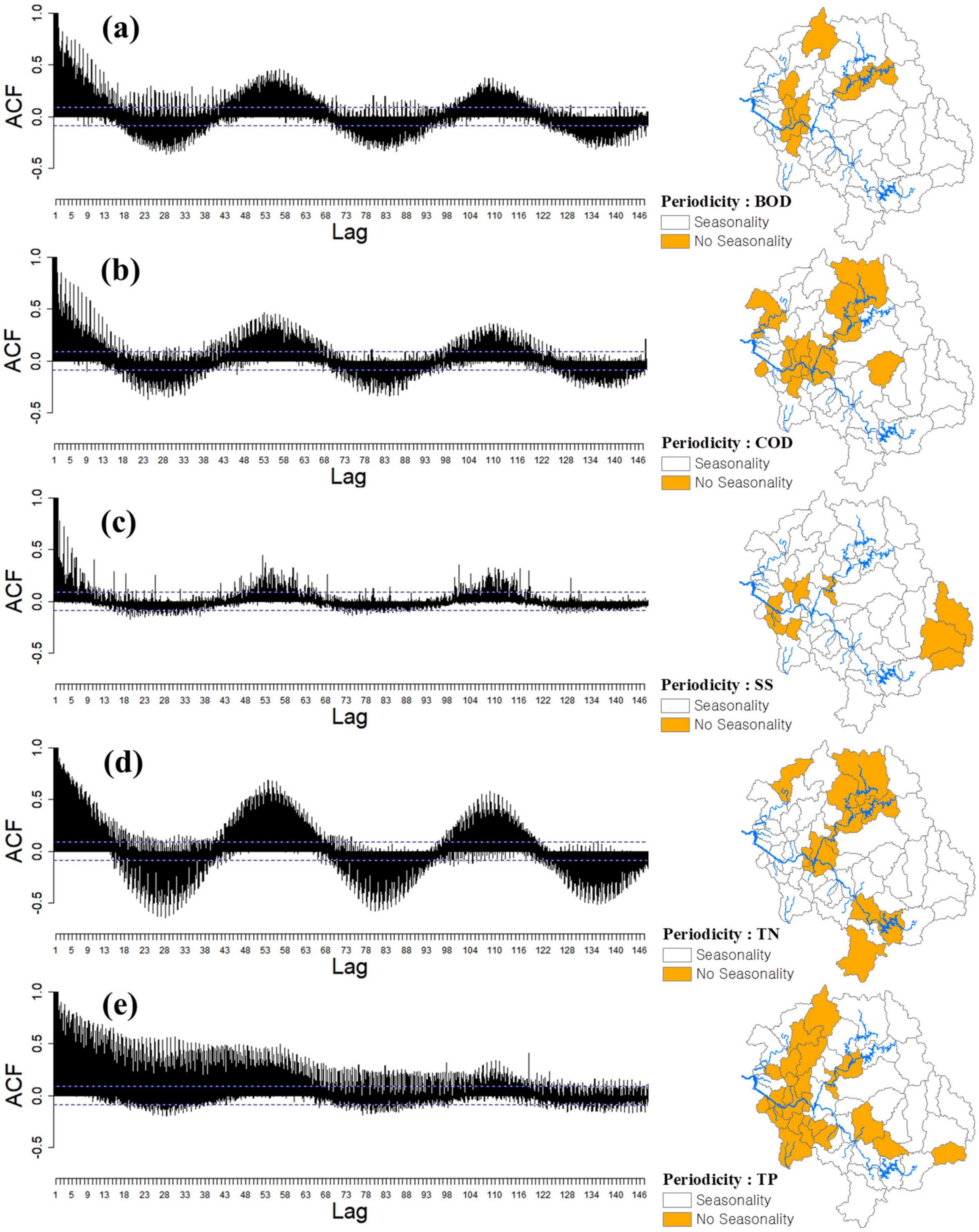

Figure 8. Autocorrelation plot and spatial distribution status: (**a**) BOD; (**b**) COD; (**c**) SS; (**d**) TN; (**e**) TP.

The five water quality indicators exhibited different periodicities in the different unit watersheds. While BOD, COD, TN, and SS showed seasonal periodicity in most of the units, TP did not exhibit season periodicity in 22 units. It was also observed that one or more water quality indicators did not show seasonal periodicity in 34 units, while four or more indicators did not show periodicity in six units (i.e., the BH_C, BH_D, WS_A, JN_A, TC_A, and HG_C units).

BOD and TP did not show seasonality in nine and 22 units, respectively. Additionally, among the nine units that did not show seasonal periodicity with respect to BOD, six, including the Hangang downstream and Sincheon units, as well as the BH_C unit, contain sewage treatment plants, while the HT_A unit has livestock wastewater as its major pollution source. Among the unit watersheds where TMDL had not been implemented, only the SY_B unit contains manure and public sewage treatment facilities. Further, TP did not show seasonal periodicity in 22 units, including eight units that predominantly consist of urban areas, except for the SY_B unit. It also appeared that the OD_A unit, located in the upstream area of Namhangang dam, is influenced by alpine fields. Furthermore, COD did not show seasonal periodicity in six units that consist of urban areas, where no BOD periodicity was observed, and in seven units that did not show typical river characteristics, such as the Gpo_A unit, or that included dam-like structures. SS showed no periodicity in alpine fields and in some urban areas in the upstream area of the Namhangang River. It was also observed that TN did not show seasonal periodicity because the nitrogen source in the Bukhangang watershed originated from soil organic matter [30].

Most of the watershed units that did not show seasonal periodicity corresponded to areas where TMDL had been implemented; these areas exhibited a decreasing trend in the concentrations of water quality indicators based on 2008 and 2013 data. It was also observed that TMDL contributed to the continuous management of point pollution sources, e.g., the installation of advanced treatment facilities at sewage treatment plants, and given that these watershed units are still influenced by several factors, including nonpoint source pollution owing to rainfall, it is necessary to accurately identify the associated causes and develop mitigation measures.

The BH_C and BH_D units, which exhibited lower water quality concentrations than the other watershed units, as well as the watershed units that showed no seasonal periodicity in the upstream area of Bukhangang, where TMDL had not been implemented, exhibited an increasing tendency from 2008 onward. In particular, the BH_C and BH_D units exhibited increases in TP after TMDL implementation, indicating that effective improvement is still possible if the influencing factors are identified, including nonpoint sources owing to rainfall.

Among the units that showed seasonal periodicity, e.g., the HG_B, HG_C, and HG_D units, it would be necessary to first of all consider the management of nonpoint source pollution owing to rainfall when TMDL is implemented in the future.

4. Conclusions

In this study, we performed the spatiotemporal analysis of water quality tendencies before and after TMDL implementation to clarify the effects of the TMDL policy on the unit watersheds in the Hangang basin, which serves as an important drinking water source in South Korea. The periodicities of water quality indicators were also analyzed and the characteristics of each unit watershed were also identified in terms of pollution sources to clarify the direction of water quality tendencies with respect to the implementation of TMDL. When all five indicators, including BOD and TP, which are typical TMDL management indices, were analyzed using weekly water quality data corresponding to the 2008–2018 period, it was observed that the concentrations of these water quality indicators were low in the upstream areas of the Bukhangang and Namhangang watersheds; however, they were high in the downstream areas of the Namhangang and Imjingang watersheds and in the Hangang downstream and Jinwicheon watersheds. Additionally, the units that exhibited high water quality were those in which TMDL had been implemented. Most of these watershed units showed decreased water quality indicators in the period after TMDL implementation; however, in some of these units (upstream areas of the

Bukhangang and Namhangang watersheds) where the concentrations of water quality indicators were already low, increasing tendencies were observed. Based on periodicity analysis results, these increasing tendencies could be attributed to the influence of nonpoint source pollution owing to rainfall. Further, even though differences existed between the watershed units with respect to the different water quality indicators, watershed units that showed decreasing trends in these indicators were characterized by high water quality; therefore, to ensure the effective implementation of TMDL in the future, additional research based on pollution source data is needed, such as land, society, and industry and various policy data.

The trend and periodicity results for the Hangang basin derived from this study can contribute to water quality management policies, such as the TMDL strategy and water quality evaluation processes.

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Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

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

Appendix A

Table A1. Kendall's tau values for 49 unit watersheds in the Hangang basin.

Name	2008~2018						2013~2018					
	n	BOD	COD	TN	TP	SS	*n*	BOD	COD	TN	TP	SS
GP_A	468	−0.226 *	−0.013	−0.39 *	−0.097	−0.153 *	240	−0.131	0.031	−0.37 *	−0.024	−0.146
GA_A	487	−0.178 *	−0.254 *	−0.249 *	−0.171 *	−0.037	243	−0.107	−0.176 *	−0.224 *	−0.156	−0.017
GA_B	536	−0.261 *	−0.289 *	−0.206 *	−0.169 *	0.038	291	−0.21 *	−0.204 *	−0.153	−0.152	0.037
GJ_A	469	−0.1	0.106	−0.049	0.097	0.048	240	−0.209 *	0.089	−0.03	0.132	0.054
GN_A	467	−0.289 *	−0.282 *	−0.264 *	−0.319 *	−0.033	239	−0.165 *	−0.171 *	−0.207 *	−0.297 *	0.024
GPo_A	467	−0.257 *	−0.301 *	−0.255 *	−0.153 *	−0.132 *	239	−0.166 *	−0.282 *	−0.216 *	−0.177 *	0.071
DC_A	468	−0.294 *	0.008	−0.236 *	0.06	−0.003	239	−0.275 *	0.063	−0.259 *	0.078	0
DC_B	466	−0.1	−0.052	−0.247 *	−0.034	−0.004	237	−0.026	0.044	−0.257 *	0.077	0.027
MS_A	470	−0.34 *	−0.427 *	−0.247 *	−0.311 *	−0.355 *	240	−0.251 *	−0.353 *	−0.213 *	−0.229 *	−0.214 *
BHa_A	468	−0.262 *	−0.199 *	−0.191 *	−0.127 *	−0.163 *	239	−0.182 *	−0.156	−0.203 *	−0.048	−0.113
BH_A	469	0.12 *	0.251 *	0.109	0.186 *	0.137 *	240	0.169 *	0.377 *	0.053	0.232 *	0.053
BH_B	468	−0.122 *	0.173 *	0.029	0.216 *	0.21 *	239	−0.009	0.303 *	−0.066	0.215 *	0.239 *
BH_C	465	−0.06	0.215 *	0.144 *	0.096	0.181 *	237	0.076	0.399 *	0.064	0.288 *	0.204 *
BH_D	467	−0.172 *	0.085	−0.07	0.038	0.066	239	−0.038	0.257 *	−0.17 *	0.215 *	0.127
SG_A	467	−0.344 *	−0.282 *	−0.206 *	−0.087	−0.064	239	−0.321 *	−0.313 *	−0.181 *	−0.093	−0.07
SG_B	542	−0.394 *	−0.36 *	−0.255 *	−0.223 *	−0.111	304	−0.386 *	−0.331 *	−0.208 *	−0.327 *	−0.112
SY_A	469	−0.161 *	0.079	−0.228 *	0.024	−0.031	240	−0.16	0.041	−0.199 *	0.046	0.024
SY_B	542	0.14 *	0.266 *	0.191 *	0.309 *	0.301 *	304	0.204 *	0.267 *	0.083	0.336 *	0.293 *
SC_A	467	−0.29 *	−0.342 *	−0.296 *	−0.209 *	−0.056	239	−0.312 *	−0.347 *	−0.277 *	−0.29 *	−0.094
AY_A	467	−0.315 *	−0.436 *	−0.358 *	−0.14 *	−0.167 *	239	−0.329 *	−0.533 *	−0.364 *	−0.299 *	−0.255 *
YH_A	468	−0.258 *	−0.112	−0.139 *	−0.117 *	−0.063	239	−0.249 *	−0.088	−0.164 *	−0.018	−0.047
YP_A	468	−0.342 *	−0.355 *	−0.146 *	−0.3 *	−0.168 *	239	−0.298 *	−0.31 *	−0.072	−0.317 *	−0.146

Table A1. *Cont.*

Name	2008~2018						2013~2018					
	n	BOD	COD	TN	TP	SS	*n*	BOD	COD	TN	TP	SS
ODa_A	469	−0.059	0.068	0.055	0.004	−0.022	240	−0.11	0.051	0.074	0.103	0.065
OD_A	468	−0.207 *	0.032	−0.267 *	−0.169 *	−0.046	239	−0.19 *	0.006	−0.174 *	−0.142	−0.024
WS_A	467	−0.227 *	−0.348 *	−0.313 *	−0.137 *	−0.112	239	−0.329 *	−0.425 *	−0.29 *	−0.271 *	−0.172 *
IB_A	469	−0.262 *	−0.036	−0.39 *	−0.126 *	−0.068	240	−0.284 *	−0.06	−0.432 *	−0.077	−0.042
IJ_A	462	−0.273 *	−0.127 *	−0.206 *	−0.045	−0.05	233	−0.347 *	−0.154	−0.21 *	−0.081	−0.079
IJ_B	455	−0.261 *	−0.309 *	−0.161 *	−0.215 *	0.003	232	−0.308 *	−0.404 *	−0.151	−0.175 *	−0.042
JC_A	470	−0.328 *	−0.286 *	−0.212 *	−0.21 *	−0.071	241	−0.391 *	−0.28 *	−0.243 *	−0.114	−0.07
JJ_A	468	−0.278 *	−0.187 *	−0.261 *	−0.052	−0.039	240	−0.263 *	−0.173 *	−0.169 *	0.032	−0.015
JuC_A	469	−0.239 *	−0.045	−0.081	0.018	−0.039	240	−0.306 *	−0.086	−0.042	0.042	−0.05
JN_A	467	−0.317 *	−0.417 *	−0.201 *	−0.07	−0.135 *	239	−0.397 *	−0.488 *	−0.167 *	−0.05	−0.188 *
JW_A	259	−0.372 *	−0.316 *	−0.277 *	−0.178 *	−0.027	235	−0.386 *	−0.352 *	−0.278 *	−0.155	−0.034
CM_A	461	−0.253 *	−0.112	−0.128 *	−0.037	0.013	233	−0.199 *	−0.065	−0.118	0.029	0.016
TC_A	467	−0.166 *	−0.235 *	−0.341 *	−0.085	−0.037	239	−0.2 *	−0.278 *	−0.34 *	−0.113	−0.083
PC_A	468	−0.286 *	−0.087	−0.107	−0.021	−0.048	239	−0.284 *	−0.086	−0.059	−0.022	−0.037
HG_A	469	−0.258 *	0.005	−0.061	0.027	−0.017	240	−0.283 *	0.005	−0.013	0.108	0.025
HG_B	468	−0.015	0.263 *	−0.379 *	−0.046	−0.113	239	0.021	0.307 *	−0.349 *	0.025	−0.046
HG_C	469	0.084	0.159 *	0.059	0.286 *	0.284 *	240	0.209 *	0.162 *	0.1	0.319 *	0.267 *
HG_D	468	−0.368 *	0.07	−0.039	0.128 *	0.005	239	−0.307 *	0.192 *	−0.028	0.195 *	−0.044
HG_E	531	−0.308 *	−0.095	−0.101	−0.004	−0.115	294	−0.224 *	−0.045	−0.095	0.051	−0.112
HG_F	468	−0.44 *	−0.111	−0.152 *	0.029	−0.065	240	−0.415 *	0.03	−0.203 *	0.094	−0.012
HG_G	466	−0.288 *	−0.058	−0.09	0.027	−0.008	238	−0.197 *	0.06	−0.084	0.081	0.08
HG_H	540	−0.388 *	−0.309 *	−0.132 *	−0.083	−0.036	304	−0.396 *	−0.24 *	−0.083	−0.062	0.105
HG_I	467	−0.362 *	−0.391 *	−0.092	−0.048	0.044	239	−0.267 *	−0.316 *	−0.005	0.004	0.159 *
HT_A	467	−0.33 *	−0.254 *	−0.243 *	−0.179 *	−0.102	238	−0.386 *	−0.276 *	−0.186 *	−0.155	−0.121
HT_B	466	−0.403 *	−0.378 *	−0.269 *	−0.289 *	−0.215 *	237	−0.396 *	−0.378 *	−0.213 *	−0.326 *	−0.185 *
HC_A	455	−0.451 *	−0.33 *	−0.3 *	−0.161 *	−0.218 *	235	−0.475 *	−0.317 *	−0.207 *	−0.205 *	−0.303 *
HkC_A	468	−0.342 *	−0.193 *	−0.302 *	−0.087	0.023	239	−0.354 *	−0.17 *	−0.235 *	−0.074	0.014

* significant at 95% confidence level.

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