

Article

Design of Non-Structural Practices for Sustainable Water Quality Improvement in an Urban River: A Case Study of South Korea

Taesung Kang ¹, Nayeong Yu ¹, Minhwan Shin ¹, Kyoungsoo Na ², Kyoung Jae Lim ³  and Jonggun Kim ^{3,*}

¹ EM Research Institute, Chuncheon-si 24408, Republic of Korea; kangstar2003@naver.com (T.K.)

² Department of Business Administration, Halla University, Wonju-si 26404, Republic of Korea

³ Department of Regional Infrastructure Engineering, Kangwon National University, Chuncheon-si 24341, Republic of Korea

* Correspondence: jgkim@kangwon.ac.kr

Abstract: Urban rivers exhibit characteristics of low flow and significant water quality fluctuations, making them susceptible to pollution from various sources such as untreated sewage, non-point pollution within the urban area, and unknown inflows. To address water quality management in urban rivers, precise investigations into background water quality, pollution levels, and the characteristics of pollution sources are essential. Following the identification of pollution sources, sustainable river management strategies, incorporating both structural and non-structural measures, are crucial. This study aims to develop continuous and long-term river management strategies, considering the characteristics of urban river basins, through citizen participation governance and non-structural approaches. Citizen networks were formed for each target urban river, and activities for water quality improvement were proposed and implemented. This study provides phased approaches to citizen participation governance, and activities include citizen-led water quality monitoring, the purification and monitoring of riverbank pollution sources, and water-related education. It emphasizes the importance of local residents' interest in urban river water quality improvement and underscores the need for sustained activities through local citizen networks. Additionally, active participation and investments from the local government, government agencies, and various experts are deemed essential.

Keywords: urban river management; citizen participation governance; non-structural practices; citizen participation water quality monitoring; sustainable water quality improvement



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1. Introduction

Urban rivers, unlike closed ecosystems such as lakes, are characterized by the free movement of substances and the continuous connection between upstream and downstream areas, making them susceptible to pollution and substance changes in upstream regions [1]. In addition to their functions of drainage and flood control, urban rivers play diverse roles, such as in water purification, air purification, a habitat for organisms, material consumption and supply, and serving as the backbone of green networks. Urban rivers, with their significant flow variations, experience increased flow during floods, while experiencing a substantial decrease during normal conditions, leading to channel degradation [2]. During normal conditions, point sources such as sewage treatment and unknown sources contribute to water quality issues. However, during floods, non-point pollution sources, such as surface runoff, have a significant impact on water quality. Due to such fluctuations in water quantity and quality, by implementing water quality improvement projects it is difficult to yield significant effects and to sustainably maintain improvements over time.

In addressing water quality issues in urban streams, strategies can be classified into structural and non-structural measures (Table 1). Commonly implemented structural measures include artificial wetlands, sedimentation ponds, vegetation filters, and infiltration

facilities (such as infiltration ditches and basins). Artificial wetlands act as purification facilities, utilizing a combination of physical, chemical, and biological processes to cleanse water polluted by both point and non-point sources. They provide benefits such as temporary flood control, the prevention of soil erosion by reducing flow velocity, and groundwater recharge, while also serving as habitats for ecosystems and leisure spaces for local residents. Sedimentation ponds, on the other hand, focus on concentrating and settling soil and pollutants entering water bodies, preventing sediment dispersion downstream and efficiently facilitating sediment deposition. The captured pollutants undergo natural purification processes within the pond, leading to water quality improvement. Vegetation filters, such as tree-filter boxes and green strips, reduce pollutants through soil filtration, adsorption, and plant absorption [3–9]. These installations are commonly placed in urban areas, including roads, tree-lined spaces, parking lots, and sidewalks. Infiltration facilities aim to channel rainfall runoff underground, minimizing pollutant levels through soil filtration and absorption. Examples include permeable pavements, infiltration rain gardens, infiltration ditches, infiltration wells, and trenches. This natural drainage system effectively reduces pollutants and enhances sustainable water management within urban environments.

Table 1. Structural and non-structural measures for urban river water quality improvement.

Structural Measures		Non-Structural Measures	
Category	Management Measures	Category	Management Measures
Artificial Wetlands	Water Purification Wetlands/Free Surface Wetlands	Common	Establishment and Operation of Resident Participation Governance
Sedimentation Facilities	On-line/Off-line Sedimentation Facilities	Livestock Sector	Operation Technology and Education Support for Self-treatment Facilities
			Consulting for Individual Treatment Facilities
Vegetated Filtration	Vegetated Filtration Basin	Land Sector (Upper Agricultural Areas)	Non-point pollutant source BMPs (Best Management Practices)
	Vegetated Ditch		Management of Agricultural Discharge
Infiltration Facilities	Infiltration Trench	Residential Sector	Management of Unknown Sources
	Infiltration Reservoir		Water Conservation

While structural measures are crucial, they may face challenges related to maintenance and functional degradation. Therefore, their integration with non-structural measures is essential for maximizing the effectiveness of water quality improvement initiatives. Non-structural measures for addressing water quality concerns focus on source management and include pollution control strategies for various sources such as domestic, agricultural, and livestock-related sources. Non-structural Best Management Practices (BMPs) offer several benefits, including cost savings, adaptability, better water quality, improved ecosystem health, increased public involvement, enhanced resilience against climate change, and help in meeting environmental regulations. They focus on preventive measures and management strategies rather than on constructing new physical infrastructure [10]. In the realm of domestic pollution control, the citizen monitoring of rivers, periodic river clean-up activities, and enhanced management of sewage facilities are essential components in a long-term perspective. Community participation in continuous water quality monitoring, river clean-up initiatives, pollution source surveillance, and monitoring of unidentified sources (the ongoing detection of continuous leakage from facilities and assessment of storm water management practices) are coupled with sustained local resident education and promotion. Measures for water conservation and quality management, such as utilizing environmentally friendly detergents (e.g., EM detergents), are also recommended. However,

proposals for specific non-structural measures are still insufficient for the urban river water quality management, and there are no cases where the reliability of resident participation monitoring data and the quantitative water quality improvement effect of the EM detergents have been presented. For agricultural pollution control, strategies include supplying eco-friendly fertilizers to upstream agricultural areas, promoting microbial agents, conducting community-oriented eco-friendly education, managing livestock facilities, inspecting and managing non-point pollution sources, applying Best Management Practices (BMPs), and participating in riverbank clean-up activities. Additionally, BMPs for farmland in urban upstream areas involve applying water management techniques like a canal for irrigation management in paddy fields and constructing Sillon dams in fields to reduce agricultural runoff [11–14]. The success of these management strategies heavily relies on the active involvement of local residents. Establishing community-based governance through citizen participation is crucial for developing sustainable non-structural measures for urban stream water quality improvement [15,16].

With the increasing importance of governance in recent water management practices, there is a need for a bottom-up approach in water management strategies, where citizen-participatory governance takes center stage in identifying and resolving on-site water issues [17,18]. Moreover, in this new system, there is a need for a shift toward on-site-centered processes, including project identification, project implementation, and post-management, to ensure a comprehensive approach. The existing urban river improvement projects have been carried out in a top-down structure, led by the government and managed by local officials, with residents in the region benefiting from this downward approach. However, this approach poses difficulties in delivering tangible benefits to the local community. To address these challenges, a restructuring is required, shifting from a centralized government and official-centric model to a bottom-up approach where local residents participate directly, with an increased involvement of relevant stakeholders [19]. The current trend in society involves diversification, improved economic conditions, and an increasing civic awareness, leading to a growing desire for citizen participation in urban policies. Advanced countries actively embrace citizen-oriented governance by accommodating citizen demands to promote a more citizen-centric governance model. The governance in this context refers to the restructuring of administrative systems to incorporate the creativity and ideas of the private sector, redistributing authority in the process. Therefore, for the future improvement of urban rivers' water quality, the top-down approach that involves citizen participation and a restructuring towards a more horizontal system involving various stakeholders is necessary for sustainable river management.

In addition, the current approach to water management relies heavily on technocratic, scenario-based methods, which are effective in the short term but are prone to unintended consequences in the long term due to insufficient consideration of dynamic feedback among natural, technical, and social aspects of human–water systems. Sociohydrology, as a discipline, is crucial in shaping policy by creating a broadly applicable comprehension of phenomena resulting from interactions between water and human systems [20].

Examples from other countries demonstrate the effectiveness of community-driven environmental initiatives. The Murasaki River in Kitakyushu City, Japan, faced severe flood damage and water pollution. However, through river revitalization efforts, flood damage was reduced, and water quality improved. The project considered ecosystem preservation and created a resident-friendly waterside space, turning it into a symbolic area in the city visited by many tourists. The Murasaki River revitalization not only focused on environmental restoration through river rehabilitation but also strategically utilized it as an opportunity for riverside urban regeneration. The project successfully restored the river and revitalized the riverside urban area. The strong determination of local leaders, public leadership, collaboration with residents and local authorities, and the incorporation of diverse opinions and ideas from the project's early stages were crucial to its success. Residents actively participated, recognizing that enhancing the value of urban rivers contributes to improving their quality of life [21,22]. In the UK, the main causes of pollution

in the Thames River are identified as household waste from residents, the government's waste separation policies, and population overcrowding. To address these issues, a continuous campaign was initiated through citizen movements to gradually reduce pollution sources in the Thames River. The campaign activities led to the formation of a harmonious relationship between environmental groups and the government. The initially somewhat adversarial relationship with the government evolved into a nationwide environmental campaign, as mutual understanding between citizen groups and the government grew, fostering collaborative efforts for environmental improvement [23]. The Elizabeth River in the United States, with its many military facilities and commercial ports, experienced significant contamination, particularly from various heavy metals in its estuary. Recognizing the urgency of this pollution issue, a community-led environmental restoration project was initiated, driven by the belief that without restoring the ecosystem, sustaining the local economy would be impossible. The project encompassed a range of activities, including the collection of litter along the riverbanks, cultivation of green plants, and reduction in detergent usage. Over 60 industrial facilities along the river, such as the Norfolk Naval Shipyard and Norfolk International Terminals, actively joined the initiative as River Stars, playing a crucial role in the collaborative endeavor to rejuvenate the river [24]. In Germany, the River Emscher faced severe pollution due to industrialization in the Ruhr region and coal mining, leading to a compromised sewage treatment environment. In response to this issue, a separate sewage pipeline was installed, and the upper reaches of the river were utilized. Residents actively participated in voluntary activities, including cleaning up riverbank litter, managing vegetation along the river, preventing bank erosion, and implementing nature-based learning programs in elementary and middle schools [25].

Examining exemplary cases of community-driven river management reveals the importance of active participation from various stakeholders, including local residents, to achieve effective urban river water quality improvement [26,27]. Moreover, diverse instances of community involvement in urban river water quality enhancement underscore the urgent need for not only the existing structural measures but also the development of non-structural measures involving the active participation of local residents.

Therefore, the purpose of this study is to identify the main sources and causes of pollution in urban rivers and to design a framework for community-participatory governance and non-structural measures for sustained urban river water quality improvement. The outcomes of this research can serve as fundamental data for establishing governance-based policies and systems for urban river water quality management. This paper contributes to the understanding of urban resilience strategies in developing countries.

2. Materials and Methods

This study aims to identify the characteristics of major pollution sources in selected urban stream basins through water quality monitoring and detailed field surveys of major inflowing streams, and to propose non-structural measures for improvement. It is particularly crucial for the sustainable improvement of water quality in urban streams that local residents actively participate, hence this study intends to present a citizen participation governance operation plan. Additionally, it seeks to verify the reliability of community participation monitoring data for continuous pollution source improvement and to quantitatively present the effects of water quality improvement through the use of eco-friendly detergents (Figure 1).

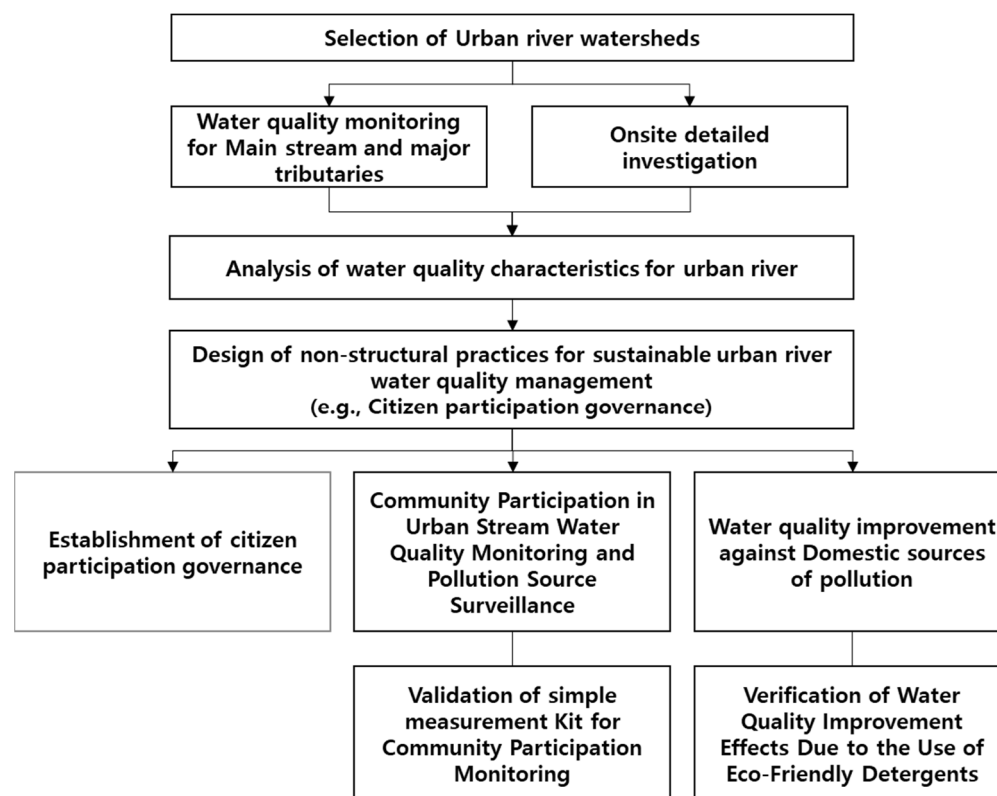


Figure 1. Flowchart of this study.

2.1. Study Area

In this study, the Gongji stream and Chungju stream located in South Korea were selected as the target urban rivers (Figure 2). The Gongji stream watershed has an area of 57.08 km² and a stream length of 19.41 km. The watershed comprises urban areas (25.2%), agricultural areas (21.8%), forested areas (43.1%), and undeveloped land (6.6%), mainly classified as an urban area with a high population of 285,585. Water quality issues related to urban streams in the Gongji stream watershed include sedimentation issues downstream, pollution sources originating from upstream rural areas, and discharge of domestic wastewater from upstream. The Chungju stream watershed has an area of 42.03 km² and a stream length of 6.93 km. The watershed consists of urban areas (25.4%), agricultural areas (32.8%), forested areas (36.0%), and undeveloped land (2.2%). Although predominantly forested and agricultural, it is considered an urban area with over 25% being urbanized, and it has a population of 210,737. Water quality challenges in the Chungju stream watershed include the distribution of farmland near the stream, unknown sources of pollution, discharge of domestic wastewater, nonpoint source pollution from initial rainfall, and incomplete separation of sewage and stormwater. Various civic organizations are actively engaged in water quality improvement activities in both the Gongji stream and Chungju stream watersheds. This study aims to identify the main pollution sources in each urban river and suggest sustainable, non-structural measures for water quality improvement in collaboration with local residents.

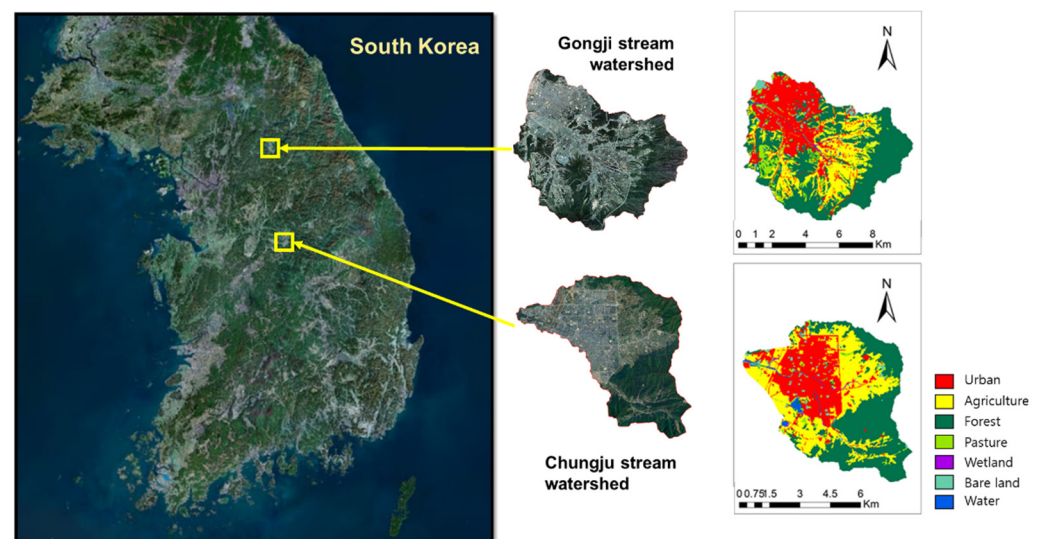


Figure 2. Study areas (Gongji stream watershed and Chungju stream watershed).

2.2. Urban River Water Quality Pollution Monitoring and Pollution Source Investigation

In this study, monitoring and on-site precision surveys were conducted in the selected urban river watersheds to identify key pollution areas and sources. Monitoring and field surveys were carried out from November 2020 to November 2022 to measure pollutants originating from each target area, with monitoring points selected at major inflow sites (7 points for Gongji stream and 5 points for Chungju stream) (Figure 3). Flow and water quality monitoring were conducted periodically twice monthly during this period (Total of 50 times).

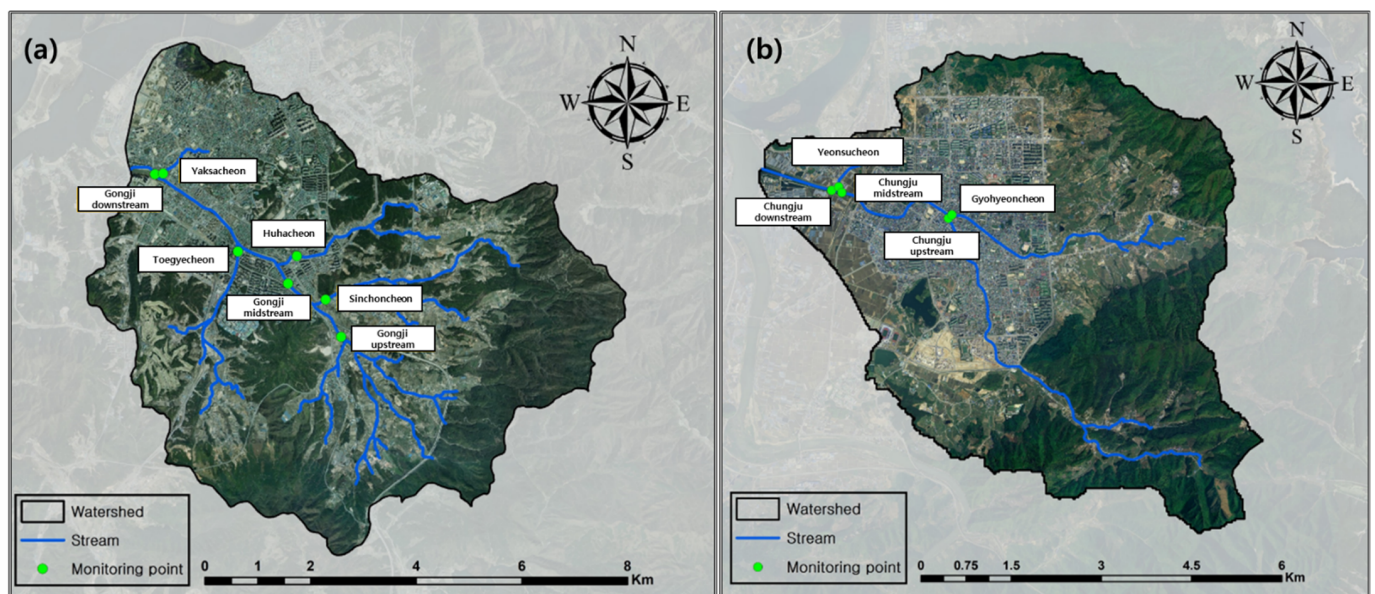


Figure 3. Monitoring sites in the urban river watersheds: (a) Gongji stream, (b) Chungju stream.

Flow measurements were performed after training personnel in hydrological surveys. Velocity, water depth, and river width were measured at the monitoring points, and flow was calculated using the velocity–area method. Water quality parameters, including water temperature, dissolved oxygen (DO), pH, and electrical conductivity (EC), were measured on-site. Parameters such as biochemical oxygen demand (BOD₅), suspended solids (SS), total nitrogen (T-N), total phosphorus (T-P), and chlorophyll-a (Chl-a) were transported to the laboratory for analysis [28] (Table 2).

Table 2. Official testing method with respect to water pollution process.

Items	Measurement Method	Preservation Method	Max. Preservation Period	Instrument
Water temperature	Thermometer	-	Instantaneous	Multi-item Water Quality Meter (EXO1, YSI Inc., Yellow Springs, OH, USA)
DO	Electrode method			
pH				
EC				
BOD ₅				
SS	Fiberglass method	4 °C	24 h	DO meter (ysi-5000, USA)
			48 h	
			7day	Drying Oven (SH-DO-150FS, SH Scientific, Sejong, Republic of Korea)
T-N	Ultraviolet/visible spectroscopy—oxidation	4 °C, H ₂ SO ₄ pH2 or less	28 day (7 day)	Autoclave and Spectrophotometer (LAC-5060SD and SM1600pc and HS3300., Labtech, Seoul, Republic of Korea and Azzota, Claymont, DE, USA)
T-P	Ultraviolet/visible spectroscopy		28 day	
Chl-a	Ultraviolet/visible spectroscopy	Filter immediately and store at −20 °C or below	7 day (24 h)	Centrifuge and Spectrophotometer (800D and SM1600pc and HS3300., KOREA and USA)

To assess the water quality status and identify pollution-prone areas in the Gongji stream and Chungju stream, a detailed survey was conducted from the downstream to upstream inflow streams of the target watersheds on 20 April 2021. Sampling was performed at unknown source points for pollution sources, including livestock, industry, land use, individual wastewater treatment facilities, classified sewage interceptors, artificial waterways, and drainage channels. Water quality samples were collected at these unknown source points, and analyses were conducted for BOD₅, SS, T-N, T-P, and TOC. Additionally, on-site surveys around the urban streams were carried out to investigate the factors directly impacting water quality, such as unidentified sources. Based on these pollution source data, an analysis of pollution contributions from major inflow streams was conducted. The identification of key pollution sources enabled the proposal of long-term, community-based, non-structural measures through citizen participation-oriented governance.

2.3. Desing of Non-Structural Practices for Sustainable Urban Stream Management

In this study, we identified the main sources of pollution in a targeted urban stream through water quality monitoring and detailed field surveys, and proposed non-structural strategies for the sustainable improvement of water quality. Non-structural measures are deemed more cost-effective and sustainable in the long term for water quality management compared to structural interventions. As part of these efforts, this research outlined ways to engage local residents in non-structural water quality improvement measures. It introduces the concept of creating community engagement governance structures, which include relevant citizen groups for each urban stream, to jointly develop various activities and non-structural approaches to improve water quality.

This research presents a step-by-step approach for forming such resident participation governance strategies and offers significant non-structural water quality improvement measures that locals can engage in. Additionally, the proposed non-structural water quality improvement initiatives include conducting quantitative evaluations to ensure the reliability of data collected through citizen participation monitoring. Furthermore, it analyzes the quantitative impacts on water quality from using eco-friendly detergents to tackle pollution sources from domestic activities.

3. Results

3.1. Water Quality Monitoring and Detailed Investigation of Pollution Sources in Main Inflowing Streams

3.1.1. Analysis Results of Water Quality Concentrations and Pollution Loadings in Main Stream and Major Tributaries

This study analyzed the flow and water quality concentrations in the Gongji stream watershed based on a total of 34 monitoring events conducted from November 2020 to November 2022. The results revealed that the average flow rates were highest at the downstream point of the Gongji stream's main channel, measuring $0.808 \text{ m}^3/\text{s}$, followed by the midstream point at $0.378 \text{ m}^3/\text{s}$. The lowest flow rate was recorded at the Huhacheon point, registering $0.104 \text{ m}^3/\text{s}$. BOD₅ and SS concentrations were found to be elevated at the downstream location, while T-N concentrations were highest in Sinchoncheon. T-P and Chl-a concentrations were most significant at the Toegyecheon point. Precision surveys conducted at different sections (upstream, midstream, downstream) and tributaries identified domestic wastewater inputs at the Huhacheon point and a combination of domestic wastewater and soil runoff at the Sinchoncheon point.

Utilizing the flow and water quality concentration analysis results, the daily pollutant loads were calculated. The combined results from the 34 monitoring events indicated that the downstream point of the Gongji stream had the highest pollutant loads, with the BOD₅ at 3758.6 kg/day, SS at 14,788.0 kg/day, T-N at 8935.2 kg/day, T-P at 137.9 kg/day, and Chl-a at 7386.0 kg/day. The midstream point of the Gongji stream ranked second in pollutant loads. Excluding the main channel, the upstream watershed and the upstream point of the inflowing streams into the Gongji stream exhibited the highest loads for the BOD₅ (578.0 kg/day), SS (2274.1 kg/day), and T-N (2294.7 kg/day). The T-P and Chl-a loads were most significant at the Toegyecheon point, measuring 40.0 kg/day and 1740.3 kg/day, respectively (Figure 4a).

This study conducted an analysis of flow and water quality concentrations in the Chungju stream watershed, revealing crucial insights from a total of 34 monitoring events conducted from November 2020 to November 2022. The average flow rate was found to be highest at the downstream point of the Chungju stream, measuring $0.667 \text{ m}^3/\text{s}$, followed by the midstream point at $0.505 \text{ m}^3/\text{s}$. The lowest flow rate was recorded at the Yeonsucheon point, registering $0.163 \text{ m}^3/\text{s}$. Water quality concentrations, specifically BOD₅, T-P, and Chl-a, were highest at the Yeonsucheon point, while SS concentrations were elevated at the downstream point of the Chungju stream, and T-N concentrations were highest at the Gyohyeoncheon point. Additionally, precision surveys conducted at different sections (upstream, midstream, downstream) and tributaries identified high concentrations of domestic wastewater at the Gyohyeoncheon point, impacting the mid- and downstream areas of the Chungju stream. The combined results from the 34 monitoring events indicated that the downstream point of the Chungju stream had the highest pollutant loads, with the BOD₅ at 4291.0 kg/day, SS at 46,282.1 kg/day, T-N at 10,542.9 kg/day, T-P at 236.8 kg/day, and Chl-a at 10,238.3 kg/day. The upstream point of the Chungju stream ranked second in BOD₅ and Chl-a loads, while the midstream point ranked second in SS, T-N, and T-P loads. Excluding the midstream and downstream areas, the upstream watershed and the upstream point of inflowing streams into Chungju stream exhibited the highest pollutant loads for BOD₅ (2164.6 kg/day), SS (22,089.0 kg/day), T-P (89.0 kg/day), and Chl-a (8304.5 kg/day), while T-N was highest at the Gyohyeoncheon point, measuring 5760.7 kg/day (Figure 4b).

During the research period, the monitoring results showed that, in the downstream section of the Gongji stream and Chungju stream, the water quality concentrations mostly exhibited similar trends of an increase or decrease in accordance with variations in flow rates. However, it was observed that certain discrepancies occurred due to external influences such as antecedent rainfall, river works, and an input of turbid water.

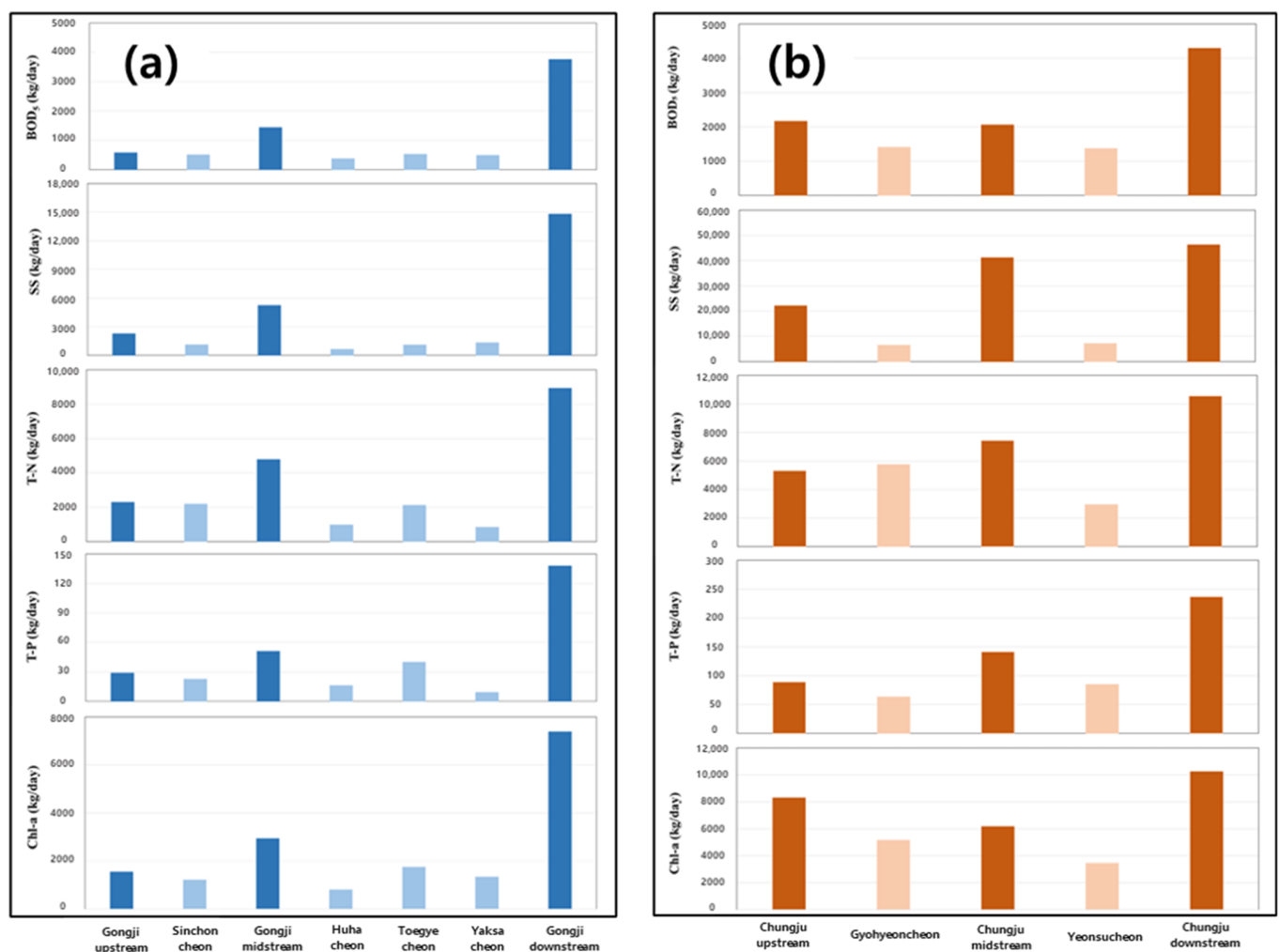


Figure 4. Pollutant load estimation using watershed monitoring results: (a) Gongji stream watershed, (b) Chungju stream watershed (dark colors represent the main rivers (Gongjicheon and Chungjucheon), and light colors represent tributary rivers).

3.1.2. On-Site Detailed Investigation for Identifying Unknown Sources and Main Pollution

This study conducted a thorough on-site investigation, starting from the upstream regions to the downstream areas, to identify unknown water pollutant sources and main pollution sources entering the urban rivers. The results of the field investigation in the Gongji stream watershed revealed the occurrence of unknown water pollutant sources at 26 out of the 86 surveyed locations (Figure 5a). The average concentration of each water quality parameter of the total investigated unknown water was high at 25.3 mg/L for the BOD₅, 188.6 mg/L for SS, 11.923 mg/L for T-N, 0.780 mg/L for T-P, and 13.1 mg/L for TOC. The major pollution sources identified through detailed surveys along the riverbanks included canal leakages and agricultural areas. Therefore, tailored pollution mitigation measures are deemed necessary for each watershed, such as strengthening the management of individual sewage treatment facilities in areas with high occurrences of domestic sewage like Sinchoncheon and Huhacheon's upper reaches, and applying BMPs for agriculture in areas like Sinchoncheon and Hakgokcheon. Additionally, regular monitoring for identifying the causes of unknown water pollutant sources is essential.

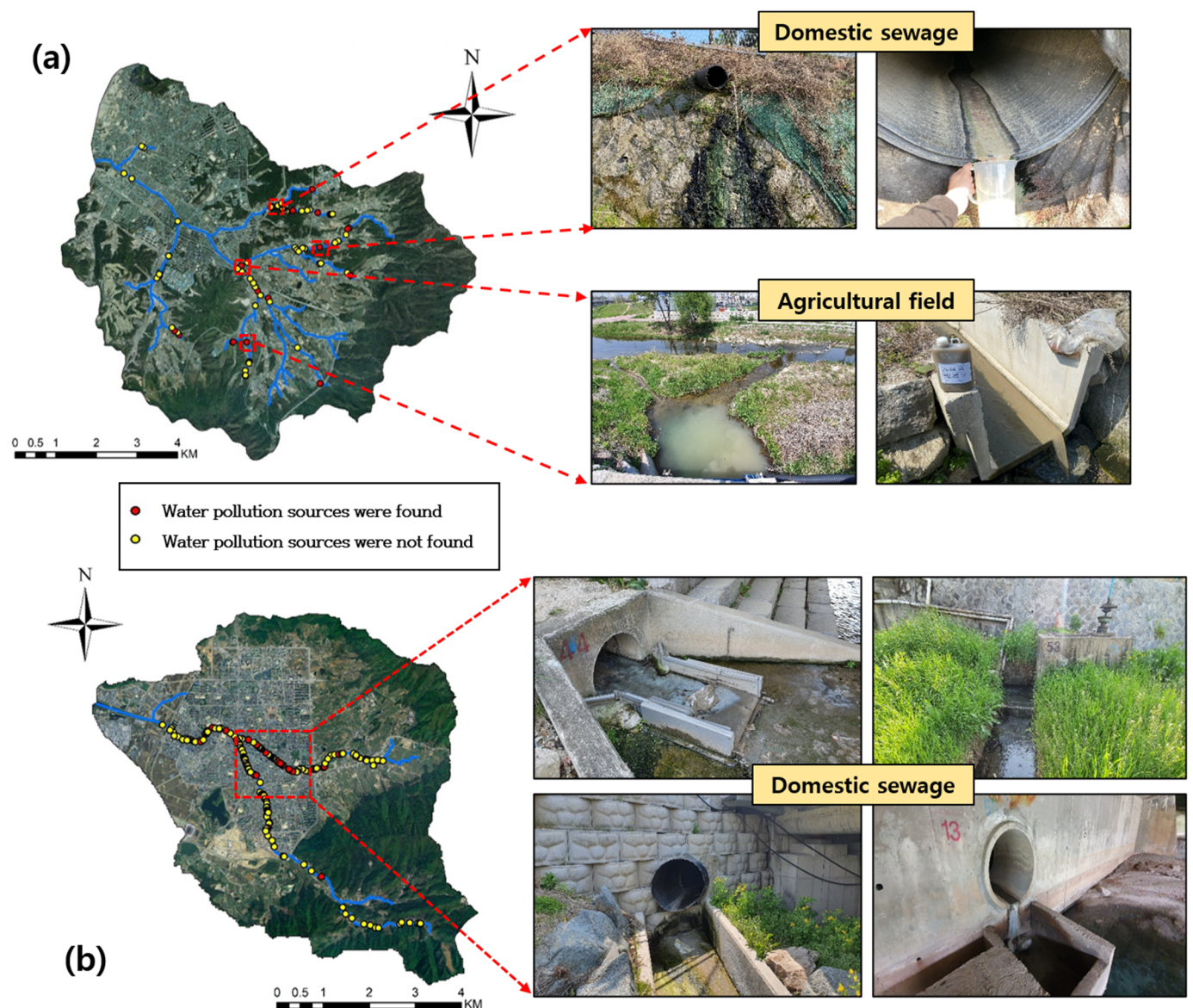


Figure 5. On-site detailed investigation results: (a) Gongji stream watershed, (b) Chungju stream watershed (dots show the points of detailed on-site investigation of the main urban river, with red dots indicating points where unknown water pollution sources were discovered, and yellow dots indicating points where unknown water pollution sources were not found).

In the case of the Chungju stream watershed, the on-site investigation identified unknown water sources at 22 out of 149 surveyed locations (Figure 5b). The average concentrations of the various water quality parameters that were investigated in the unspecified number of samples were reported as follows: BOD₅ at 20.5 mg/L, SS at 11.2 mg/L, T-N at 7.191 mg/L, T-P at 0.523 mg/L, and TOC at 5.0 mg/L, indicating high levels. Through detailed riverbank surveys, the major pollution source was determined to be domestic sewage from canal leakages. Therefore, specific measures, including leak detection in sewage conduits, continuous inspection of sedimentation basins, and enhanced management of individual sewage treatment facilities, are recommended for the Chungju stream and Gyohyeoncheon watersheds to reduce the influx of domestic sewage into the rivers.

3.1.3. Analysis of Urban River Pollution Sources and Assessment of Water Quality Contamination Contributions

This study utilizes river flow and water quality monitoring results in the Gongji stream watershed to analyze the contamination contributions of BOD₅, T-N, and T-P. The analysis focuses on the Gongji stream's upper stream and the main tributaries. The results show that for the BOD₅, the upper stream of the Gongji stream contributes the most significant contamination load at 23.2%, with inflowing streams contributing in the order of Togyechon at 21.3%, Sinchoncheon at 20.5%, and Yagsacheon at 19.8%. Regarding T-N, the upper stream of the Gongji stream has the highest contribution at 27.3%, followed by Sinchoncheon at 26.1%, Togyechon at 25.1%, and Huhacheon stream at 11.6%. For T-P, Togyechon has the highest contribution at 34.1%, with the upper stream of the Gongji stream at 24.7%, Sinchoncheon at 19.3%, Huhacheon at 13.9%, and Yagsacheon at 8.0%. The identified pollution hotspots, based on calculated contamination loads, are prioritized as the upper stream of the Gongji stream, Togyechon, and Sinchoncheon.

A comprehensive analysis of priority polluted streams within the Gongji and Chungju watersheds was conducted by integrating land use, discharge load, and on-site inspection data. The results reveal that the priority order for polluted streams in the Gongji watershed is as follows: Togyechon, Gongji upper stream, Huhacheon, Sinchoncheon, and Yagsacheon (Table 3). The upper stream of Togyechon and the Gongji stream, characterized by significant agricultural land distribution, specifically Jeongjok-ri and Jeung-ri in the upper reaches of Togyechon (approximately 24% of the total administrative area as agricultural land) and Saram-ri in the upper reaches of the Gongji stream (approximately 28% of the total administrative area as agricultural land), emphasize the need for pollution reduction measures targeting land-based sources. Implementing suitable BMPs and measures to mitigate livestock-related pollutants, such as the proper treatment of livestock manure, are essential in these prioritized areas. Moreover, there is a need for ongoing monitoring of agricultural non-point source pollution and water quality monitoring at key sites. In this context, non-structural measures involving community engagement in monitoring and the surveillance of pollution sources are expected to play a vital role.

Table 3. Contamination load and water quality contribution in the Gongji stream watershed.

Stream Name	BOD ₅ (kg)	Contribution Rate (%)	T-N (kg)	Contribution Rate (%)	T-P (kg)	Contribution Rate (%)
Gongji upstream	578.0	23.2	2294.7	27.3	29.0	24.7
Sinchoncheon	510.8	20.5	2192.1	26.1	22.7	19.3
Huhacheon	375.3	15.1	971.7	11.6	16.3	13.9
Togyechon	530.7	21.3	2111.3	25.1	40.0	34.1
Yagsacheon	493.7	19.8	841.4	10.0	9.4	8.0

In the Chungju watershed, the analysis of water quality contribution indicates that the priority order for polluted streams is as follows: Chungju upper stream, Gyoheoncheon, and Yeonsucheon. BOD₅, T-N, and T-P contribute most significantly to the upper stream of the Chungju watershed, Gyoheoncheon, and Yeonsucheon, respectively. The upper stream of the Chungju watershed is identified as contributing 43.9% of the BOD₅ pollution load, emphasizing the need for effective pollution reduction strategies in this area. Gyoheoncheon and Yeonsucheon contribute significantly to T-N and T-P pollution loads, respectively. Therefore, implementing targeted measures, such as BMPs for non-point source pollution control, and encouraging local residents to actively participate in pollution reduction activities are recommended for the prioritized polluted streams in the Chungju watershed. The analysis of highly polluted streams in the Chungju watershed reveals that Gyoheoncheon, the upper stream of the Chungju watershed, and Yeonsucheon are the top three priorities. The Gyoheoncheon watershed is characterized by extensive agricultural

land, contributing significantly to land-based discharge and pollution loads within the Chungju watershed. In the case of Jikdong, located in the upper stream of the Chungju watershed, the analysis of discharge contributions indicates a higher impact from land use, followed by urban and livestock sources (Table 4).

Table 4. Contamination load and water quality contribution in the Chungju stream watershed.

Stream Name	BOD ₅ (kg)	Contribution Rate (%)	T-N (kg)	Contribution Rate (%)	T-P (kg)	Contribution Rate (%)
Chungju upstream	2164.6	43.9	5316.3	37.9	89.0	37.5
Gyohyeoncheon	1403.0	28.4	5760.7	41.1	63.3	26.7
Yeonsucheon	1365.8	27.7	2950.2	21.0	84.7	35.7

Moreover, the effective management of untreated water directly entering the urban streams is essential within the Chungju watershed. Therefore, it is crucial to implement pollution reduction measures targeting land-based sources and strengthen strategies such as sewage discharge detection and improved management of sedimentation basins to reduce pollution from urban and agricultural sources. Consideration should be given for extending environmental cleanup activities by citizen groups not only of the main streams but also of the upper stream of tributaries. To achieve a comprehensive management of urban rivers, a network approach involving civic engagement and diverse activities is necessary.

This study proposes non-structural measures for managing water quality pollution sources in urban rivers. To ensure a sustained management of urban stream water quality, the establishment of civic engagement governance and the presentation of various non-structural measures are suggested. Additionally, key measures such as citizen-participatory stream water quality monitoring, stream restoration activities, pollution source surveillance, effective use of environmentally friendly detergents (EM detergents), and systematic operational plans for controlling non-point source pollution from paddy fields are suggested.

3.2. Establishment and Activities of Citizen Participation Governance for Sustainable Urban Stream Water Quality Management

3.2.1. Establishment of Citizen Participation Governance

This study investigated citizen groups and their activities related to the management of urban streams in each city. Activities observed among citizen groups for urban stream water quality management included stream cleaning, water quality monitoring, urban stream education, pollution source surveillance, and distribution of EM products. Existing citizen groups operated independently, lacking information exchange or coordination, which led to small-scale and potentially duplicative efforts.

To address this, this study proposes the formation of a network among existing citizen groups, fostering information exchange and collaborative initiatives for urban stream water quality improvement. By establishing synergy among these groups, a greater number of local residents can be encouraged to participate. Additionally, this study emphasizes the need to build a cooperative framework involving not only citizen groups but also local governments and community stakeholders for sustainable urban stream management.

The proposed model outlines a step-by-step collaborative governance structure (Figure 6) to establish and operate a civic engagement network for urban stream improvement. The preparatory stage involves investigating watershed characteristics for water quality improvement. In the first phase, a collaborative framework among citizen groups is established, followed by the operation of a citizen network and collaboration with local governments in the second phase. Finally, in the third phase, expansion to the broader community and establishment of collaboration structures with local societies are suggested.



Figure 6. Procedure for organizing citizen participatory governance.

In the preparatory stage, a detailed investigation of watershed characteristics, major inflowing streams, and pollution sources is conducted to identify key contributors to urban stream pollution. This investigation comprises fundamental surveys, river surveys, and on-site surveys, as detailed in Section 2.2.

During the first phase, “Civic Group Network”, various citizen groups related to urban stream watershed and river environmental issues are surveyed. The activities and participants of each citizen group are examined, with a focus on identifying any overlapping activities among them, such as river cleaning, education and promotion, and resident participation monitoring. To facilitate efficient resident engagement and ensure ongoing water quality management, a citizen network composed of these citizen groups is established. Following the formation of the citizen network, specialized sections are created for governance activities related to urban stream water quality management. These sections include “Resident participation water quality monitoring”, “Environmental cleanup and surveillance”, and “Water-Environmental Education”, each defining specific activities for urban stream water quality improvement.

In the second phase, the major activities of each section within the citizen network are specified, and a systematic framework is established to facilitate a smooth collaboration with local governments (“Civic Group-Governance System”). While each section operates autonomously, various support mechanisms are explored, and collaborative approaches between different departments within local governments are devised to address urban stream water quality improvement.

For the third phase, “Local community Cooperation System”, the citizen network’s participation scope is expanded to include various stakeholders beyond existing citizen groups, such as relevant agencies, local businesses, and community leaders. A collaborative system at the watershed level is developed to resolve conflicts between the upper and lower reaches of urban streams. Strategies for expanding the watershed-level cooperation system are devised, focusing on resolving conflicts and gathering opinions from residents during urban stream water quality improvement projects. Cooperation mechanisms within the citizen network for each section are reviewed to establish collaborative frameworks with experts, local governments, and other stakeholders, leading to discussions on financial and administrative support measures.

Non-structural water quality improvement measures involving local residents include the following activities.

- Resident participation water quality monitoring: Selection of river water quality measurement points and regular water quality monitoring using simple measurement kits.

- Environmental cleanup and surveillance: Regular environmental cleanup activities and conducting surveillance activities for main cause analysis in case of water quality pollution, in coordination with citizen monitoring activities.
- Water-Environmental Education: Education for residents related to water and environment and promotion of eco-friendly detergents.

As mentioned earlier, unidentified discharges into urban rivers are identified as a major pollution source in the Chungju River watershed. In response to this water quality challenge, an additional Living Lab concept [16] is proposed. A community-led program, combining resident monitoring with pollution source surveillance activities, forms the basis of this Living Lab initiative. The goal is to encourage voluntary participation from citizens in environmental forums, facilitating the discovery of water quality issues in urban streams, conducting root cause analyses, and collectively devising solutions.

In the Chungju River watershed, the continuous resident monitoring and pollution source surveillance activities led to the identification of non-point source pollution at the Yongsan Bridge No. 64 sewage outlet. To address this issue, discussions with local authorities were initiated, and a thorough root cause analysis was conducted. Subsequent field surveys, combined with rain-event water quality measurements, revealed that the problem was related to a culvert near the sewage outlet. The local authorities decided to include the culvert removal in next year's budget, providing a resolution to the identified water quality concern (Figure 7).

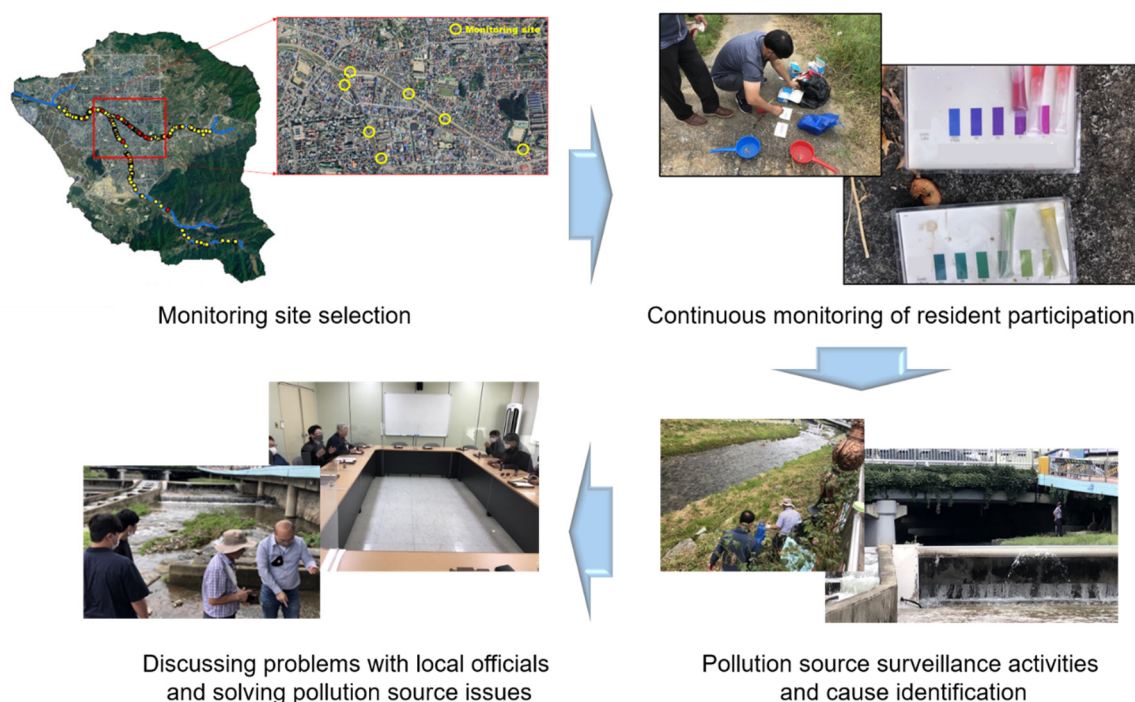


Figure 7. Case studies of citizen-participatory governance activities to manage the urban river (resident participation monitoring and pollution source surveillance).

3.2.2. Citizen Participation Water Quality Monitoring

The utilization of simple water quality measurement kits enables periodic community participation in water quality monitoring (Figure 8). This not only enhances community involvement but also facilitates the collection of highly relevant water quality data at key locations in urban streams. Additionally, the ease of measurement accessible to local residents or civic groups is a notable advantage. The ongoing research on community-involved stream water quality monitoring using water quality measurement kits aims not only for routine water quality assessments but also for continuous monitoring to identify anomalies indicating potential pollution sources.



Figure 8. Instructions on how to use a simple water quality measurement kit.

This method serves as a means to detect abnormal occurrences through periodic and sustained monitoring rather than solely for the purpose of assessing the water quality of the streams. Furthermore, this approach empowers local residents to actively engage in monitoring, thereby enhancing their willingness to participate in water quality improvement initiatives. The collected data can also be utilized for educational and promotional materials. Key water quality parameters measurable through the portable kits include COD, T-N, $\text{PO}_4\text{-P}$, ABS, and more.

In this study, field measurements using water quality measurement kits were conducted to validate their reliability. For the verification process, the same parameters were analyzed by certified laboratories after testing the water samples with the measurement kits on-site. Considering the nature of water quality measurement kits, which involve placing the sample in a tube containing a color reagent and visually comparing the resulting color with standard colors after a specified time, the precise determination of water quality concentrations can be challenging. However, the comparison between the measured results from the kits and the standard color concentration ranges with certified water quality analysis showed a consistent correlation, as illustrated in Figure 9.

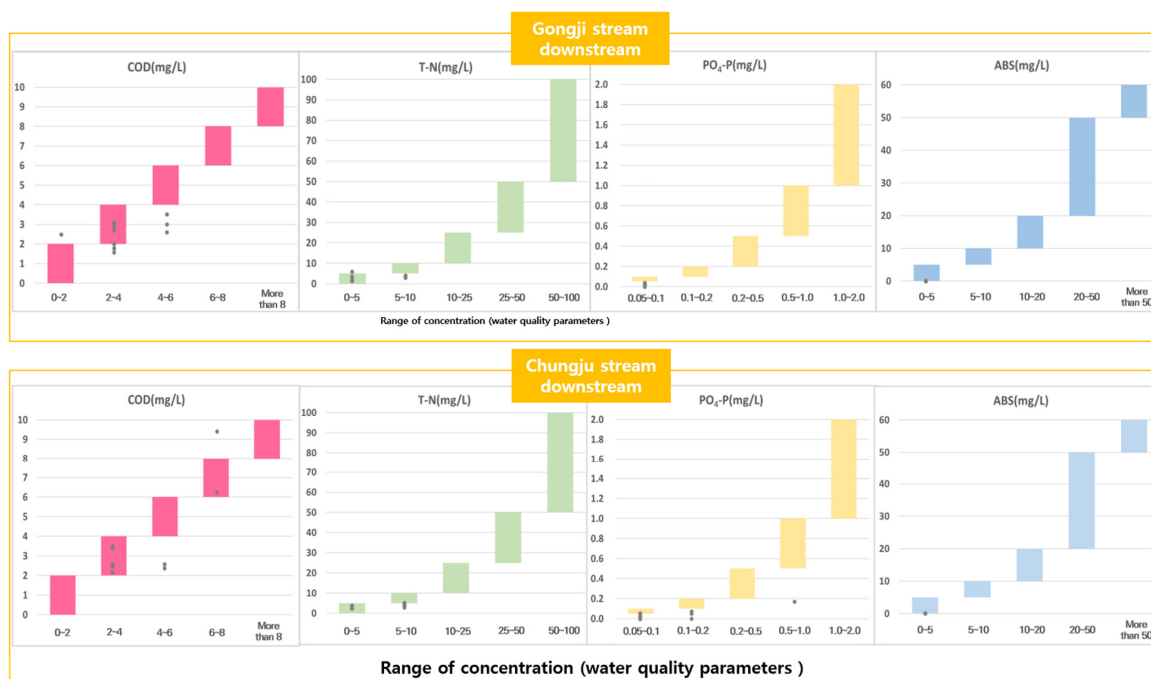


Figure 9. Comparison of water quality result using a certified experimental method (block) and simple measurement kit (Dot).

3.2.3. Analysis of Water Quality Pollution Reduction Effects in the Domestic Sector through EM Detergent

Effective Microorganisms (EM)-fermented liquid is known for its versatile applications, including odor removal, indoor cleaning, washing, food waste fermentation, and agricultural fertilization. However, the quantitative water quality improvement effects of EM-fermented liquid have not been well-documented. This study conducted experiments to analyze the water quality improvement effects of EM-fermented liquid.

The experiment aimed to replicate conditions similar to using EM-fermented liquid in a typical household. Three samples were prepared by mixing 50 mL of regular detergent with 3 L of tap water for EM0, a mixture of 40 mL regular detergent and 10 mL EM-fermented liquid for EM1, and 50 mL of EM-fermented liquid for EM2 (Figure 10). The analysis included five parameters: BOD₅, SS, T-P, T-N, and ABS (Alkyl-Benzene Sulfonate), a type of surfactant. ABS is known to be harmful to aquatic life when accumulated in water bodies, and it poses health risks due to incomplete decomposition in wastewater treatment plants. This experiment focused on evaluating the reduction effect of ABS, generated by regular detergent use, to assess the water quality improvement effects of EM-fermented liquid.



Figure 10. View of EM fermentation experiment.

EM0, which used only regular detergent, exhibited the highest concentrations for most water quality parameters, followed by EM1, which used a combination of regular detergent and EM-fermented liquid, and EM2, which used only EM-fermented liquid. Specifically, for the T-P parameter, EM1 (0.353 mg/L) showed a higher water quality concentration than EM0 (0.153 mg/L). The water quality concentrations of EM2, using only EM-fermented liquid, were, on average, 58.6% lower compared to EM0 for the parameters BOD₅, SS, T-N, and T-P. Notably, the ABS concentration in EM2 was 0.03 mg/L, indicating a substantial reduction of approximately 98.7% compared to EM0 (2.30 mg/L) (Figure 11).

Additionally, to evaluate the water quality improvement effects during rainfall in rivers, three samples were prepared by mixing 3 L of muddy water with 50 mL of regular detergent for SW0, 40 mL of regular detergent and 10 mL of EM-fermented liquid for SW1, and 50 mL of EM-fermented liquid for SW2. The experiment results showed that, similar to tap water, SW0, which used only regular detergent, exhibited the highest concentrations for most water quality parameters. Following the trend observed in tap water experiments, SW1, which used a combination of regular detergent and EM-fermented liquid, and SW2, which used only EM-fermented liquid, showed lower concentrations. The ABS water quality concentration in SW2 was reduced by approximately 98.6% compared to SW0 (2.14 mg/L), and other water quality parameters were, on average, reduced by 47.6% compared to SW0.

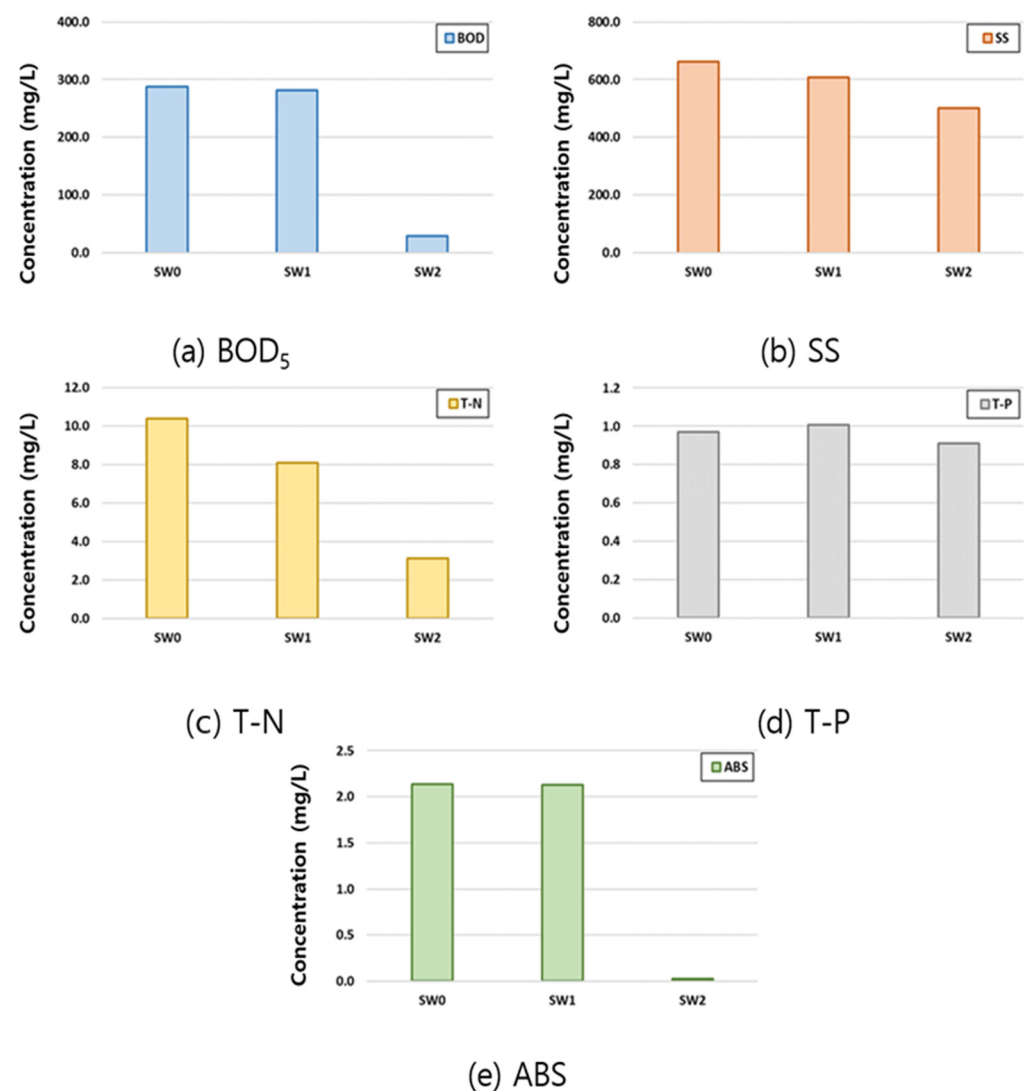


Figure 11. Analysis results of water quality improvement effects of EM fermentation solution in tap water.

When EM-fermented liquid was used, the ABS concentration in tap water was reduced by approximately 98.7%, and in muddy water, it was reduced by about 98.6%, compared to using only regular detergent. Moreover, the concentrations of most water quality parameters (BOD₅, SS, T-N, T-P) were reduced by an average of 58.6% in tap water and 47.6% in muddy water. The research results suggest that using EM-fermented liquid instead of regular detergent can reduce water pollution, especially demonstrating significant effects in reducing ABS concentrations. Therefore, besides mitigating domestic sources of pollution, using EM-fermented liquid enables easy public participation in pollution reduction activities, making it a valuable resource for education and promotional materials (Figure 12).

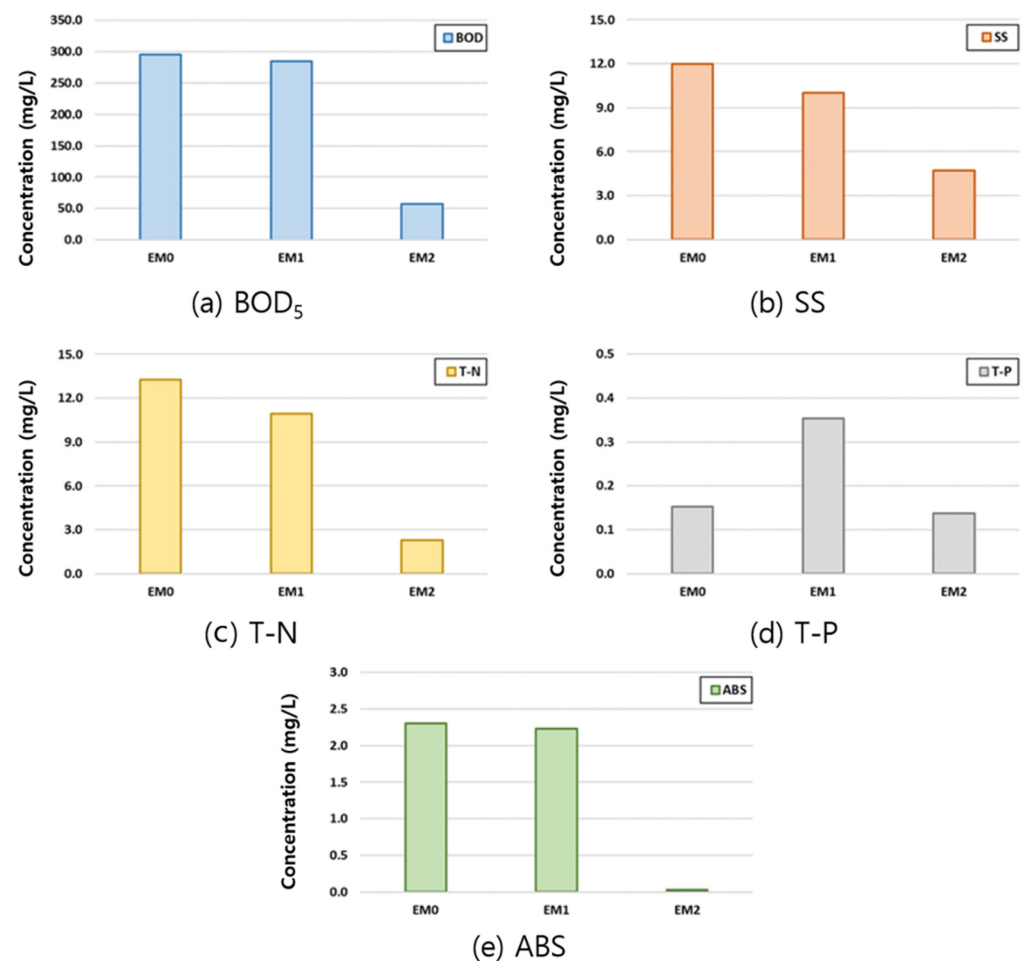


Figure 12. Analysis results of water quality improvement effects of EM fermentation solution in soil water.

4. Conclusions

This study aims to develop a resident-friendly sustainable river management plan for polluted urban rivers and propose a governance operating system and non-structural water quality improvement measures. Long-term solutions for upstream land and urban river pollution involve the active participation of local residents. The fundamental approach for improving urban river water quality lies in the active involvement of local residents. To achieve this, citizen forums were established for the target rivers, forming citizen networks to explore solutions for major pollution sources. Continuous resident monitoring was conducted to address issues related to domestic wastewater and unknown sources, and solutions were devised through discussions with local authorities. The limitations of short-term water quality improvement activities were recognized, emphasizing the need for a long-term perspective in water quality improvement through resident participation governance activities. Recognizing the importance of local residents' interest in urban river water quality improvement, the establishment and continued activities of local citizen networks were deemed essential. Furthermore, active participation and investment from local government agencies, governmental bodies, and various experts are crucial. To encourage resident participation in revitalizing urban rivers, efforts should not only focus on water quality aspects but also incorporate diverse themes such as ecological characteristics, history, culture, and other river-related themes. In order to facilitate the smooth implementation of community-led river development as an institutional mechanism, it is necessary to move away from the existing top-down central-government-driven system. Instead, a regime that focuses on residents' daily lives, enhancing a situationally centered approach,

and transforming administrative structures based on the comprehensive perspective of residents in local governments is needed. This requires the integration and systematic planning of local government administration, legal provisions for planning similar to those of Japan, and the internalization of mid-term fiscal plans connected to budgets. Enhanced coordination among local government departments is crucial, shifting towards a more horizontal system that supports residents' activities. Additionally, the establishment of a comprehensive support system, such as a resident autonomy support system, is necessary, including dedicated departments or support centers to reduce the distance between residents and the administration.

For sustainable urban river management, it is essential to institutionalize a discussion structure involving stakeholders and experts from various fields. Establishing and supporting citizen networks operationally and financially is also necessary. Funding strategies for governance operation, especially in terms of securing budgets for watershed governance, need careful consideration, and a portion of existing river project budgets could be allocated for this purpose. Expanding participation from experts, local schools, businesses, and general residents in various fields, including water quality, ecology, environment, and culture, can lead to a more desirable collaborative network. This network, when utilized for policy discussions and programs, has the potential to become a successful model for sustainable urban river management through effective community-led governance. In terms of educational programs, developing continuous programs with parental involvement for elementary students can naturally promote residents' awareness and education, requiring ongoing support for education and program development.

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