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Analyzing impairment of water bodies considering watershed characteristics in Geum River basin in Korea

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ABSTRACT

Determining impairment of water bodies in the light of watershed characteristics is useful in selecting applicable water quality indicators as target pollutants for the watershed management. This study investigated impaired water bodies using frequency analysis on a stream zone basis in Geum river basin in Korea. The river basin was divided into three stream zones by its characteristics. Selected water quality parameters discussed in this study were pH, DO, BOD, COD, SS, T-P, T-Coli, and F-Coli. Excess ratios of the water quality parameters were used to discriminate water bodies that did not meet water quality standards. Excess levels were used to classify the water quality degradation. Contributions of the tributaries were also estimated to identify the major contributors to the stream zones. The upstream zone showed that the indicators for impaired water bodies were BOD, COD, T-P, and T-Coli which indicated especially high excess level. The downstream zone revealed that COD, T-P, and T-Coli were the indicators and the M/D stream zone revealed that the indicators were BOD, COD, and T-P. The major contributors in the upstream are Okcheon, Juwon, Bonghwang, and Pumgok tributaries. In the downstream, Nonsan, Seokseong, Gab, Yudeung, and Daejeon were the major contributing tributaries and in the M/D stream zone, the major contributors were Iksan, Gobu, and Jeongeup tributaries.

Keywords: Contributing tributaries; Excess level; Excess ratio; Impairment of water bodies; Water quality indicators; Watershed characteristics

1. Introduction

Water quality standards and the related legislations are used as the main administrative means to manage water quality in order to achieve user requirements [1]. Water quality requirements can be usefully determined only in terms of suitability, for a purpose, in relation to the control of defined impacts on water quality [2]. The most common national requirement is for drinking water of suitable quality, and many countries base their own standards on the World Health Organization guidelines for drinking water quality [3,4]. Pollution and water quality degradation interfere with vital and legitimate water uses at any scale [5]. Excess loads in a water body can have many detrimental effects on designated or existing uses, including drinking water supply, recreational use, aquatic life use, and fishery use [6].

Pollution loads discharged from watershed should be controlled in total amount in the region where the

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water body does not meet the goal or the water pollution may cause serious impact on residents' health or properties, or aquatic life [7]. Total maximum daily load (TMDL) is based on the relationship between pollution sources and in-stream water quality conditions. TMDL establishes the allowable loadings or other quantifiable parameters for a water body and thereby provides the basis to establish water quality-based controls [8]. It seeks to harmonize preservation and development by allowing regional developments to be carried out in an environment friendly manner and within the scope of achieving and maintaining the desired water quality [9]. Pollutant sources are managed so as to keep the total amount of pollutants in public watershed under a certain level (total allowance) in accordance with the water quality goal [10]. Section 303(d) of the Clean Water Act provides that states, territories, and authorized tribes are to list waters for which technology-based limits alone do not ensure attainment of water quality standards. Beginning in 1992, states, territories, and authorized tribes were to submit their lists to EPA every two years. Beginning in 1994, lists were due to EPA on April 1 of each even numbered year. States, territories, and authorized tribes are to set priority rankings for the listed waters, taking into account the severity of the pollution and the intended uses of the waters [6,11,12]. The first legal basis was prepared to introduce TMDL right after Han River Act was enacted in 1998 in Korea. Thereafter Nakdong, Geum, and Youngsan·Seomjin River Acts were enacted. The TMDL was enforced mandatorily in these three river basins. The first stage TMDL began in 2004 in Nakdong river basin, and in 2005 in Geum river basin and Youngsan·Seomjin river basins [13–15].

For an effective watershed management, it is necessary to have one or more quantitative measures that can be used to evaluate the relationship between pollutant sources and their impacts on water quality. Such measurable quantities are termed target water quality indicators [16]. Before developing the TMDLs for a river basin, applicable water quality indicators are supposed to be selected as target pollutants by the stage in order to manage the pollution loads in total basis. A water quality indicator, BOD, was selected as a target pollutant for the 1st stage TMDL, the period of 2004–2010 [17–19]. BOD, then, had a long series of data as well as its institutional basis in comparison to other indicators considering the beginning of TMDLs [20]. Research works were performed to select additional applicable water quality indicators in the three river basins [21–23]. T-P was added to the water quality indicator as another target pollutant for the second stage TMDL planned from 2011 to 2015 with reference to the research works [24–26].

Impairment of water bodies is mainly caused by the pollution load discharged from the watershed, but the water quality is also affected by the flow variation on the stream. The water quality indicators for TMDLs would have very close relation with hydrological characteristics as well as pollution sources [27,28]. Careful attention should be paid in order to select the applicable water quality indicators that best represent the target pollutants and the water body characteristics [29]. A selective and concentrated effort should be made to heighten the effect of institutional implement and the improvement on water quality in stream. It is a fundamental step to identify impaired waters in the process of selecting applicable water quality indicators as target pollutants for the watershed management in a river basin [30]. Identification of the impairment enables to investigate heavily polluted area along with causing materials by which the water body is polluted. This is naturally used to determine pollutants and regions to be controlled in the river basin. To the greatest extent possible, the problem identification should be prepared based on currently available information, including water quality monitoring data, watershed analyses, best professional judgment, information from the public, and any previous studies of the water body [6,11].

Geum river basin is one of the major four river basins in Korea. The river basin has a very unique feature. The characteristics of the river basin differ significantly from the others. Geum river basin has also an important place for its geographical location. The Integrated Government Building has recently been located in Sejong Metropolitan City in this river basin. The quality of water in the river and its tributaries is of vital importance to the people that depend on the water for its many uses such as public supply, human health, ecological, esthetic, recreational, and irrigation concerns.

The identification of water impairment will still depend on the proper application of the most appropriate method. Arithmetic mean concentration method is generally used for evaluating the achievement of water quality standards for rivers and lakes. However, the method is much affected by singular values of water quality measurements. Therefore, it has difficulty in applying to the identification of pollutants which become persistently problematic in the long term in a water body. Instead, frequency analysis can be applied to the evaluation of the water bodies in terms of water quality standard attainment. The analysis calculates the frequency of the achievement and the exceedence of the water quality indicator in a certain water body and the frequency ratios are mutually independent. The result of the analysis enables us to identify priority pollutants and to select the most appropriate target water quality indicators in the water body. The objective of this study is to analyze water impairment using the frequency analysis on a stream zone basis so that essential sources can be provided for determining priority in the selection of water quality indicators as target pollutants in Geum river basin for the watershed management.

2. Materials and methods

2.1. Study area

The study area, Geum river basin, is located in the central part of Korea. One metropolitan city and three provinces are the administrative areas in this basin. The river basin consists of the mainstream of Geum river and Mangyeong/Dongjin (M/D) rivers. Many anthropogenic structures affect streamflow in the river basin. The mainstream has two large dams in the course of the river way. These dams alter the natural flow of the river, often dampening seasonal effects and allowing increased evapotranspiration. The main stream is distinctively divided into two stream zones, upstream and downstream zones, with Daecheong Dam as a point. The M/D stream zone has a separate drainage area [31].

Water quality monitoring network is now in operation in order to provide water quality data which can be used for water management policies on river and lake waters. Geum river basin comprises 16 medium influential areas and each medium influential area has its own monitoring stations, respectively. Water quality parameters are being monitored at 125 stations in Geum river basin. Water qualities are measured on a monthly basis at each monitoring station for the priority pollutants and the other related pollutants [32]. We divided Geum river basin into three stream zones, (1) upstream zone, (2) downstream zone, and (3) M/D stream zone, as shown in Fig. 1, according to their geographical and hydrological characteristics to analyze the impairment of water bodies by the stream zone.

Land use in the upstream zone (GS1) is predominantly forest and agricultural. The headwaters of the upstream zone are in Jangsugun and Jeonlabukdo, and the stream reaches Daecheong Dam. Another dam called Yongdam Dam is also located in this upstream zone. There are 10 tributaries in the upstream zone. Six tributaries such as Jinan, MujuNamdae, Bonghwang, youngdong, Chogang and Bocheong are flowing into upper parts of Daecheong Dam. Four tributaries, Okcheon, Hoiin, Juwon, and Pumgok, are directly connected to Daecheong lake. Chogang has the largest watershed area among 10 tributaries. Bonghwang and Okcheon seem to have considerable influence on the stream due to the concentrated pollution sources on the watersheds despite the area is very small.

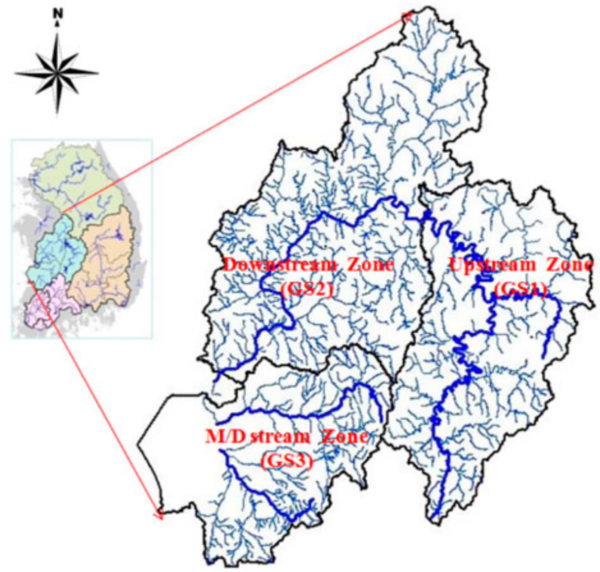

Fig. 1. The watershed map of Geum river basin.

The downstream zone (GS2) stretches from Daecheong Dam to the mouth of Geum river and has large urban areas. There are 13 tributaries in the downstream zone. The major tributaries are Gab, Miho, Yougu, Ji, Seokseong, and Nonsan. Especially two of them seem to affect the stream a lot. The one is Gab which flows through Daejeon Metropolitan City. Other is Miho which is the longest tributary in Geum river basin. There is an estuary dyke in the mouth and the water is stagnant. As a new administrative city is constructed, environmental issues will be critical concerns in this zone.

The M/D stream zone (GS3) has wide plains and seven tributaries. Four tributaries, Soyang, Jeonju, Iksan, and Tap, flow into Mangyeong river. Three tributaries, Jeongeup, Gobu, and wonpyeong, flow into Dongjin river. The serious tributaries for water quality management are Jeonju, Iksancheon, Mokcheonpo, and Tap, which carry urban and livestock wastewater into Mangyeong river. Jeongeup and wonpyeong are also the ones, which carry urban wastewater into Dongjin river. Irrigation is the predominant water-use category in this zone. Numerous irrigation diversions and return flows are in the wide plains. Irrigation channels intercept the M/D rivers water and return it to the rivers. At the end of the M/D rivers along the coast, a breakwater was constructed between 1991 and 2010 to reclaim land and artificial fresh water lake.

This land is supposed to be developed as a multi-functional city in the near future.

2.2. Analyzing impairment of water bodies

Water quality standards serve as the foundation of the water quality based control programs to protect uses of water bodies. US EPA has presented national recommended water quality criteria for the protection of aquatic life and human health in surface water for approximately 150 pollutants. Aquatic life criteria list chemical concentration goals to protect surface water for aquatic life use and are separated by water bodies, fresh water, and salt water. The criteria for each water body are classified into six parts; criteria maximum concentration (acute), criterion continuous concentration (chronic), acute averaging period, chronic averaging period, acute frequency of allowed exceedence, and chronic frequency of allowed exceedence. Human health criteria include technical information and guidance on surface water, drinking water, and microbials. Each pollutant in human health criteria is designated as a priority pollutant or a non-priority pollutant. The criteria are classified into two parts for the consumption of water plus organism and organism only [33]. In Korea, water quality standards are designated separately for rivers and lakes in surface water. The parameters of water quality standards for rivers are categorized into two groups, living environment and human health, as presented in Table 1 [34]. Living environment criteria are classified into seven grades (Ia, Ib, II–VI) according to the water uses. The parameters on living environment are composed of 8 items and on human health 17 items.

This study selected the parameters on living environment for the analysis of the impairment with the exception of the parameters on human health showing no symptoms of their deterioration.

Accurate and reliable procedures are necessary to identify the cause of water quality standards violations and can help identifying pollutants causing impacts [30]. The procedures for this analysis include identifying the impaired water bodies, estimating the degree of water impairment, and investigating the major influencing tributaries. The three stream zones with their inflow tributaries were analyzed in this study. Water quality data obtained from 2005 to 2009 were used to perform the analysis [35].

Excess ratios of eight water quality parameters were calculated. Excess concentration levels, hereafter referred to as excess levels, and contributions of tributaries were also calculated. Excess ratio refers to the proportion of the excess frequency over water quality standards to whole water quality measurements. The excess ratio of 25% was used as a criterion to classify the impairment. The indicator showing an excess ratio above the criterion was classified into impaired waters, which meant the water body did not meet its water quality standard [31]. Excess level is to classify the water quality degradation by the difference in concentrations between the impaired water quality indicators and water quality standards. The excess ratio only offers the information on the attainment of water quality standards but the excess level provides with the degree of water deterioration, thus this can play a vital role to make the priority in the establishment of water quality management plans. In order to classify the degree of excess, the range of excess concentration was divided into four levels, from Level 1 to Level 4. Level 1 (L1) means that the excess concentration is below 25%, Level 2 (L2) between 25 and 50%, Level 3 (L3) between 50 and 75%, and Level 4 (L4) above 75%. The contribution ratio of a tributary indicates the excess frequency of the tributary to the overall excess frequency of all tributaries in the stream zone. Determining the contributions of tributaries in a stream is useful in identifying the main cause of the impairment and the effects of pollution sources on the stream.

3. Results and discussion

3.1. Impaired water quality indicators

The excess ratios of eight water quality parameters over water quality standards by the stream zone in Geum river basin are shown in Figs. 2–4.

Table 1
The parameters in the water quality standards for rivers in Korea

	Water quality parameters
Living environment	pH, BOD, COD, T-P, SS, DO, coliform (total coliform, fecal coliform)
Human health	Cd, As, CN, Hg, Organic phosphate, PCB, Pb, Cr^{6+}, ABS, carbon tetrachloride, 1,2-dichloroethane, PCE, dichloromethane, benzene, Chloroform, DEHP, antimony

In the upstream zone, the excess ratios ranged from 2.3 of SS to 67.0% of COD. The excess ratios of SS and DO were very small while those of COD, T-Coli, and T-P were considerably large. Three water quality parameters, pH, DO, and SS, had the excess ratios of less than 25% and met their water quality standards. But five water quality parameters, BOD, COD, T-P, T-Coli, and F-Coli, had the excess ratios of more than 25% and did not meet their standards in this upstream zone. The small excess ratio of SS in this stream zone was due to the land covers comprised of forest and agricultural area, which hardly cause the occurrence of high SS concentration. Water quality parameters representative of organic matters and nutrients have serious problems. While there are many factors that influence dissolved oxygen, the most important is the amount of organic matter decomposing in the water. Oxygen in the surrounding water is consumed as micro-organisms decompose this organic matter [36]. Nutrients are elements that are essential to living organisms. Because of the scarcity of nitrogen and phosphorus relative to other essential elements, nitrogen and phosphorus are considered to regulate or limit plant productivity. The excess ratio of COD was very high relative to BOD, approximately 2.5 times that of BOD. A possible cause for the high excess ratio of COD could be attributed to a huge influx of humus soil including non biodegradable matters generated from natural background area with surface run-off. Organic matter arising from living organisms makes an import contribution to the natural quality of surface waters. Natural organic compounds are not usually toxic, but exert major controlling effects on the hydrochemical and biochemical process in a water body [37].

The excess ratios ranged from 0.5 of DO to 57.5% of T-Coli and F-Coli in the downstream zone. Four water quality parameters, pH, DO, SS, and BOD had the excess ratios of less than 25% and met their water quality standards. But four water quality parameters, COD, T-P, T-Coli, and F-Coli, had the excess ratios of more than 25% and did not meet their standards in this downstream zone. The small excess ratio of DO in this stream zone was due to the effluent discharged from Daecheong Dam throughout the year, which had provided channel flow for maintenance enough to maintain the water level not depleting dissolved oxygen in the water. The excess ratios of T-Coli and F-Coli were high relative to other parameters. It was mainly caused by domestic sewage and various industrial wastewater resulting from large number of people in the urban area throughout the basin.

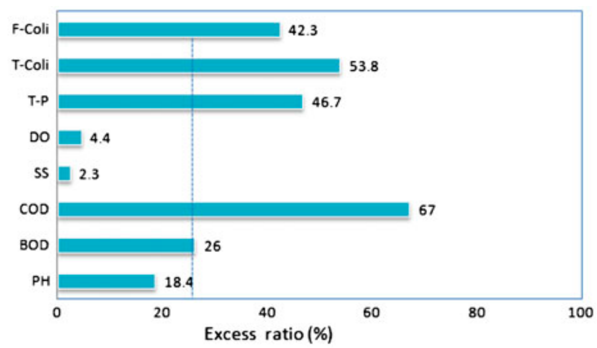

Fig. 2. The excess ratio of water quality parameters over water quality standards in the upstream zone (GS1).

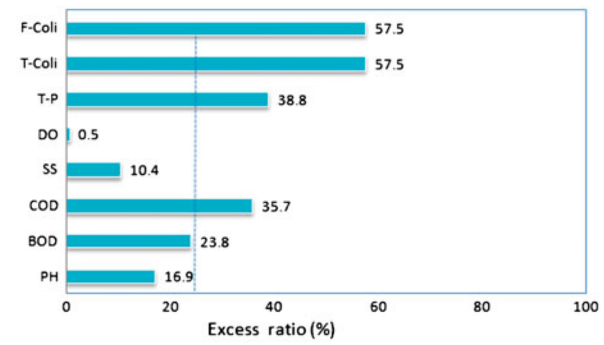

Fig. 3. The excess ratio of water quality parameters over water quality standards in the downstream zone (GS2).

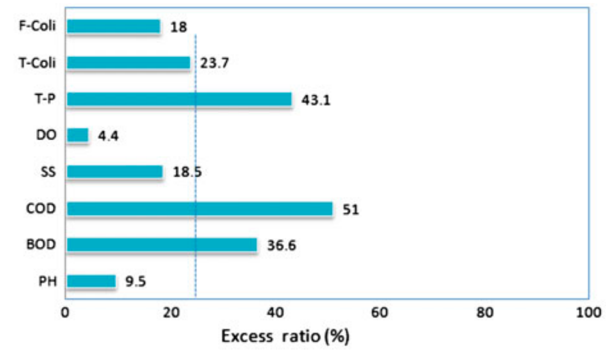

Fig. 4. The excess ratio of water quality parameters over water quality standards in the M/D stream zone (GS3).

The excess ratios ranged from 4.4 of DO to 51.0% of COD in the M/D stream zone. The excess ratios of pH and DO were very small while those of COD and T-P were considerably large. Five water quality parameters, pH, DO, SS, T-Coli, and F-Coli, had the excess ratios of less than 25% and met their water quality standards. But three water quality parameters, BOD, COD, and T-P, had the excess ratios of more than 25% and did not meet their standards in this M/D stream zone. The M/D stream zone has thousands of hectares of agricultural land throughout the zone resulting in lots of fertilizer uses. Surface water diverted for irrigation is routed back to the rivers. Return flows carry lots of organic matter and nutrients are responsible for the high excess ratios of COD and T-P in this stream zone.

T-Coli and F-Coli are the water quality indicators for pathogens. The excess ratios of T-Coli are higher than those of F-Coli in all water bodies. In terms of exceedence, T-Coli can be considered as a target water quality indicator as well as the other indicators addressing water impairment in Geum river basin.

It is helpful for the analysis to check out if there are any significant changes in the excess ratios in a given period of time. Figs. 5–7 show the trends in the annual excess ratios of eight water quality parameters for the last five years by the stream zone in Geum river basin. In the upstream zone, the trends in the annual excess ratios indicate three patterns. The annual excess ratios of pH, COD, and T-Coli tended to increase slightly while that of SS tended to decrease very slightly as time goes by. There were no annual changes in the excess ratios of the other four water quality parameters including BOD, SS, DO, and F-Coli. In the downstream zone, the trends indicate two patterns. The annual excess ratios of pH, COD, and T-Coli tended to increase slightly. The annual excess ratios of BOD, SS, DO, T-P, and F-Coli remained relatively constant during the period. In the M/D stream zone, the trends also indicate two patterns. The annual excess ratios of pH, BOD, COD, T-Coli, and F-Coli tended to increase slightly. The annual excess ratios of SS, DO, and T-P remained relatively constant during the period.

3.2. Degradation levels of the impaired waters

The excess levels of four water quality parameters which did meet water quality standards are shown in Figs. 8–10 by the stream zone in Geum river basin. The distribution of the excess levels describes the water quality degradation. The more the high level

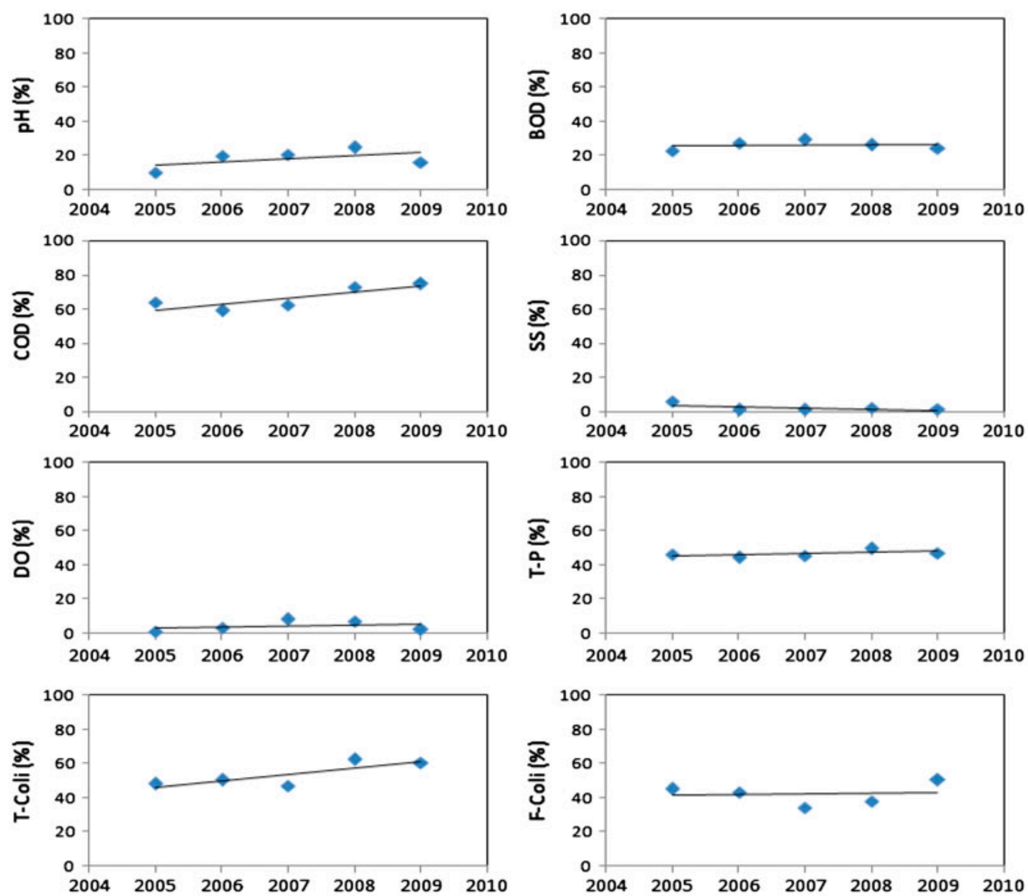

Fig. 5. The trends in the annual excess ratios of water quality parameters in the upstream zone (GS1).

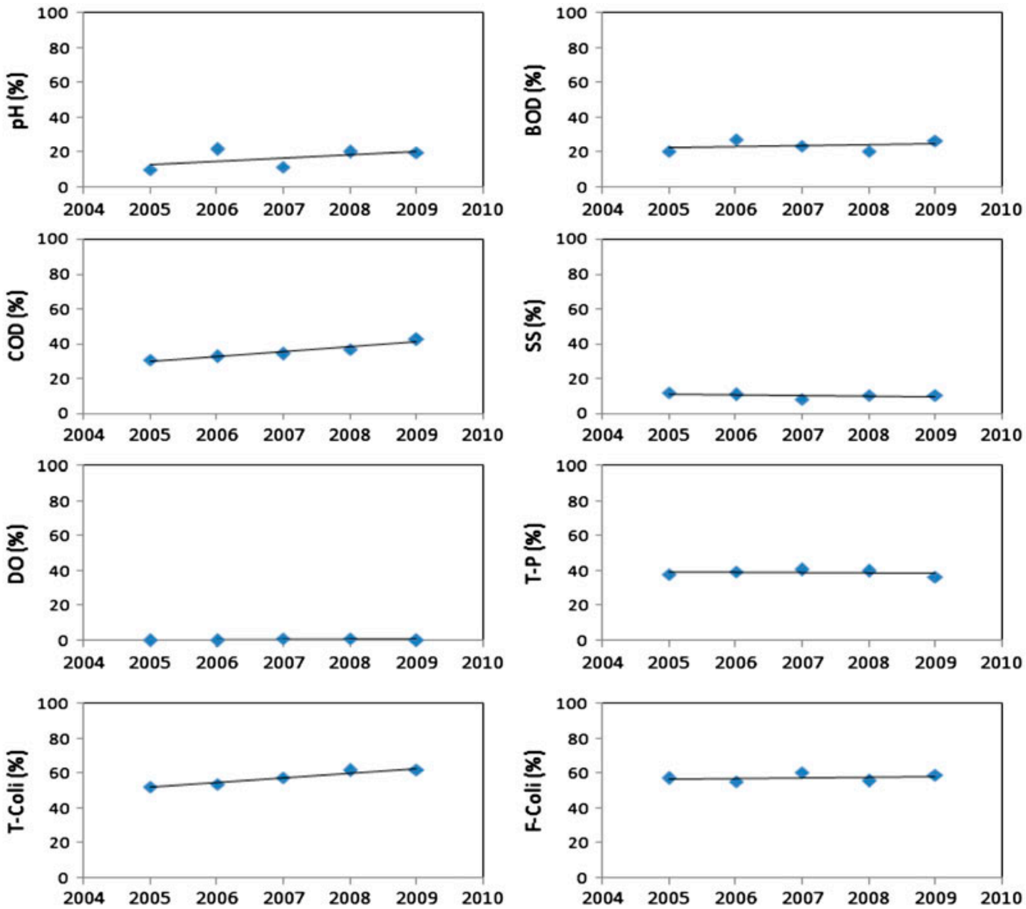

Fig. 6. The trends in the annual excess ratios of water quality parameters in the downstream zone (GS2).

distributes, the more the water body is degraded. In the upstream zone, the excess levels for BOD were distributed the most in L1 by 90% and for COD predominantly fell in L3 by 34%. The excess levels for T-P were distributed the most in L1 by 43% and for T-Coli appeared the most in L4 by 88%. T-Coli exceeded the water quality standards especially in high level causing serious degradation of the water body while BOD exceeded the standards in low level in this upstream zone. In the downstream zone, the excess levels for BOD were distributed the most in L1 by 88% and for COD predominantly fell in L1 by 75%. The excess levels for T-P were distributed the most in L1 by 63% and for T-Coli appeared the most in L4 by 53%. Most of excess levels were considerably in low level except F-Coli in this downstream zone. In the M/D stream zone, the excess levels for BOD were distributed the most in L1 by 67% and for COD predominantly fell in L3 by 48%. The excess levels for T-P were distributed the most in L1 by 56% and for T-Coli appeared the most in L4 by 50%. The excess levels for water quality indicators except BOD had similar distribution between L1 and other levels in this M/D stream zone.

3.3 Contributions of inflow tributaries

The excess ratios of four water quality parameters and the contributions of 10 tributaries to the excess ratios of the upstream zone are given in Table 2. There were big differences in the excess ratios of BOD ranging from 4.0 to 90.0% (average 41.8%). The biggest BOD contributor was Okcheon which accounted for 21.5% of contribution followed by Juwon which accounted for 19.5%. The excess ratios of COD also made a big difference ranging from 7.0 to 100.0% (average 64.2%). Okcheon was also the biggest COD contributor which accounted for 15.6% followed by Bonghwang which accounted for 14.8%. As to T-P, the ratios ranged from 17.7 to 93.8% (average 61.2%). Okcheon was the biggest T-P contributor which accounted for 16.1% followed by Bonghwang which

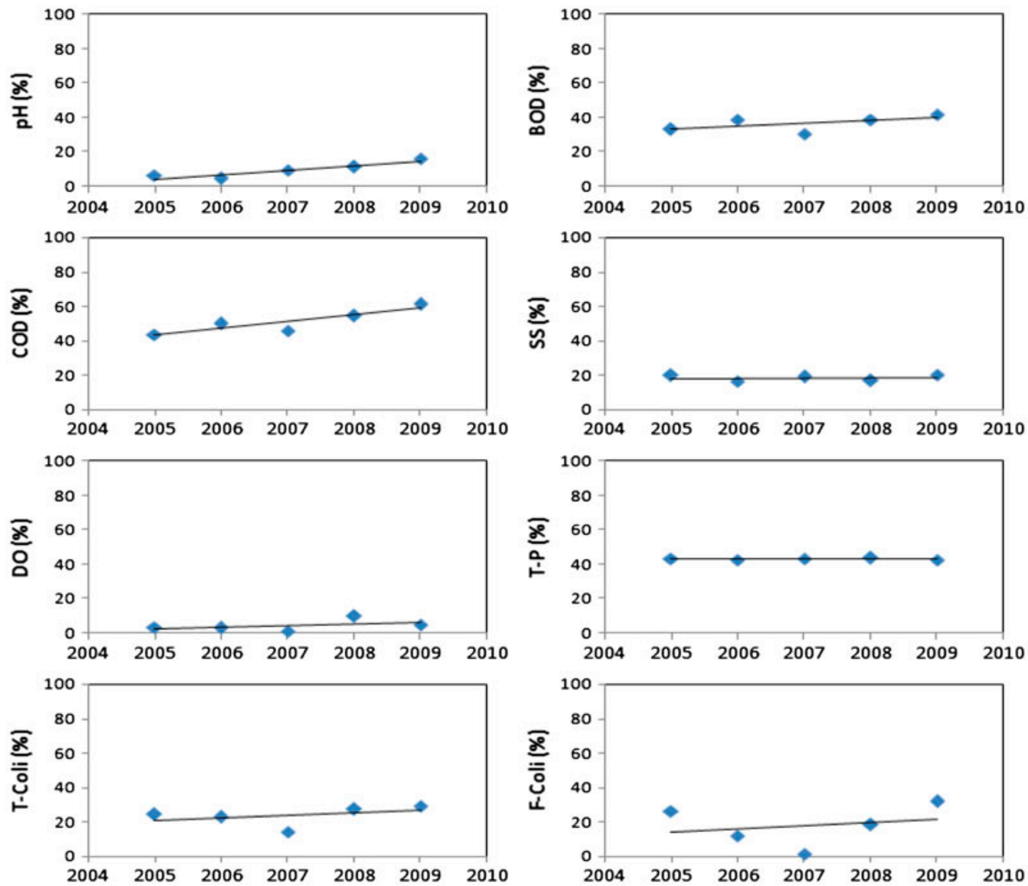

Fig. 7. The trends in the annual excess ratios of water quality parameters in the M/D stream zone (GS3).

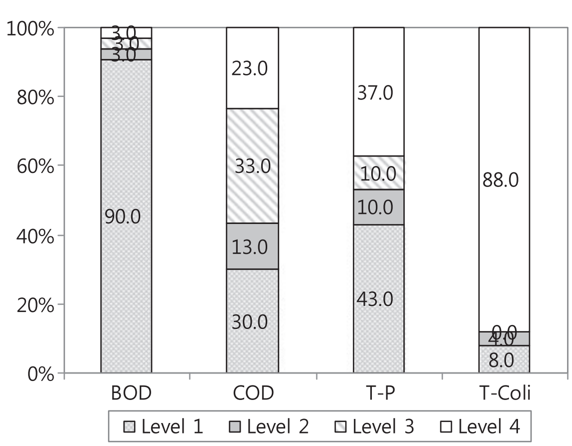

Fig. 8. The distribution of the excess levels of four water quality parameters in the upstream (GS1).

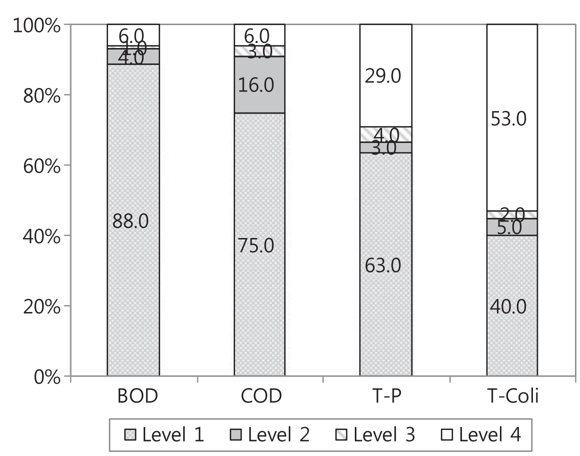

Fig. 9. The distribution of the excess levels of four water quality parameters in the downstream (GS2).

accounted for 15.5%. As to T-Coli, the ratios ranged from 1.7 to 100.0% (average 66.6%). Juwon was the biggest T-Coli contributor which accounted for 15.0% followed by Pumgok which accounted for 14.0% in this upstream zone.

The excess ratios of four water quality parameters and the contributions of 13 tributaries to the excess ratios of the downstream zone are given in Table 3. The excess ratios of BOD had considerable differences

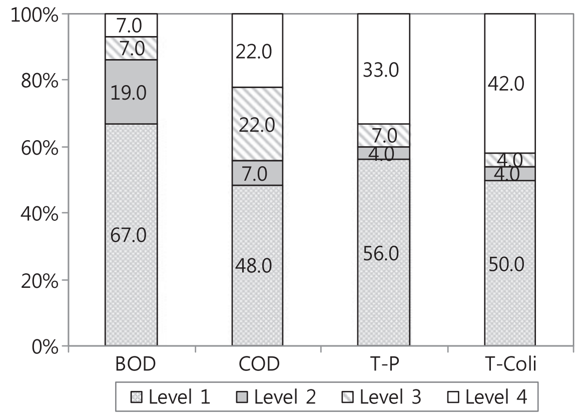

Fig. 10. The distribution of the excess levels of four water quality parameters in the M/D stream (GS3).

among tributaries ranging from 0.0 to 68.2% (average 21.2%). The biggest BOD contributor was Nonsan which accounted for 24.8% followed by Seokseong which accounted for 22.4%. The ratios of COD ranged from 0.0 to 70.4% (average 26.3%). The biggest COD contributor was also Nonsan which accounted for 20.6% followed by Seokseong which accounted for 20.5%. As to T-P, the ratios ranged from 0.5 to 91.7% (average 25.5%). Seokseong was the biggest T-P contributor which accounted for 27.7% followed by Nonsan which accounted for 25.4%. As to T-Coli, The ratios ranged from 11.7 to 100.0% (average 57.4%). Gap, Yudeung, and Daejeon were the biggest T-Coli contributors which accounted for 13.4% respectively in this downstream zone.

The excess ratios of four water quality parameters and the contributions of seven tributaries to the excess ratio of the M/D stream zone are given in Table 4. There were big differences in the excess ratios of BOD depending on the tributaries with the range of 0.8 to 93.3% (average 49.3%). The major BOD contributors were Iksan and Gobu tributaries which accounted for 27.1 and 24.2% respectively. The ratios of COD ranged from 2.5 to 98.6% (average 65.7%). The major COD contributors were also Gobu and Iksan tributaries which accounted for 21.4% respectively. As to T-P, the ratios ranged from 0.8 to 100.0% (average 51.1%). Iksan and Gobu tributaries were the major T-P contributors which accounted for 27.9 and 23.0% respectively. As to T-Coli, the ratios ranged from 0.0 to 51.7% (average 18.6%). Jeongeup and Iksan tributaries were the major T-Coli contributors which accounted for 39.8 and 30.8% respectively in this M/D stream zone.

3.4. *Impaired water bodies and polluted tributaries*

Water quality indicators for impaired water bodies with excess level sequences are given in Table 5. The major contributing tributaries also are given in this table. The upstream zone showed that the indicators for impaired water bodies were BOD, COD, T-P, and T-Coli. The downstream zone revealed that COD, T-P, and T-Coli were the indicators. The M/D stream zone revealed that the indicators were BOD, COD, and T-P. COD and T-P were the indicators for impaired water bodies in all three stream zones in Geum river basin. The excess levels of BOD were generally low in the three stream zones. There were some differences in the excess levels of COD depending on the stream zones. The excess levels of T-P were also relatively low in the three stream zones. The excess levels of T-Coli were especially high in the upstream zone and relatively high in the downstream zone. The major contributing tributaries were Okcheon, Juwon,

Table 2
The excess ratios and the contributions of 10 tributaries in the upstream zone

	Excess ratio (%)				Contribution (%)			
	BOD	COD	T-P	T-Coli	BOD	COD	T-P	T-Coli
Jinan	13.3	18.3	66.7	1.7	3.2	2.9	10.9	0.3
Muzumandae	32.3	78.1	54.2	57.3	7.7	12.2	8.9	8.6
Bonghwang	60.0	95.0	95.0	88.3	14.3	14.8	15.5	13.3
Youngdong	34.2	88.3	74.2	71.7	8.2	13.8	12.1	10.8
Chogang	22.8	83.3	44.4	63.9	5.5	13.0	7.3	9.6
Bocheong	4.0	7.0	17.7	41.0	1.0	1.1	2.9	6.2
Okcheon	90.0	100.0	98.3	61.7	21.5	15.6	16.1	9.3
Hoiin	36.7	33.3	43.3	86.7	8.8	5.2	7.1	13.0
Juwon	81.7	86.7	63.3	100.0	19.5	13.5	10.3	15.0
Pumgok	43.3	51.7	55	93.3	10.4	8.1	9.0	14.0

Table 3
The excess ratios and the contributions of 13 tributaries in the downstream

	Excess ratio (%)				Contribution (%)			
	BOD	COD	T-P	T-Coli	BOD	COD	T-P	T-Coli
Gab	6.6	11.4	33.3	100.0	2.4	3.3	10.1	13.4
Youdueng	0.0	1.0	0.5	100.0	0.0	0.3	0.2	13.4
Daejeon	0.0	0.0	0.8	100.0	0.0	0.0	0.2	13.4
Miho	11.4	25.7	25.1	33.7	4.1	7.5	7.6	4.5
Musim	2.2	6.7	4.4	48.3	0.8	2.0	1.3	6.5
Byongcheon	4.8	11.9	9.5	23.3	1.7	3.5	2.9	3.1
Jo	25	30.0	46.7	53.3	9.1	8.8	14.1	7.1
Yougu	11.7	3.3	3.3	28.3	4.3	1.0	1.0	3.8
Ji	15.0	11.7	3.3	30.0	5.5	3.4	1.0	4.0
Guem	51.7	50.0	18.3	66.7	18.8	14.6	5.5	8.9
Seokseong	61.7	70.0	91.7	78.3	22.4	20.5	27.7	10.5
Nonsan	68.2	70.4	84.0	72.1	24.8	20.6	25.4	9.7
Gilsan	16.7	50.0	10.0	11.7	6.1	14.6	3.0	1.6

Table 4
The excess ratios and the contributions of seven tributaries in the M/D stream zone

	Excess ratio (%)				Contribution (%)			
	BOD	COD	T-P	T-Coli	BOD	COD	T-P	T-Coli
Soyang	0.8	2.5	0.8	9.2	0.2	0.5	0.2	7.1
Jeonju	20.0	32.0	27.0	18.0	5.8	7.0	7.5	13.8
Iksan	93.3	98.3	100.0	40.0	27.1	21.4	27.9	30.8
Tap	45.8	91.7	50.0	0.0	13.3	19.9	14.0	0.0
Jeonguep	30.0	41.3	27.3	51.7	8.7	9.0	7.6	39.8
Gobu	83.6	98.6	82.2	8.3	24.2	21.4	23.0	6.4
Wonpyoung	71.4	95.3	70.6	2.8	20.7	20.7	19.7	2.2

Table 5
The water quality indicators for impaired water bodies with excess level sequences and major contributors in Geum river basin

Stream zone	Indicator for impaired water body	Excess level sequences	Major contributing tributaries
Upstream	BOD	L1 > L2 = L3 = L4	Okcheon, Juwon
	COD	L3 > L1 > L4 > L2	Okcheon, Bonghwang
	T-P	L1 > L4 > L2 > L3	Okcheon, Bonghwang
	T-Coli	L4 > L1 > L2 > L3	Juwon, Pumgok
Downstream	COD	L1 > L2 > L4 > L3	Nonsan, Seokseong
	T-P	L1 > L4 > L3 > L2	Seokseong, Nonsan
	T-Coli	L4 > L1 > L2 > L3	Gab, Yudeung, Daejeon
M/D stream	BOD	L1 > L2 > L3 = L4	Iksan, Gobu
	COD	L1 > L3 = L4 > L2	Gobu, Iksan
	T-P	L1 > L4 > L3 > L2	Jeongeup, Iksan

Bonghwang, and Pumgok in the upstream zone. In the downstream zone, the major contributing tributaries were Nonsan, Seokseong, Gab, Yudeung, and Daejeon. And the major contributing tributaries were Iksan, Gobu, and Jeongeup in the M/D stream zone. These major contributing tributaries, presumed to be polluted, are regarded to have much effect on the stream zones which they are flowing into and should be paid special attention.

The degradation of water bodies is mainly due to the pollution load discharged from the watershed in Geum river basin. To improve water quality for impaired water bodies, it is necessary to investigate major pollution sources and identify their impact on water quality. Pollutant reduction facilities can be installed in case the causes are the point sources. Best management practices and low impact development can be considered as effective measures to lessen the pollution loads from the non-point sources.

4. Conclusions

Impairment of water bodies were analyzed to provide essential data in selecting water quality indicators as target pollutants by the stream zone in Geum river basin. The excess ratios and excess levels were calculated in the three stream zones. Contributions of the tributaries on the stream zones were also calculated and major contributing tributaries were identified.

The excess ratios of pH, DO, and SS were shown very low in all stream zones. The ratios of BOD, COD, T-P, and T-Coli were considerably high in most stream zones. The ratios of pH were below 20% in all stream zones and for BOD, the ratios ranged from 24.2 to 36.6% depending on the stream zones. The ratios of COD were a little bit higher than those of BOD and ranged from 23.7 to 67.0%. The ratios of SS were also below 20% in three stream zones. Especially, the ratios of DO were very low showing below 5% in all stream zones. The ratios of T-P were considerably high and ranged from 38.8 to 46.7. In terms of T-Coli and F-Coli, the ratios were very high in upstream and downstream zones except M/D stream zone. The excess levels of BOD were very low in all stream zones. The excess levels of COD in three stream zones were considerably different depending on the stream zones. COD tended to have the higher excess levels compared to BOD. The excess levels of T-P were relatively high in all stream zones. The excess levels of T-Coli were high in all stream zones. The excess level of T-Coli appeared to be the highest among four parameters in Geum river basin.

In the upstream zone, BOD, COD, T-P, and T-Coli were the indicators for impaired waters. COD, T-P, and T-Coli were the indicators in the downstream zone. In the M/D stream zone, the indicators were BOD, COD, and T-P. The major contributors were Okcheon, Juwon, Bonghwang, and Pumgok tributaries in the upstream zone. In the downstream zone, Nonsan, Seokseong, Gab, Yudeung, and Daejeon were the major contributing tributaries. In the M/D rivers zone, the major contributors were Iksan, Gobu, and Jeongeup tributaries. The indicators identified in this study should be considered in selecting applicable water quality indicators as target pollutants for the management of TMDLs. The major contributing tributaries are presumed to have much effect on the stream zones which they are flowing into. Authorities concerned should pay special attention to those tributaries in order to make effective water quality management for the basin.

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