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Analysis of diverse methods of water quality evaluation according to practical application

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ABSTRACT

The South Korean government has developed various policies and systems with the aim of improving water quality and restoring the health of aquatic ecosystems. Evaluation of whether a target water quality has been achieved may produce different results depending on the systems and policies used, which can undermine the reliability of the results. This study aimed to identify a scientific and systematic water quality evaluation method to enable the government to implement rational policies and systems. We used data from the "Youngbon A" location to evaluate target water quality according to the total maximum daily load of pollutants in the Youngsan River watershed, and applied existing and new evaluation methods to verify the validity of each method and identify the optimal choice. We found that different evaluation methods produced different results in terms of meeting the target water quality. For the point of "Youngbon A", manifesting great fluctuation in the level of water quality due to increasing inflow of pollutants, the level of water quality evaluation, calculated by removing part of the upper outlying values of water quality attributable to increased inflow of pollutants, was derived as reasonable measurement.

Keywords: Youngsan River basin; Water quality evaluation; Total maximum daily load; Water management policy

1. Introduction

Industrialization and urbanization accompanying economic growth have resulted in a dramatic increase in the production of various pollutants which affect adjacent rivers, including domestic sewage, industrial wastewater, livestock wastewater, and landfill leachate, as well as an increase in the area of the impermeable layer brought about by direct discharge without filtration, worsening river water quality, and declining health of aquatic ecosystems. For this reason, the South Korean government has introduced and developed various policies and systems to improve water quality and restore the health of aquatic ecosystems.

The water quality control of Korea is generally focused on achieving goals set to complete certain levels to have cleaner water by implementing systems and policies. A constant monitoring system gauges the performance level to adjust the policies enabling a flexible management.

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Apart from the concerted efforts, the feedbacks and opinions on a system or policy are often inconsistent and vary depending on each person's perspectives undermining the reliability.

Whether or not the target water quality has been met may be assessed differently depending on differences in the evaluation methods used, even if monitoring is conducted on the same river or specific point in the river, which means that the evaluation results may vary depending on the criteria used. Such discrepancies often cause confusion in implementation of various types of plans including plans for reducing pollution.

As a prior study on methods of evaluation of water quality, the Han River Water System Management Committee [1] conducted the study on allocation of pollution load to accomplish and keep target water quality complying with the total maximum daily load (TMDL) [2], wherein the mean level of water quality for 3 y was analyzed together with distinguishing the measurements of flow rate, obtained on every 8th days by Ministry of Environment, into those of days of excess percentage to calculate the mean concentration of biochemical oxygen demand (BOD) in unit watershed to suggest the method of evaluation of water quality through comparing target levels of water quality in each watershed.

Also, a study by Park et al. [3] endeavored to identify a standardized evaluation method for effluent water quality depending on type of water quality data through improvements in statistical methods of evaluating the effluent water quality of basic environmental facilities to measure TMDL.

Adimalla and Taloor [4] used a total of 194 groundwater samples collected from hard, rocky terrain in Medak, a rapidly urbanizing region of Telangana State, South India, to assess groundwater quality using geographic information system (GIS) and groundwater quality index (GWQI) techniques. Groundwater quality in the Medak region is fettered by geogenic and anthropogenic activities; therefore, people in the region are advised to maintain a groundwater management strategy to protect future sustainability.

When a state determines various environmental policies, it is necessary to precisely define the target water quality level and to verify the validity of that level, which involves, for example, identifying the underlying causes of pollution. Thus, it is necessary for a method of evaluating whether the target water quality has been met to reflect regional characteristics such as the policies and systems that are currently in place, to establish subsequent standards, and to apply rational and scientific methods to minimize confusion pursuant to implementing efficient management protocols for the aquatic environment. The assessment on government policies implemented to control the level of water quality requires the continuous monitoring and identification of characteristics of points selected for the evaluation of water quality, for which the methods of evaluation of water quality reflecting characteristics of the point properly needs to be applied.

This study used data measured at "Youngbon A", a measurement point for target water quality for the TMDL [1] of the Youngsan River watershed, and applied existing and new evaluation methods to verify the validity of each method and identify the optimal method. Additionally, we surveyed and analyzed various water evaluation methods, assessed the application status of each method, and evaluated its advantages and disadvantages to identify an evaluation method appropriate to the characteristics of the Youngbon A unit watershed in consideration of its flow rate, water quality, and river characteristics. Water quality of Youngsan River varies depending on non-point pollution sources of the small- and medium-sized urban areas as well as pollution sources of metropolitan area from its origin to the sea, for which the assessment of policies implemented to control water quality is important. The point of "Youngbon A", selected for the present study to evaluate the level of water quality of Youngsan River, was found with the water quality degraded further in 2015 comparing to that of 2010, wherein the evaluations resulted from the arithmetic- and converted means exceeded the target level of water quality (2.1 mg/L).

The present study intended to derive reasonable methods of evaluation of the level of water quality of Youngsan River by taking the accounts of flow rate, water quality, characteristics of river, etc., for which the conventional and new methods of evaluation will be applied to the corresponding point by employing the analysis and evaluation of measurements collected at the unit area of "Youngbon A" of the total water pollution load management system, selected to appraise the level of water quality of Youngsan River. Besides, the merits and demerits of the methods of evaluation of the level of water quality will be appraised to identify the methods of evaluation of water quality pertinent to the point of "Youngbon A".

2. Study method and basic data analysis

2.1. Study method

We conducted a survey and analysis of previous water quality evaluation methods and fixed the direction of this study through this survey and analysis and respective theoretic reviews of these methods.

To analyze the water quality evaluation methods, this study reviewed the application of the existing water quality evaluation methods, including arithmetic mean, natural logarithmic converted value, linear interpolation, load duration curve (LDC), and observed LDC. Basic data analysis was used in this endeavor, including flow rate and water quality survey, flow rate and water quality trend analysis, frequency analysis, and peculiar feature analysis. We also examined the application of new evaluation methods, such as percentiles, exclusion of upper and lower sections, and hydrological condition-specific evaluations.

Additionally, this study applied various water evaluation methods and used long-term monitoring data from Youngbon A, a measurement point for target water quality for the TMDL of the Youngsan River watershed, to compare the advantages and disadvantages of the existing and new evaluation methods and to verify their validity. Additionally, the results of the applied water quality evaluation methods were used to analyze the advantages and disadvantages of each method. We discuss methods of evaluating water quality considering regional characteristics and review matters related to various policies and systems for water quality management. A cap-and-trade water pollution system, one of the Korean water management plans, evaluates whether target waters meet the standards in terms of BOD (for organic matter management) and T-P (for eutrophication in rivers) levels.

Fig. 1 shows the Youngbon A unit watershed, the targeted area in the Youngsan River watershed.

2.2. Water quality evaluation methods

2.2.1. Arithmetic mean

To evaluate water quality, we used data measured by the monitoring network managed by the Ministry of Environment to calculate the annual arithmetic mean using Eq. (1) [5,6].

$$\text{Mean water quality} = \frac{\text{annual}\begin{pmatrix}\text{measured water quality} + \\ \text{measured water quality} + \ldots\end{pmatrix}}{\text{frequency of annual measurements}} \tag{1}$$

2.2.2. Natural logarithmic converted value

This study established the water quality concentration predicted when pollutant emissions are reduced by a level technically and economically possible under mean low water level (LWL) or abundant water level (AWL) conditions over 10 y to assess target water quality using the TMDL. We also used data measured at 8 d intervals more than 30 times yearly over 3 y as the logarithmic mean water quality values. The water quality value was converted into a logarithmic value to obtain the average value for log normal distribution, and was then converted into an exponential function, as shown in Eqs. (2)–(4).

$$\text{Mean water quality} = e\left(\begin{matrix}\text{converted mean water quality} + \\ \dfrac{\text{converted variance}}{2}\end{matrix}\right) \tag{2}$$

$$\text{Converted mean water quality} = \frac{\begin{matrix}1n\left(\text{measured water quality}\right) + \\ 1n\left(\text{measured water quality}\right) + \ldots\end{matrix}}{\text{frequency of measurements}} \tag{3}$$

$$\text{Converted variance} = \frac{\begin{matrix}1n\left(\text{measured water quality}\right) - \\ \left(\text{converted mean water quality}\right)^2 + \ldots\end{matrix}}{\text{frequency of measurements} - 1} \tag{4}$$

2.2.3. Linear interpolation

Among nonparametric statistical analysis techniques, interpolation was generally performed by calculating the presumed value of the Pth percentile by setting n as the analysis factor of all data, by using $k = P(n + 1)$ to calculate the value of the kth largest data point. When k was not an integer, it was acquired from its two nearest neighbors using linear interpolation [7]. The formula, done in Excel, is shown in Eq. (5). The effluent water quality data were calculated by using data measured over the course of 1 y to calculate the annual mean water quality value.

$$\text{Excel}: r = 1 + \frac{P(n-1)}{100} \tag{5}$$

Herein,
r = rank values arranged in descending order.
P = percentile, n = number of data.

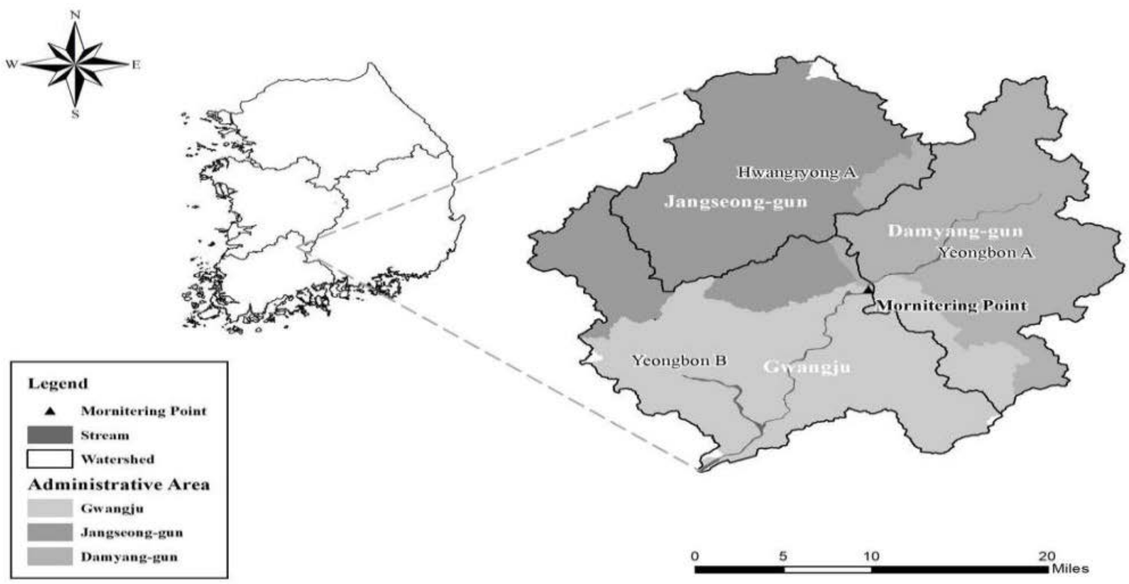

Fig. 1. Youngbon A, the targeted area in the Youngsan River watershed.

Eq. (6) shows the linear interpolation method which was used if r in Eq. (5) was not an integer.

$$Y = (1 - b)Xa + bX_{(a+1)} \quad (6)$$

Herein,

$a = r$ in Eq. (5), which indicates the fractional part of "1 + P (percentile) × (count of measurement – 1)/integer part of 100".

b = 1 + P (percentile) × (count of measurement – 1)/ fractional part of 100.

Y = Value of specified percentile.

$[X_1, X_2, X_3, \ldots, X_a, \ldots, X_n]$ = Ath value among effluent water quality values in ascending order.

Effluent water quality $X_{(a+1)}$ = (a + 1)th value among measured data values in ascending order.

2.2.4. Load duration curve

The LDC provides a visual representation of the target water quality for TMDLs and pollution loads. It is easy to understand and is valuable in identifying the reasons for exceeding the target water quality [8]. The LDC is generated in three steps. First, the flow duration curve (FDC) is generated using the daily flow data. Second, the target LDC or the loading capacity duration curve is generated based on the FDC. Third, the observed loads measured through actual surveys are schematized on this curve. The LDC records the flow duration interval (or the flow exceedance probability) on the horizontal axis and the load on the vertical axis, and generates the entire duration curve based on the flow rates measured over a long period of time under various flow conditions [9].

2.2.5. Observed LDC

The observed load duration curve (OLDC) is a valuable tool that visually shows the relationship between flow rate and pollution load, such as the LDC. This curve is generated as follows. First, the observed loads are calculated by multiplying the measured water quality by the flow rate or daily average flow rate on the measurement date. Second, the target LDC is generated by multiplying the flow rate by the target load. Third, linearity is generated from the target loads and the observed loads. The horizontal axis of the OLDC indicates the observed loads at points corresponding to the flow exceedance probability, while the vertical axis shows the pollution loads.

2.2.6. Percentiles

Water quality was evaluated by uniformly decreasing the top probability ranking to the top 95%, 90%, 85%, 80%, 75%, and 50%, step by step.

2.2.7. Exclusion of upper and lower sections

To minimize the influence of abnormal water quality (extreme values) on the measured data and to ensure stable evaluation of water quality, water quality was measured by incrementally excluding the upper and lower sections by 0%, 2.5%, 5%, 20%, 30%, 40%, and 50%.

2.2.8. Hydrological condition

BOD, a target substance of TMLD for the Youngsan River watershed, is based on LWLs, and T-P is the standard flow rate corresponding to worse water quality between the ordinary water level and the LWL. As pollution load is allocated using water quality modeling to meet the target water quality in accordance with the standard flow rate, the Ministry of Environment has been measuring the water quality of the targeted measurement points since 2004. Because these measured flow rates have a significant influence on the water quality, a hydrological condition-specific evaluation was developed to measure water quality under various hydrological conditions.

2.2.8.1. Evaluation of water quality of peculiar flow sections

By extending the flow duration of high-flow conditions and mid-range conditions, both of which were applied with the standard flow rate, the water quality under high-flow, mid-range, and dry conditions were measured and compared.

2.2.8.2. Weighted evaluation of water quality in consideration of measurement frequency

As deviations occurred under different hydrological conditions, as demonstrated by the analysis of flow measurement time and the analysis of measurement frequency under each hydrological condition, weighted mean water quality values were calculated considering the measurement frequency. Water quality was evaluated by multiplying the mean water quality value under each hydrological condition with its weighted coefficient according to the measurement frequency.

2.3. Basic data analysis of target watershed

The Youngsan River, a target basin, originates from Damyang, Jeon-nam (far south of Seoul) and finally flows into the West Sea via several cities and farming communities, such as Gwangju, Najoo, Muan, and Mokpo. The Youngbon A water point is one of the areas most affected by pollutants originating from agricultural activities. Basic data about the basin and characteristics of the target points to be measured were analyzed to understand the properties of water quality.

This study analyzed the characteristics of the measurement points by taking into account such factors as geographic location, inflow and discharge of flow rate, trend and distribution of water quality, and human activity. Table 1 shows the characteristics of the sources of contaminants in the target unit watershed and of the water quality changes. Tables 2–4 and Fig. 2 show precipitation, rainfall, flow rate, BOD, and T-P (mg/L) status by year at Youngbon A.

3. Application and characteristics of water quality evaluation methods

3.1. Water quality evaluation methods – test results

This study applied each evaluation method to the evaluation point and compared the results with the target

Table 1
Characteristics of contaminant source and water quality changes in the Target Basin

Characteristics
As it was in the upper section of the Youngsan River, the impermeable layer was small.
Four water intake facilities, three sewage treatment plants, 42 village sewerage systems, one livestock manure treatment plant, and one manure treatment plant were distributed along the section.
Because of the major difference between the maximum and minimum concentration ranges, it showed dramatic changes in the water quality.
The water quality had deteriorated in 2015, compared to 2010.

Table 2
Measurement of rainfall by measured year (mm)

Year	Rainfall
2003	5.4
2004	4.6
2005	3.6
2006	4.1
2007	4.4
2008	2.7
2009	4.0
2010	4.4
2011	3.7
2012	4.4
2013	3.3
2014	3.5
2015	3.0

Table 3
Measurement of flow rate by measured year (m^3/s) [10]

Year	Maximum	Average	Minimum
2003	–	–	–
2005	23.958	6.869	1.174
2007	25.381	7.693	1.556
2009	23.795	4.828	0.733
2011	61.456	13.563	2.097
2013	24.242	9.412	3.179
2015	9.359	5.380	2.513

Table 4
Measurement of contamination load of BOD and T-P by measured year (mg/L) [11]

Year	BOD		T-P	
	Maximum	Minimum	Maximum	Minimum
2003	6.9	0.8	0.240	0.040
2005	7.6	0.9	0.484	0.044
2007	9.9	1.0	0.233	0.059
2009	12.9	1.2	0.166	0.042
2011	7.4	1.0	0.288	0.042
2013	5.2	1.0	0.194	0.034
2015	7.0	0.7	0.193	0.033

water quality of the second stage (2011–2015) to identify the advantages and disadvantages of each evaluation method, assess its applicability to Youngbon A, and establish a valid evaluation method.

3.1.1. Application of the water quality evaluation methods for Youngbon A

3.1.1.1. Results of BOD evaluation

Target level of BOD at the point of "Youngbon A" is 2.1 mg/L. It was found that the evaluations, employing values of the converted- and arithmetic means, linear interpolation, percentiles, and methods removing upper and lower intervals, rendered results exceeding the target level (2.1 mg/L). Under part of conditions of evaluation (50% of percentile, 2006), the corresponding evaluations satisfied the target level. In regard to the level of concentration of BOD at the point of "Youngbon A", the distribution of water quality, in terms of extreme values and upper percentile values, appeared higher. The deviations of concentration of BOD at each year appeared significantly bigger as 1.12 (2013)~2.24 (2009).

The LDC showed that the target water quality was exceeded in high-flow sections, but was met in some low-flow sections, indicating that water quality is influenced by a non-point contaminant source from discharge. The results of BOD evaluation at Youngbon A are shown in Table 5.

3.1.1.2. Results of T-P evaluation

T-P deviated substantially in different years, ranging from 0.03 (2013) to 0.30 (2004). The 85th, 90th, and 95th percentile exceeded the target water quality in 2003–2008, while the upper and lower section exclusion method under the exclusion condition of 5% surpassed the target water quality in 2004.

As there was a high distribution of measured water quality in the upper percentiles, the water quality was evaluated to be high by the percentile method and the upper and lower section exclusion method. In the hydrological condition-specific evaluation, water quality significantly changed according to the inflow in the upstream section.

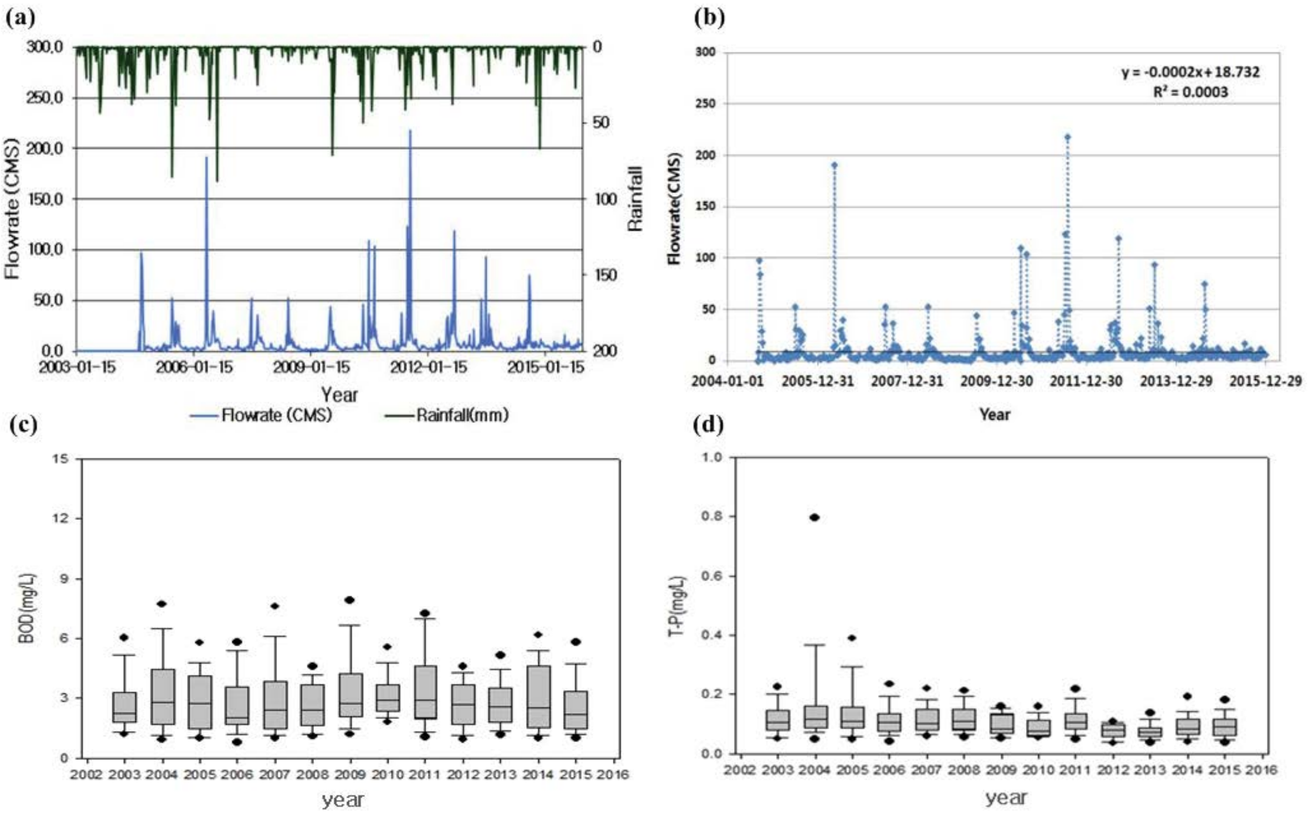

Fig. 2. Flow rate and water quality (BOD, T-P), 2003–2015: (a) flow and rainfall, (b) flow rate, (c) BOD water quality by year, and (d) T-P water quality by year [10].

Table 5a
Results of the water quality evaluation using BOD

Evaluation method	Water quality evaluation	Water quality evaluation (mg/L)												
		'03	'04	'05	'06	'07	'08	'09	'10	'11	'12	'13	'14	'15
Arithmetic mean		2.7	3.4	2.9	2.7	3.1	2.7	3.6	3.1	3.4	2.7	2.8	3.0	2.5
Natural logarithmic converted value		2.7	3.4	2.9	2.7	3.1	2.7	3.6	3.1	3.4	2.7	2.8	3.0	2.5
Linear interpolation		2.6	3.2	2.8	2.6	2.9	2.6	3.4	3.1	3.3	2.6	2.7	2.9	2.5
Achievement probability by LDC (%)		–	71	33	53	33	44	20	22	29	35	31	38	46
Achievement probability by observed load duration curve (%)		–	71	33	53	33	44	20	22	29	35	31	38	46
Evaluation by percentiles	95%	5.5	7.3	5.5	5.8	6.6	4.4	7.6	5.1	7.2	4.5	4.9	6.0	5.1
	90%	4.7	6.0	4.7	5.2	5.9	4.1	6.4	4.6	7.0	4.2	4.4	5.3	4.5
	85%	4.4	5.4	4.2	5.0	4.9	4.1	5.6	4.2	5.7	4.1	4.0	5.1	3.8
	80%	4.2	4.9	4.2	4.0	4.3	3.8	5.3	3.9	5.0	3.9	3.7	4.9	3.4
	75%	2.9	4.4	4.1	3.5	3.8	3.7	4.1	3.5	4.4	3.7	3.5	4.5	3.2
	50%	2.3	2.8	2.8	2.0	2.4	2.4	2.8	2.9	2.9	2.7	2.6	2.6	2.2
Exclusion of upper and lower sections	5%	2.6	3.4	2.8	2.6	3.0	2.6	3.4	3.1	3.4	2.7	2.8	3.0	2.5
	10%	2.6	3.3	2.8	2.7	2.9	2.6	3.4	3.0	3.3	2.7	2.7	2.9	2.5
	20%	2.6	3.3	2.8	2.6	2.7	2.6	3.3	3.0	3.3	2.7	2.7	2.9	2.4
	30%	2.4	3.0	2.8	2.5	2.6	2.6	3.2	3.0	3.2	2.7	2.7	2.9	2.3
	40%	2.4	3.0	2.8	2.4	2.7	2.6	3.1	3.0	3.1	2.7	2.7	2.8	2.2
	50%	2.2	3.0	2.8	2.3	2.7	2.5	3.0	3.0	2.8	2.6	2.7	2.7	2.2

The water quality was low under some hydrological conditions, indicating that water quality was influenced by the measurement period and discharge conditions. As Youngbon A recently showed an improvement in water quality, as well as a narrow fluctuation (deviation), it is reasonable to apply the percentile method considering the probability distribution of the water quality as a path to evaluating the water quality. The results of T-P evaluation at Youngbon A are shown in Table 6, and the results of applying each water quality evaluation method are

Table 5b
Results of the water quality evaluation using BOD

	Water quality evaluation (mg/L)		
Hydrological condition	Moist condition + Mid-range flow + Dry condition	Mid-range flow + Dry condition	Result of water quality weighted evaluation
	2.8	2.8	2.9

Table 6a
Results of Water Quality Evaluation Using T-P

Evaluation method \ Water quality evaluation		Water quality evaluation (mg/L)												
		'03	'04	'05	'06	'07	'08	'09	'10	'11	'12	'13	'14	'15
Arithmetic mean		0.116	0.194	0.141	0.112	0.117	0.118	0.096	0.089	0.115	0.077	0.079	0.093	0.094
Natural logarithmic converted value		0.117	0.171	0.139	0.113	0.117	0.118	0.096	0.088	0.115	0.078	0.079	0.093	0.095
Linear interpolation		0.113	0.155	0.132	0.108	0.114	0.116	0.094	0.085	0.111	0.076	0.077	0.090	0.092
Achievement probability by LDC (%)		–	93	72	83	76	73	90	96	84	100	98	92	90
Achievement probability by observed load duration curve (%)		–	93	72	83	76	73	90	96	84	100	98	92	90
Evaluation by percentiles	95%	0.222	0.490	0.361	0.207	0.204	0.208	0.157	0.145	0.201	0.106	0.132	0.179	0.166
	90%	0.195	0.313	0.283	0.194	0.176	0.177	0.151	0.134	0.186	0.105	0.113	0.138	0.149
	85%	0.160	0.193	0.191	0.152	0.169	0.166	0.144	0.120	0.154	0.103	0.110	0.127	0.142
	80%	0.151	0.176	0.172	0.137	0.158	0.160	0.137	0.116	0.138	0.100	0.100	0.120	0.133
	75%	0.145	0.159	0.156	0.133	0.149	0.150	0.133	0.112	0.133	0.098	0.088	0.114	0.112
	50%	0.105	0.116	0.110	0.105	0.103	0.109	0.082	0.075	0.104	0.081	0.074	0.086	0.091
Exclusion of upper and lower sections	5%	0.115	0.162	0.134	0.110	0.115	0.117	0.095	0.086	0.113	0.077	0.078	0.092	0.094
	10%	0.114	0.146	0.130	0.112	0.115	0.116	0.096	0.084	0.111	0.078	0.077	0.089	0.094
	20%	0.114	0.139	0.127	0.109	0.111	0.116	0.095	0.083	0.111	0.079	0.077	0.089	0.093
	30%	0.110	0.122	0.120	0.106	0.110	0.114	0.093	0.082	0.109	0.079	0.077	0.088	0.092
	40%	0.111	0.111	0.118	0.104	0.111	0.113	0.092	0.081	0.108	0.080	0.076	0.088	0.089
	50%	0.109	0.109	0.115	0.103	0.111	0.112	0.089	0.081	0.103	0.080	0.076	0.087	0.090

Table 6b
Results of water quality evaluation using T-P

	Water quality evaluation (mg/L)		
Hydrological condition	Moist condition + Mid-range flow + Dry condition	Mid-range flow + Dry condition	Result of water quality weighted evaluation
	0.097	0.095	0.102

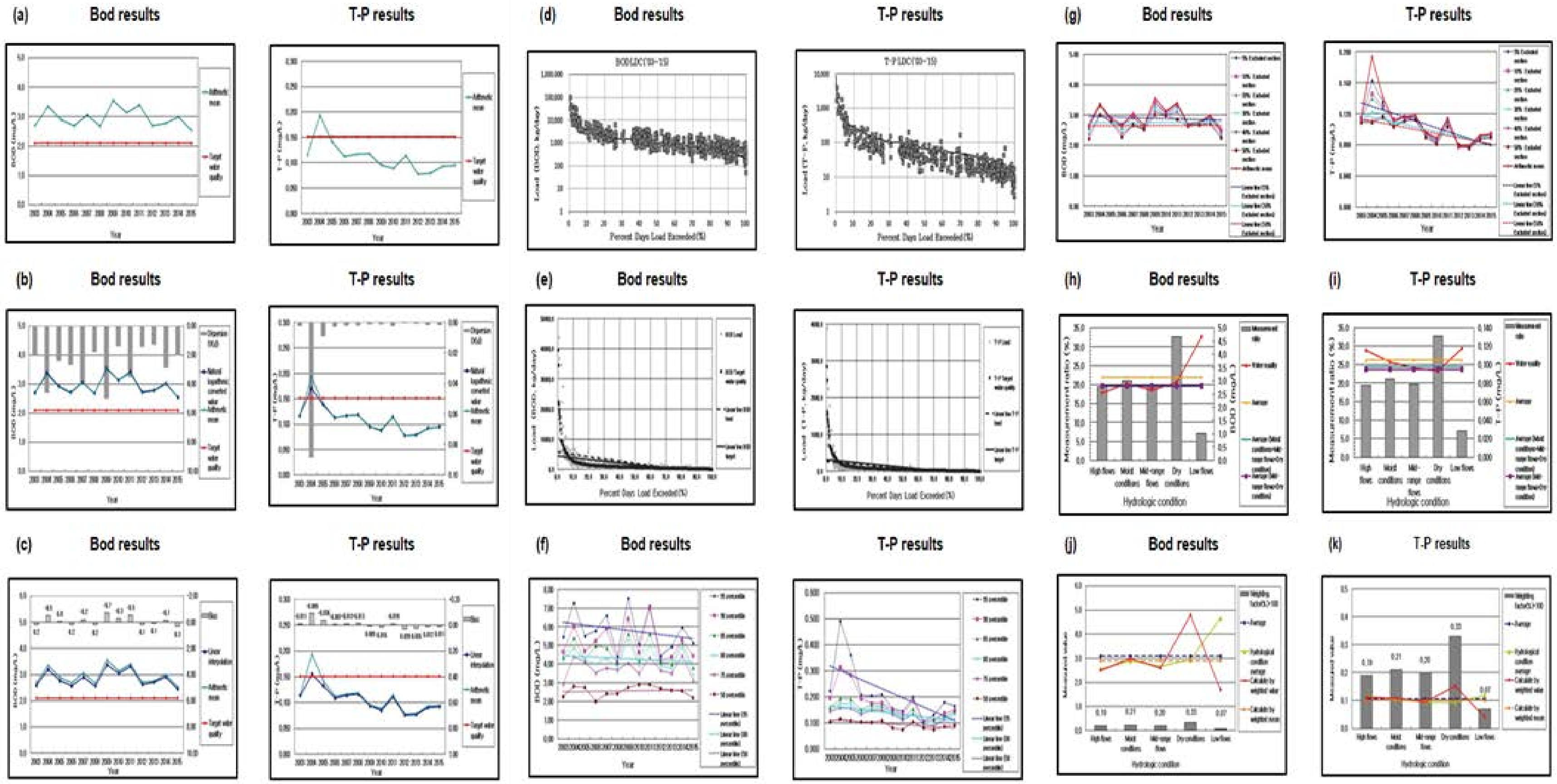

Fig. 3. Results of water quality evaluation: analysis results using (a) arithmetic means, (b) natural logarithmic converted value, (c) linear interpolation, (d) load continuation curve (LDC), (e) observed load duration curve, (f) analysis result by evaluation using percentiles, (g) analysis results using upper and lower section exclusion, (h) hydrological conditions-(a) results of T-P analysis according to the set flow rate, (i) hydrological conditions-(a) results of T-P analysis according to the set flow rate, (j) hydrological conditions-(b) results of BOD analysis considering measurement frequency, and (k) hydrological conditions-(b) results of T-P analysis considering measurement frequency.

shown in Fig. 3. Table 7 represents the deviations of results obtained from each method of water quality evaluation.

3.2. Discussion of water quality evaluation methods through application cases

Different evaluation methods produced inconsistent results at the same measurement point due to the characteristics of Youngbon A, such as water quality, flow rate, river shape, and natural conditions. The advantage and disadvantage of each evaluation method were examined to identify a method appropriate for Youngbon A.

Percentile-based analysis is good in that it is not influenced by unusual water quality characteristics (outlying values). On the other hand, it cannot be used to evaluate the water flow load when water quality is set as the load factor. As the quality of the Youngsan River system has recently improved, the water quality changes less drastically than before. Still, it should be considered before application of this method that the quality may deteriorate due to rainfall or effluent water from environmental infrastructure. An analysis that excludes the upper and lower sections of the river works well for a measurement point which is less likely to be affected by water flux and has little fluctuation in water quality. But more research is necessary to identify reasonable standards for the exclusion zone. Therefore, the method of excluding the upper and lower zones of the river is recommended for a region with a low degree of water flux and point subject to water quality assessment, whereas the percentile-based method is reasonable for a region with a small change in water flux.

As the evaluation methods that use discharge conditions were affected by measurement periods and the discharge conditions of basins, it is possible to apply them to an upstream area with a low flow rate and slight variations in water quality. It is possible to apply the evaluation methods that use discharge conditions to analyze the influence of the TMDL management plan on pollution reduction and to identify the causes of exceeding the assigned load. As the LDC and the OLDC can be used to identify sections that exceed target levels, to identify point or non-point contaminant sources, and to evaluate pollution loads, it is possible to apply them regardless of upper or lower sections.

As the LDC sets the target water quality considering the standard flow rate, flow rate data are needed to apply consistent standards to the evaluation. Currently, the target water quality for the Youngbon A point in the Youngsan River watershed is fixed by using the daily data of neighboring water level-gauging stations managed by the Ministry of Land, Infrastructure, and Transport. However, as some other measurement points did not have neighboring water level-gauging stations, it was difficult to apply the LDC because the relevant data were not available.

The hydrological condition method can be used to evaluate all measurement points considering flow rates and water quality and is mainly used to evaluate a specific section during a specific period. It may lack representativeness without data collected through long-term monitoring. Thus, it is appropriate to apply this method to a point which has been monitored on a long-term basis, and the evaluated

Table 7
Deviations of values resulted from methods of water quality evaluation

Evaluation method / Item	Arithmetic mean	Natural logarithmic converted value	Linear interpolation	Achievement probability by LDC (%)	Achievement probability by observed load duration curve (%)	Evaluation by percentiles (%)						Exclusion of upper and lower sections (%)					
						95	90	85	80	75	50	5	10	20	30	40	50
BOD	0.335	0.335	0.301	14.087	14.087	1.070	0.913	0.657	0.581	0.487	0.287	0.329	0.295	0.301	0.287	0.281	0.285
T-P	0.031	0.026	0.023	9.612	9.612	0.103	0.061	0.028	0.025	0.023	0.014	0.024	0.021	0.019	0.016	0.015	0.014

water quality is quite useful in meeting the target water quality.

If it is possible to secure more data on improved water quality and reduced fluctuation, and from newly added measurement points using these evaluation methods, it is possible to secure the variety of evaluation methods and results.

4. Conclusion

Comprehensive watershed management measures are implemented in order to improve water quality and restore a healthy aquatic ecosystem. This study met the target water quality and applied various methods to evaluate the target water quality considering the characteristics of river water.

This study examined and applied five existing water quality evaluation methods, arithmetic mean, natural logarithmic converted value, LDC, linear interpolation, achievement probability by LDC (%), and achievement probability by observed LDC (%) in addition to three new methods, percentile, upper, and lower section exclusion, duration curve, and hydrological condition. In all, eight different water quality evaluation methods were applied to Youngbon A, the measurement point used to assess TMDL in the Youngsan River watershed.

Different water quality evaluation methods produced different results in terms of whether or not target water quality was met. Because the results depended on which water quality evaluation method was applied, a careful approach to selection and application of a water quality evaluation method is necessary.

Applicability of the method of water quality evaluation was examined through the association of regional characteristics with methods of water quality evaluation, from which the method of removing part of specific values was found reasonable with smaller values of deviation for the point of "Youngbon A" exhibiting great fluctuation in the level of water quality due to inflow of river.

Among the methods of evaluation, the method disregarding the flow rate and the method removing part of values of upper specific water quality (specific values) due to inflow of water, appeared as appropriate ones.

However, the percentile method must be improved by allowing the selection of evaluation standards (strict, generous), and its shortcomings must be overcome by securing stable water quality data, controlling contaminant sources, and conducting analysis of the inflow of contaminant sources by flow rates. Therefore, the standards for the percentile-based method should be clearly established.

As demonstrated above, only when the water quality of a region is evaluated through a multi-faceted review of geographic location, inflow and discharge, contaminant sources, and river shape will it be possible to conduct an accurate diagnosis and to identify causes of pollution. It is difficult to properly evaluate water quality and to identify causes of poor water quality with only one method.

In future, an integrated method that can mitigate the shortcomings of the methods assessed by this study and that can reflect the characteristics of a given region should be developed. This would make it possible to prevent confusion in policies and to implement rational policies and systems with demonstrable reliability.

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