Journal of Wetlands Research
Vol. 25, No. 4, November 2023, pp. 274-283

ISSN 1229-6031 (Print) / ISSN 2384-0056 (Online)
DOI https://doi.org/10.17663/JWR.2023.25.4.274

Investigation on the water quality challenges and benefits of buffer zone application to Yongdam reservoir, Republic of Korea

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용담호의 홍수터 적용을 위한 문제점 및 이점 조사 연구

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(Received : 10 August 2023, Revised : 13 October 2023, Accepted : 13 October 2023)

Abstract

Buffer zones, an example of nature-based solutions, offer wide range of environmental, social and economic benefits due to their multifunctionality when applied to watershed areas promoting blue-green connectivity. This study evaluated the effects of buffer zone application to the water quality of Yongdam reservoir tributaries. Particularly, the challenges and improvement of the buffer zone design were identified and suggested, respectively. Water and soil samples were collected from a total of six sites in Yongdam reservoir from September 2021 to April 2022. Water quality analyses revealed that among the sites monitored, downstream of Sangjeonmyeon Galhyeonri (SG_W_D2) was found to have the highest concentration for water quality parameters turbidity, total suspended solids (TSS), chemical oxygen demand (COD), total phosphorus (TP) and total nitrogen (TN). This finding was attributed to the algal bloom observed during the sampling conducted in September and October 2021. It was found through the soil analyses that high TN and TP concentrations were also observed in all the agricultural land uses implying that nutrient accumulation in agricultural areas are high. Highest TN concentration was found in the agricultural area of Jeongcheonmyeon Wolpyeongri (JW_S_A) followed by Jucheonmyeon Sinyangri (JS_S_A) while the lowest TN concentration was found in the original soil of Sangjeonmyeon Galhyeonri (SG_S_O). Among the types of buffer zones identified in this study, Type II-A, Type II-B and Type III were found to have blue-green connectivity. However, initially, blue-green connectivity in these buffer zone types were not considered leading to poor design and poor performance. As such, improvement in the design considering blue-green network and renovation must be considered to optimize the performance of these buffer zones. The findings in this study is useful for designing buffer zones in the future.

Key words : Blue-green network, buffer zones, nature-based solutions, watershed management

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요 약

자연기반해법 중 하나인 홍수터는 블루-그린 네트워크로서 유역의 환경, 사회 및 경제적 이점을 제공한다. 본 연구는 용담호 지류의 수질에 대한 홍수터의 적용 효과를 평가하였다. 특히, 홍수터의 문제점과 개선점을 파악하고 제시하였다. 2021년 9월부터 2022년 4월까지 용담호 내 총 6개 지점에서 수질 및 토양 시료를 채취하였다. 수질 분석 결과, 모니터링 지점 중 상전면 갈현리 하류(SG_W_D2)에서 탁도, 총 부유물질(TSS), 화학적 산소요구량(COD), 총인(TP), 총질소(TN) 농도가 가장 높은 것으로 나타났다. 이는 9월과 10에 실시된 샘플링은 녹조발생에 기여 가능한 것으로 분석되었다. 또한, 토양 오염도 분석을 통해 모든 농경지에서 높은 TN및 TP 농도를 보여 농경지의 영양물질 축적량이 높은 것으로 평가되었다. TN 농도는 정천면 월평리 농경지(JW_S_A), 주천면 신양리(JS_S_A) 순으로 나타났으며, 가장 낮은 곳은 상전면 갈현리 원지반(SG_S_O)로 조사되었다. 본 연구에서 확인된 홍수터 유형 중 II-A 유형, II-B 유형, III 유형은 블루-그린네트워크의 기능을 갖는 것으로 나타났다. 그러나, 초기 홍수터의 경우 블루-그린네트워크를 고려하지 않아 설계가 부실 및 성능이 저하되는 결과가 초래되기에, 이러한 홍수터의 성능을 최적화하기 위해서는 블루-그린 네트워크를 고려한 설계 개선 및 보수가 필요하다. 본 연구 결과는 향후 홍수터 설계시 활용 가능할 것을 사료된다.

핵심용어 : 블루-그린네트워크, 홍수터, 자연기반해법, 유역관리

1. Introduction

Blue-Green network is defined as multi-functional and beneficial interconnected natural and man-made landscape composed of water bodies and green spaces (Ghofrani et al., 2017). Blue-green network provide habitats for different biodiversity and improve quality of life in the cities by creating corridors and connecting natural spaces. Blue green-network is also considered as a new concept in improving the implementation of integrated water resource management since its application encompasses both the watershed area and the bodies of water. An innovative way of promoting blue-green network is through the application of nature-based solutions (NBS) concept and approach. NBS may be defined as systematic interventions that bring more diverse, nature and natural features and processes that address different challenges while providing environmental, social and economic benefits including biodiversity, climate change mitigation and adaptation, resilience, human well-being (Nika et al., 2020). Examples of NBS for water which are considered as decentralized systems include wetlands, bioretention systems, green roofs, infiltration basins and riparian buffer zones.

Riparian buffer zones in particular, are areas between uplands and water bodies that buffers the influx of water and associated constituents through complex interaction

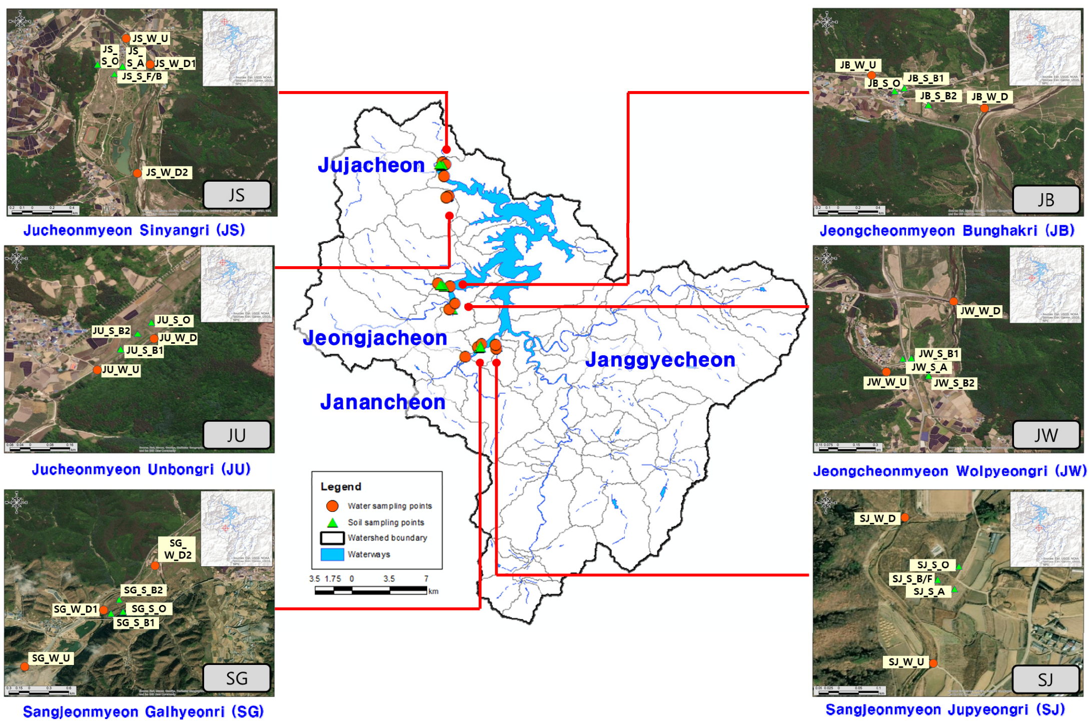

Fig. 1. Map of Yongdam Reservoir with the water and soil sampling points

associated with and helps improve different ecosystem services. Application of riparian buffer zones provide different benefits include but not limited to water quality improvement, peak flow attenuation, enhancement and supporting biodiversity, and providing aesthetics and social parks to public. While the other NBS water are mostly efficient when applied in smaller catchments, riparian buffer zones may be applied to larger watershed areas. Proper design and management of riparian buffer strips have the potential to provide much wider range of ecosystem services (Cole et al., 2020). However, even at present, challenges in the design and maintenance of the existing buffer zones are being faced in many countries due to varying environmental conditions and lack of environmental investigation after the development of buffer zones. Lack of design consideration to blue-green connectivity was also identified as one of the major problems hindering the attainment of desired performance of buffer zones. As such, this study evaluated the effects of buffer zone application to the water quality of Yongdam reservoir tributaries. Particularly, the challenges and improvement of the buffer zone design were identified and suggested, respectively.

2. Materials and Methods

2.1 Study Area

Yongdam watershed covers 930.43 km^2 of land area. Being one of the important water resources in Korea, the watershed is mostly composed of Forest area covering about 70.5% of its total land area. Forest area is followed by agricultural area, meadow and highly developing area which is composed of 21.4% 3.3% and 2.4%, respectively. The remaining 5% of the area is composed of wetlands and water bodies. Both agricultural areas and developing areas or urbanized areas are known to affect water quality where in most of the high pollutant concentrations are generated and directed to the receiving water bodies draining to the Yongdam reservoir. Investigation of buffer zones located in Janancheon, Jujacheon and Jeongjacheon was conducted since the agricultural areas, and highly urbanized areas in the three tributaries comprises 36% and 32%, respectively of the total agricultural area, and highly developing area in the whole Yongdam reservoir. The two rainfall stations located near Yongdam reservoir including Jinanjucheon station and Geumsan station receives 10-year annual average rainfall of 1371 ± 234 mm and 1216 ± 260 mm, respectively. Between the months of June to August, 33% to 68% and 35% to 70% of the annual rainfall occurred in Jinanjucheon station and Geumsan station, respectively.

2.2 Soil and Water Sampling and Analytical Analysis

Site investigation regarding the sample collection points was conducted in July 21, 2021 through the initial locations of buffer zones provided by the managers of Yongdam reservoir. Figure 1 shows the summary of water and soil sampling locations in Yongdam reservoir. Water and soil samples were collected monthly from September 2021 to April 2022. Water sampling points were selected to compare the upstream and downstream concentrations in each study area which was confirmed through flow direction and elevation of the study area. Water samples were tested for water quality parameters including pH, dissolved oxygen (DO), turbidity, conductivity, total suspended solids (TSS), chemical oxygen demand (COD), biochemical oxygen demand (BOD), total organic carbon (TOC), total nitrogen (TN), total phosphorus (TP), orthophosphate (PO_4P), nitrite (NO_2N), nitrate (NO_3N) and ammonium nitrogen (NH_4N) according to the standard methods for the examination of water and wastewater (APHA, AWWA, and WEF 1992). On the other hand, soil sampling locations were selected based on the size of agricultural area in each study area. Large agricultural area entailed that sampling in agricultural sites should be conducted. Otherwise, only original soil and buffer zone soils were collected. Soil quality parameters including moisture contents, ignition loss, conductivity, pH, COD, TN, TP were tested according to the soil sampling and methods by Carter and Gregorich, 2006. On the other hand, analytical analysis of the phosphorus forms including adsorbed phosphorus (Ads-P), non-apatite phosphorus (NAIP) and apatite phosphorus (Apatite P) were conducted in accordance to the methodology used by Kim et al., 2003. Water quality removal efficiencies of the buffer zones was calculated using equation 1. Results were statistically analyzed and calculated using Microsoft Excel including coefficient of variation (CV).

$$\text{Removal efficiency (\%)} = \frac{DownstreamConcentration - UpstreamConcentration}{DownstreamConcentration} \times 100$$

Eqn. 1

3. Results and Discussion

3.1 Comparison of water quality from upstream and downstream of each buffer zones

Demonstrated in Figure 2 are the comparison of water quality from the different monitoring locations in Yongdam reservoir. Water samples collected from upstream and downstream passed the water quality limit Classes Ia, Ib and II for both pH and DO. Lowest DO concentration amounting to 3.2 was observed in the downstream of SG (SG_W_D2) where algal bloom was observed during September and October sampling. Highest conductivity was detected in the upstream of SG (SG_W_U) which receives runoff and outflow from urban and agricultural areas. This finding might have affected the algal bloom causing high turbidity in the downstream due to the ionic compounds from the urban and agricultural areas in the upstream. Apparently, the water collected from the downstream of SG (SG_W_D2) was found to have the highest concentration for all the water quality parameters tested. It was also observed that

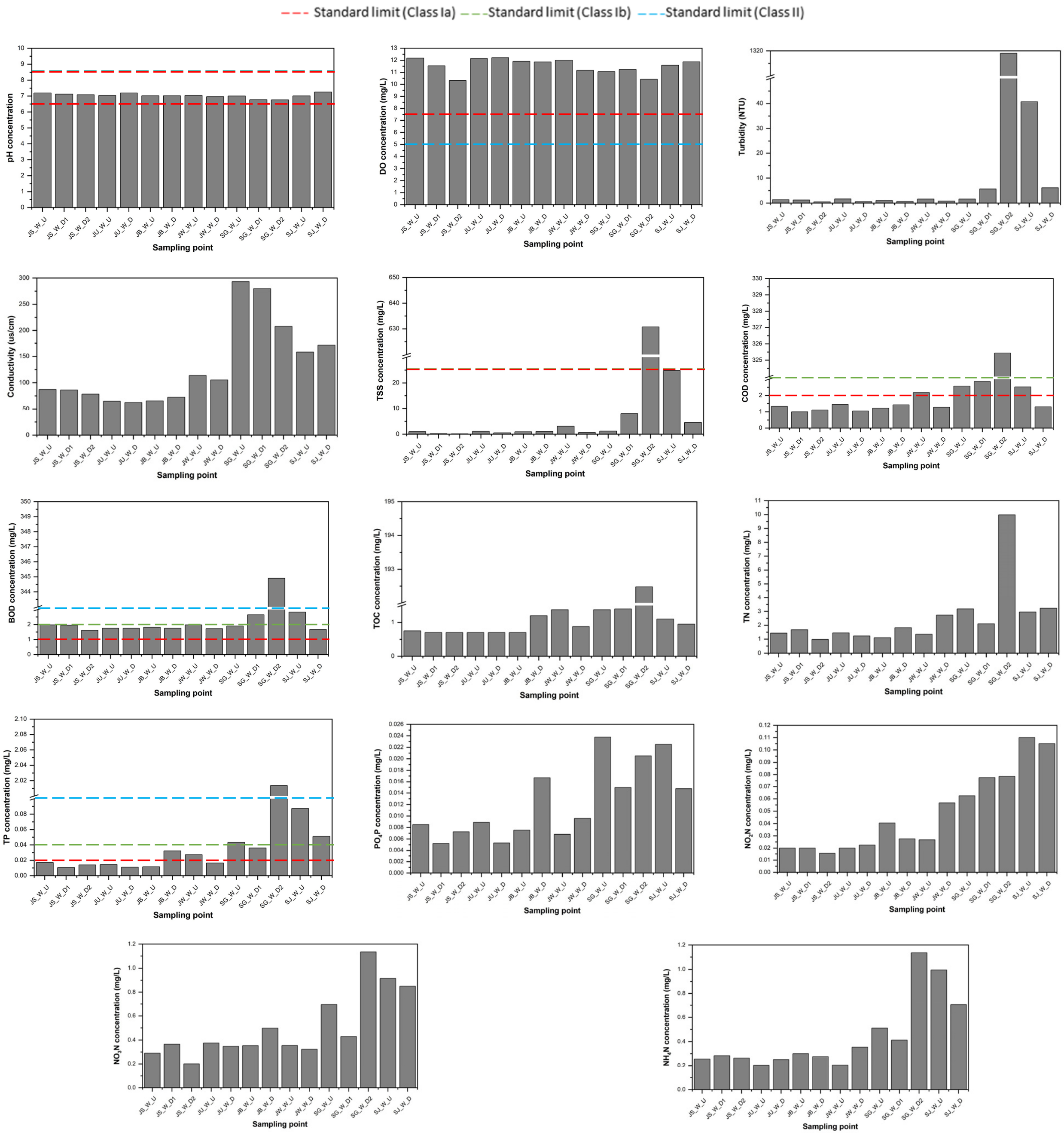

Fig. 2. Comparison of mean upstream and downstream water quality from different sampling sites

the algal bloom which was observed in SG (SG_W_D2) only occurred seasonally. Implying that other factors including seasonal changes in agricultural activities and lake hydraulic conditions caused the algal bloom of Yongdam reservoir. In addition, among the monitoring sites, only SG (SG_W_D2) exceeded the water quality limit Classes Ia, Ib and II for SS. This finding was also attributed to the noticeable algal bloom of this part of Yongdam lake during the monitoring conducted. During the site visit in September 27, 2021 the lake's excessive algal bloom was very apparent since the lake's water was color green. This is supported by the TSS concentration which was found to be more than 600 times greater compared to downstream. This finding may be attributed to the wash off of agricultural runoff and non-point source pollution and high temperature during the rainy months of June to August. During the second monitoring on October 18, 2021, lake water was still observed to be have algal bloom but appeared to be less in intensity compared to the previous monitoring. Except for SG_W_D1 (SG), SG_W_D2 (SG) and SJ_W_U (SJ), all the sampling sites were found to have passed the water quality standard limit Class Ia for BOD. Except for JW_W_U (JW), SG_W_U (SG), SG_W_D1 (SG) and SJ_W_U (SJ), all the other monitoring sites passed the water quality standard limit class Ia for COD. Apparently, SG_W_D2(SG) surpassed even the surpassed the water quality standard limit Class II for BOD and COD. High availability of organics from nearby water bodies can increase the potential for nitrate removal by plant uptake and microbial activity in riparian buffer zones (US EPA, 2005). TN and TP concentration in SG was also found to be 92 and 8 times greater in the downstream compared to the upstream. It was observed that among the monitoring sites, only SG_W_U (SG), SJ_W_U (SJ) and SJ_W_D (SJ) exceeded the water quality standard limit Class Ib for TP while SG_W_D2 (SG) exceeded the water quality standard limit Class II for TP. Except for conductivity and DO, grab sampling revealed that the water quality parameters in JS were found to have the lowest concentration among the monitoring locations. This finding is useful in identifying the appropriate design of buffer zone in a specific site based on water quality.

3.2 Characterization of soil quality from different land uses in Yongdam reservoir

Particle size analysis of the soil samples collected from the different land uses in Yongdam reservoir revealed that agricultural soils were mostly composed

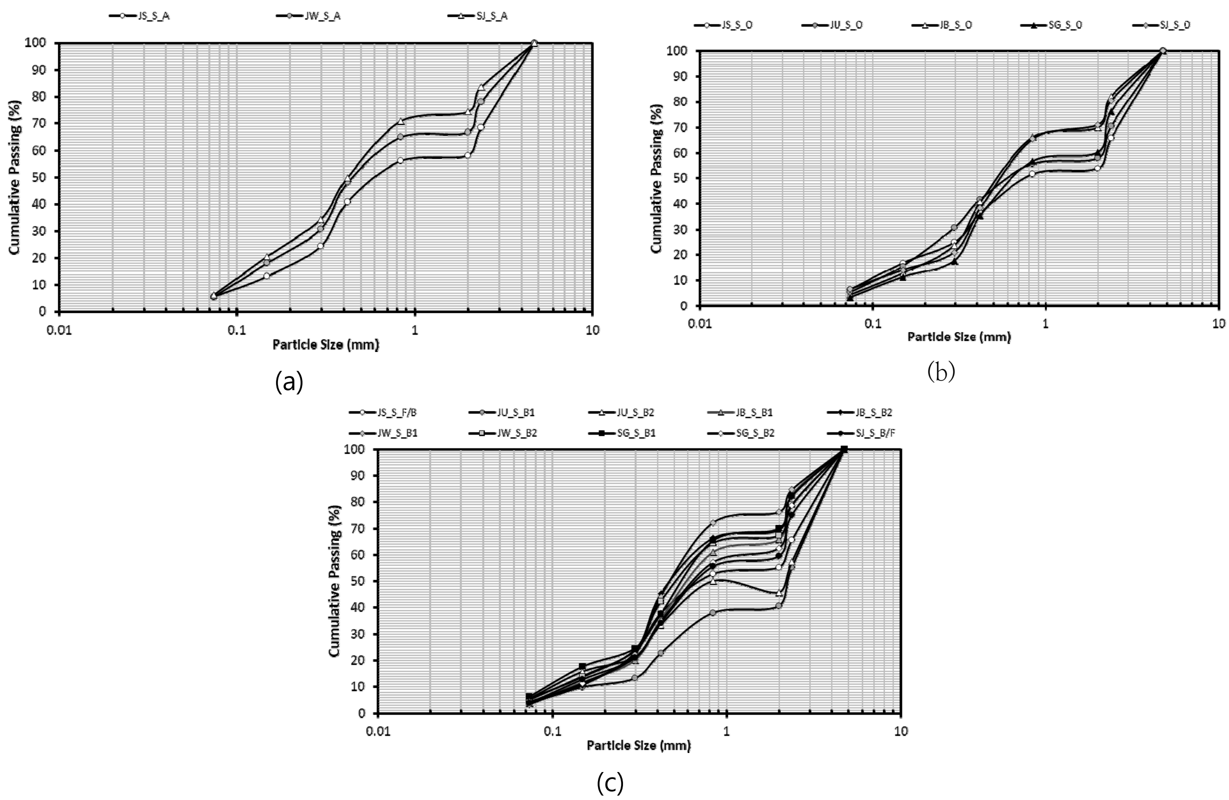

Fig. 3. Comparison of mean upstream and downstream water quality from different sampling sites

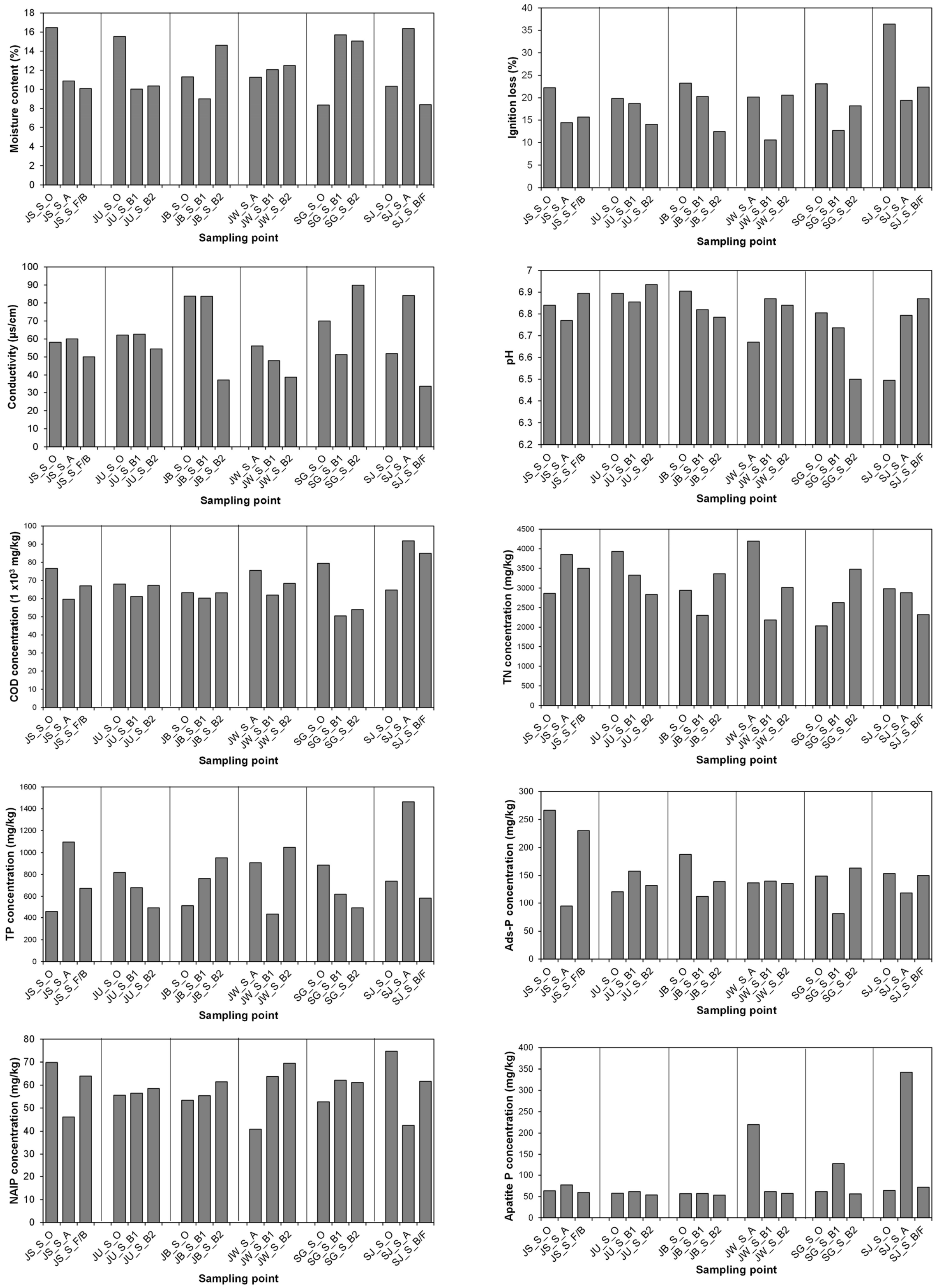

Fig. 4. Average soil quality from agricultural, forest and original soils in different sampling points

of sand ranging from 61% to 75% followed by gravel amounting to 19% to 38% exhibited in Figure 3. On the other hand, original soils were mostly composed of sand ranging from 19% to 3% followed by gravel amounting to 30% to 46%. Except for JU, the buffer zone and forest soils were mostly composed of sand ranging from 54% to 75% followed by gravel amounting to 24% to 45%. Majority of the soil from the buffer zone in JU were composed of 54% to 59% gravel and 39% to 44% sand. Soil particle size distribution is important when developing a buffer zones nearby streams and rivers since it affects the attainment of water quality management and ecosystem services objectives for buffer zones. In a study conducted by Dosskey et al., 2011, it was found that by using finer particle for soil from silty clay loam to fine sandy loam, pollutant trapping efficiency may be improved. However, in selecting the appropriate soil for buffer zone design, high permeability and infiltration rate soils particularly sandy loam soils are required to ensure runoff volume mitigation (USDA, 2008). At present, there is still lack of information about the proper selection of soil for the design of buffer zones since depending on the primary objective, an appropriate soil may be selected. Another consideration in selecting soil is the survival of native vegetation especially since buffer zones are prone to frequent changes from dry and wet and vice-versa conditions depending on the water flow, water level and climate.

Understanding the performance of buffer zone for water quality management in reservoirs require proper environmental investigation. Figure 4 shows the comparison of soil quality from different sampling locations. Moisture content of soils collected were found to be ranging from 8.4% to 16.5% with the original soil in JS having the highest moisture content. Specifically, the moisture content of buffer zones ranges from 8.4% to 15.7%. The high soil moisture content and nutrient-rich status of riparian zones provide excellent conditions for tree growth and, consequently, wooded buffers can be extremely effective at carbon sequestration, particularly in the early stages of development (Cole et al., 2020). Apparently, pH concentration ranges from 6.5 to 6.94 in all the sampling locations implying that the soil are in neutral state. Soil pH is an important factor affecting the solubility of minerals and nutrients in the existing buffer zones for water quality management. Ignition loss, a measure of the organic matter in soils were found to be ranging from 10.6% to 36.4% with the greatest ignition loss observed in the original soil in SJ. Higher ignition loss represents higher organic matter which will imply greater capacity to retain and exchange positively charged ions. High organic content in soil will also support nutrient cycling and helps in improving soil structure by maintaining tilth and minimizing erosion (Australian Department of Primary Industries, 1993). Lastly, the soil conductivity ranges from 33.5 us/cm to 89.8 us/cm. Soil conductivity was found to be highly correlated to nitrates, potassium, sodium, chloride, sulfate, and ammonia by US Department of Agriculture. COD and TP concentrations were found to be highest in the agricultural area located in SJ (SJ_S_A). Apparently, COD concentration in all sites were almost in the same range with CV amounting to 0.16 compared to TN and TP with CV amounting to 0.20 and 0.36, respectively. High TN and TP concentrations were also observed in all the agricultural land uses implying that nutrient accumulation in agricultural areas are high. Highest TN concentration was found in the agricultural area of JW followed by JS while the lowest TN concentration was found in the original soil of SG. In riparian buffer zones, high nitrogen removal would require organic rich soils (USDA, 2008). Adsorbed P and Apatite P in all sites monitored were almost in the same range with CV values ranging from 0.16 to 0.3 implying that there is no significant difference between the values. NAIP, on the other hand, have high variability with CV value 0.84. Adsorbed P are composed of inorganic phosphorus mostly attached to the clay surface, and iron (Fe) and aluminum (Al) oxides which are usually slowly absorbed by plants. NAIP are phosphorus forms related to metals including Fe and Al which are easily adsorbed and highly dependent on environmental conditions such as oxidation reduction potential (ORP), temperature and DO. Lastly, Apatite P are phosphorus form included in calcium. The adsorption of this phosphorus type is not easily affected by environmental conditions such as oxidation reduction potential (ORP), temperature and DO. Understanding the physico-chemical characteristics of the soil is important in designing buffer zones since these affects different biogeochemical cycle in the buffer zone. For instance, plants and microbes release phosphatase enzymes to mineralize organic P compounds. Phosphatase activity refers to the actions of two complementary, but distinct enzymes: phosphodiesterase (PDE) and phosphomonoesterase (PME). PDE hydrolyses complex organic P compounds such as nucleic acids and phospholipids into phosphomonoesters (mononucleotides and inositol phosphates). These extracellular enzymes are key agents in organic P mineralization and play important roles in plant response to limited P availability or increasing P demand in soil (Cabugao et al., 2017). Other studies have shown increases in phosphatase activity with soil pH in moderately well drained soil, with maximal activity occurring at a pH between 6.5 and 6.9 (Amador et al. 1997).

3.3 Blue-green network challenges and its implication on the performance of buffer zones

Figure 5 shows the different types of buffer zones in the Yongdam reservoir based on water flow and blue-green network. Type I which may be found in JB, JW, SJ lacks blue-green connectivity since the river water is not passing through the buffer zone. In designing riparian buffer zones, it is important to consider both the overland and subsurface water flow path to ensure that the attainment of both water quality and quantity objectives (Fischer and Fischenich, 2000). Type IIA and IIB buffer zones were equipped with free-water surface and sub-surface wetlands, respectively. This type of buffer zone was observed in JS and SG. While an existing blue-green network may be observed, this type of buffer zone should also consider proper design of wetland for optimized buffer zone efficiency. Wetlands in buffer zones help in treating water by removal or retention of nutrients and other diffuse pollution present in waters moving from terrestrial to riverine ecosystems, such as from agricultural fields to rivers (Carstensen et al., 2020). By properly designing a wetland buffer zone, 31% to 80% of total nitrogen may be expected from the similar system as reported by Walton et al. (2020). In buffer zones, the removal of nitrogen can be achieved by vegetation uptake, anaerobic ammonium oxidation, microbial nitrification and denitrification, and conversion of nitrate-nitrogen (NO_3-N) to nitrogen which are some of the pollutant removal mechanisms present in wetlands (Yi et al., 2021). Type III buffer zone was observed in JU. This type of buffer zone treats the effluent of a wastewater treatment plant (WWTP). This type of buffer zone has limited blue-green connectivity since only the treated water from the WWTP is directed to the buffer zone for further treatment. The natural blue-green network specifically for the river and the buffer zone is not observed in the upstream of the buffer zone. These findings were supported by the comparison of the

Table 1. Summary of pollutant removal efficiencies of different buffer zones

Location	Buffer zone type	Site code	Removal efficiency (%)						
			TSS	BOD	COD	TOC	TN	TP	PO4P
JS	Type II	JS_W_D1	46	7	25	5	-*	30	39
JS	Type II	JS_W_D2	39	18	16	6	33	4	15
JU	Type III	JU_W_D	51	3	32	-	18	25	40
JB	Type I	JB_W_D	-	-	-	-	-	-	-
JW	Type I	JW_W_D	56	8	25	22	-	22	-
JG	Type II	SG_W_D1	-	-	-	2	38	23	37
SG	Type II	SG_W_D2	-	-	-	-	-	-	14
SJ	Type I	SJ_W_D	7	35	23	-	-	30	34
Average	Type I		21	14	16	7	-	18	11
	Type II		21	6	10	3	18	14	26
	Type III		51	3	32	-	18	25	40

* signifies negative removal efficiency

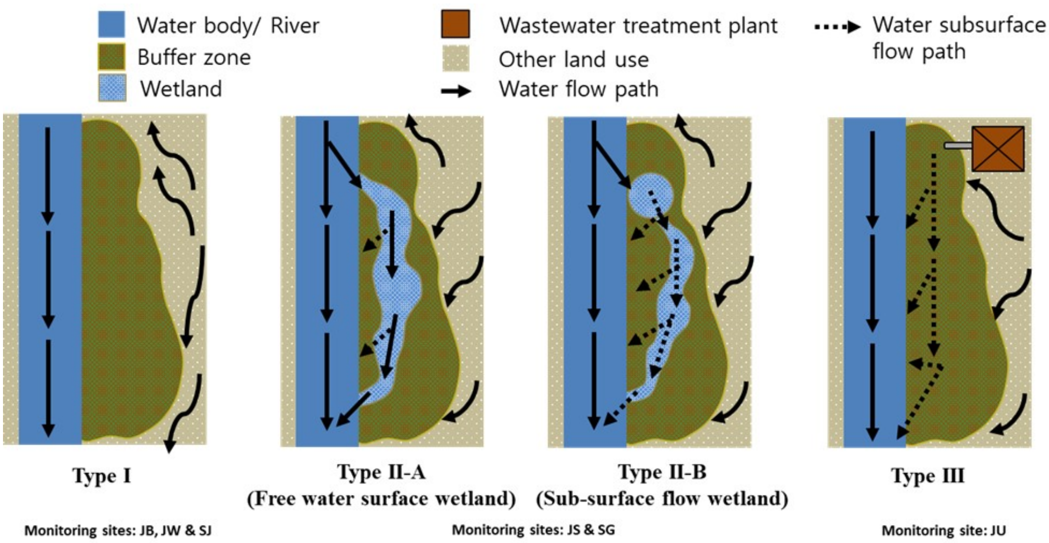

Fig. 5. Classification of buffer zones according to blue-green connectivity

pollutant removal performance of the different buffer zone types summarized in Table 1. Among the buffer zone types, Type II-A, Type II-B and Type III were the buffer zone types that has blue-green connectivity. However, initially, blue-green connectivity in these buffer zone types were not considered leading to poor design and poor performance. As such, improvement in the design considering blue-green network and renovation must be considered to optimize the performance of these buffer zones. In addition, it was found that rehabilitated buffers have larger rates of soil organic carbon sequestration as compared to natural forest buffers (Ofosu et al., 2021).

4. Conclusion

Buffer zones, an example of NBS, enhances ecosystem services by complex interaction between biodiversity, water bodies and uplands. There are still a lot of uncertainties in designing buffer zones to achieve its optimum multi-beneficial performance. As such, this study investigated the benefits and challenges of buffer zone application to Yongdam reservoir, an important water source in the Republic of Korea. It was found that water quality in the reservoir was apparently affected by different environmental conditions including but not limited to temperature, rainfall and land use. Except for SG, all the site investigated were found to pass the Korean Water Standard Limit II which was affected by extreme algal bloom observed during the water quality monitoring. Among the land uses that were investigated around the buffer zones, agricultural land uses were found to have the highest TN, TP and COD concentrations attributed to high nutrient and organics accumulation in agricultural areas. Blue-green connectivity of buffer zones was also found to be an important consideration in its design. Among the buffer zone types investigated in this study, Type II-A, Type II-B and Type III were the buffer zone types that has blue-green connectivity. However, enhancing the design to further improve blue-green network in these buffer zone types must be considered to optimize the performance of these buffer zones. The findings in this study is useful for designing buffer zones in the future.

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