A Study on the Development of Sustainable Water Circulation City

By

KIM, Jiwon

CAPSTONE PROJECT

Submitted to

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Executive Summary

The global trend of urbanization is increasing impervious urban land areas, resulting in distortion of hydrological water flow in cities. In addition, urbanization and population growth are leading to a sharp increase in water demand, while the climate change is reducing the stability of the water supply, causing water shortages.

To restore the soundness of water circulation and to implement sustainable urban water management, it is necessary to accurately identify problems of the urban water circulation system and evaluate its soundness. Urban water problems can also conflict with various stakeholders from various perspectives, such as water supply, urban planning, infrastructure, environment, and urban amenity. The urban water circulation system should be considered holistically, including not only natural water circulation but also artificial water circulation.

This study aims to develop a sustainable water circulation city model by considering complex and diverse urban water circulation factors as a whole. To do so, a number of urban water circulation factors and policies are examined through literature review and the case studies of Germany, the United States, and Australia. Various efforts, achievements, and limitations of urban water circulation policies in Korea are also investigated. Following the analysis, the paper proposes a differentiated water circulation city model for Korea, catering to its specific local contexts and conditions. Four issues are given particular attention: institutional issues, project planning issues, governance issues, and evaluation indicator issues. The outcome of this study is expected to contribute to the establishment and revitalization of the water circulation city in Korea.

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1. Introduction

Today, more than half of the world population lives in urban areas. Rapid and massive urbanization has led to sometimes indiscriminate land-use changes, resulting in an increase of impervious land areas and the distortion of hydrological water flow in cities. The distortion of the water cycle is causing several problems such as reduction of groundwater content, deterioration of water quality, an increase of urban heat island, and lack of flow rate in urban streams. In addition, urbanization and population growth are resulting in a sharp increase in water demand, while the climate change is reducing the stability of the water supply, causing water shortages. Therefore, it is critical to restore the soundness of water circulation in cities and to implement sustainable urban water management. To do so, it is necessary to accurately identify problems of the urban water circulation system and evaluate its soundness. In the process, the urban water circulation system should be considered holistically, including both natural water circulation (hydrologic flow), such as rainfall, evapotranspiration, underground water infiltration and runoff and artificial water circulation (anthropogenic flow), such as water demand, water supply and reuse of water.

To solve the distortion of urban water circulation, various concepts or techniques, such as Green Infrastructure, Low Impact Development (LID), Decentralized Water Management, and Urban Water Metabolism, have been introduced and practical researches for sustainable urban water management has been actively conducted in the developed countries of the West (Farooqui et al., 2016; Hong et al., 2010; Kang, 2018; Kennedy, 2007; Kim et al., 2014; Zhang et al., 2009). Also, evaluation indicators of urban water circulation have been explored to figure out the current status of urban water issues and to support the decision-making of various stakeholders in urban water management. In particular, a number of studies are actively conducted to evaluate the performance of urban water management within the entire frame of urban water circulation by linking natural and artificial water circulation (ARCADIS; Bousiotas et al., 2019; Farooqui et al., 2016; SDEWES Centre).

In South Korea, there have also been many studies on the application and performance assessment of various urban water circulation techniques (Choi et al., 2018; Hong, 2010; Kang, 2020; Kim, 2018; Lee, 2003). However, most of the research has focused on restoring natural water circulation, such as reducing impervious areas, installing LID facilities, and managing rainwater. Accordingly, the soundness of water circulation has been evaluated based only on natural flow, without considering anthropogenic flow. These evaluations of urban water circulation, which is limited to natural water circulation, cannot accurately represent the water circulation of the whole city. It is necessary to include artificial water circulation (i.e., reuse, saving, demand, and supply of water) to comprehensively access the urban water balance.

This paper aims to develop a sound and sustainable model of water circulation city (It's a city that has a good water circulation system or where the water circulation system has been restored.) by considering the complex and diverse elements—both natural and artificial—of urban water circulation. By introducing appraisal elements of sustainable urban water management that are actively conducted overseas, this study attempts to develop suitable urban water circulation models for Korea, taking into consideration its domestic laws, institutions, environment, technology level, and civic awareness.

2. Literature review

2.1 Urban Water Circulation System

When large-scale residential districts, commercial buildings and various infrastructures are established due to urban development, the natural circulation system of hydrological elements such as precipitation, evapotranspiration, infiltration, and runoff is inevitably distorted (Kang, 2018). Urbanization has intensified globally, and the increase in the impermeable area by urbanization has caused problems such as reduction of groundwater content, deterioration of water quality, increase of urban heat island, and lack of flow rate in urban streams. In addition, meteorological and hydrological changes by climate change are increasing flood and other water disasters, and water shortages by severe drought are decreasing water self-sufficiency rates. To cope with these urban water issues, interest in the diversification of water source and water reuse in cities is increasing (Lee, 2018).

Water circulation refers to a system of continuous water flow in which rainwater falls on the ground, changes into the form of surface water or underground water, flows into streams, lakes and seas, then evaporates, returning to the sky, and becomes rainwater again. This hydrological flow is called natural water circulation. Artificial water circulation refers to the flow of water newly generated by man-made structures and facilities. For example, people use water supplied by pipes and then discharge wastewater into streams through sewage pipes and sewage treatment plants (Park, 2017).

Urban water problems can also conflict with various stakeholders from various perspectives, such as water supply, urban planning, infrastructure, environment, and urban amenity. So, it is necessary for the urban water circulation system to be considered holistically, including both natural hydrological flow (evapotranspiration, rainfall, groundwater infiltration, runoff) and anthropogenic flow (managed by urban water infrastructure) (Farooqui et al., 2016). In particular, urban water circulation system in South Korea has applied artificial methods rather than natural circulation and installed centralized infrastructure focusing on water use and control. In addition, the legislations related to urban water circulation are insufficient, and the regulations are too broad and ambiguous (Hong et al., 2010).

2.2. Sustainable Urban Water Management

Sustainable development was first mentioned in the Bruntland Report, published by the World Commission on Environment and Development (WCED). Sustainable development can be defined as development that meets the needs of the present without compromising the ability of future generations to meet their own needs (WCED, 1987). In terms of sustainable development, urban water management should have a cyclical structure that considers climate change, economic perspective and current and future generations as well as water utilization and water control. In particular, when developing or redeveloping cities, sustainable urban water management aims to ensure that there is no change in the water circulation before and after development. As a result, the environmental impact of development can be minimized. In addition, by actively encouraging the storage, utilization, and infiltration of rainwater, it is possible not only to increase water self-sufficiency but also to decrease unnecessary energy consumption for intake, treatment, and conveyance of water (Park, 2017).

A number of studies have used urban metabolism to interpret urban problems in terms of organic linkage (Kennedy, 2007; Zhang & Yang, 2007). According to the urban metabolism paradigm, a city is defined as an organism that, as in the metabolic process of living things, receives resources and energy from the outside, uses it for internal activities, and discharges waste as a byproduct (Ban et al., 2018). Urban metabolism identifies factors threatening the sustainable urban development by analyzing its material flow and circulation process (Kennedy et al., 2007). Within the framework of urban water metabolism, urban water circulation can be considered holistically including natural and artificial water circulation. Furthermore, the use of alternative water resources such as storm-water/rainwater harvesting and wastewater/greywater recycling can be reviewed (Farooqui et al., 2016). From this perspective of metabolism, the efficiency of resources through minimization of consumption and maximization of recycling will enable sustainable urban development and solve urban problems (Ban et al., 2018).

2.3 Evaluation Indicators of Water Circulation

Indicators refer to the elements that can represent any phenomenon or change, and the summarized information that can help to identify the whole. The purpose of establishing indicators is to understand the current situation, to select priorities, to include stakeholders, to strengthen capabilities, and to resolve conflicts (Kim et al., 2014). For example, evaluation indicators of sustainability can reduce the environmental impact of development projects by appraisal of the project plan in advance, induce the projects to become environmental-friendly, and can be applied as a basis for planning the design (Lee, 2003).

In this regard, evaluation indicators of water circulation can be a goal, direction, and evaluation criteria of various water circulation policies and projects, so it is necessary to establish appropriate indicators and use them as a basis for sustainable policies and project implementation. However, in South Korea, the Water Environment Conservation Act sets the mid- to long-term water circulation target using the ratio of impervious area and the rate of water circulation (the amount of rainfall, runoff, infiltration and evapotranspiration). The water circulation system is very complex and sophisticated, so a systematic and holistic approach is needed; the current water circulation indicator is limited to only natural water circulation (Kang, 2018). These evaluations of urban water circulation, which is limited to natural water circulation, cannot accurately represent the water circulation of the whole city.

It is necessary to include artificial water circulation (i.e., reuse, saving, demand, and supply of water) to comprehensively access the urban water balance.

On the other hand, in the developed countries of the West, a number of studies are actively conducted to evaluate the performance of urban water management within the entire frame of urban water circulation by linking natural and artificial water circulation. Kenway et al. (2011) presented a paradigm of urban water metabolism and performance indicators quantified based on the results of the metabolic analysis. Also, Farooqui et al. (2016) suggested water efficiency indicators and hydrological performance indicators in order to assess the extent to which to reduce demand for external water supply and the extent to which to maintain or restore hydrological conditions before urban development by analyzing interaction of natural and anthropogenic water cycle within the urban water metabolism framework. On the other hand, a pilot village study conducted by Bousiotas et al. (2019) introduced a variety of decentralized water management technologies (rainwater harvesting, graywater recycling, sustainable urban drain system) and suggested indicators for evaluating urban water management in terms of water demand, water supply, and water reuse. To assess the sustainability of urban water services, the TRUST project (Transitions to the Urban Water Services of Tomorrow) presented 23 detailed indicators in 5 dimensions, which are social, environmental, economic, governance and assets (Alegre et al., 2012).

Indicators related to the sustainability of urban water management include Sustainable Development of Energy, Water, and Environment Systems Index (SDEWEI), Sustainable Cities Water Index (SCWI), and City Blueprint Approach (CBA). The SDEWEI was developed at the SDEWES Centre to encourage sustainable development of urban energy, water resources and environment. Currently, 120 cities, including Paris, Washington, D.C., and Istanbul, were assessed, and most of the indicators are related to climate change and reduction of energy and carbon dioxide while only five indicators are directly related to water management (SDEWES Centre, 2017). SCWI was developed by ARCADIS, a private consulting firm in the Netherlands, to evaluate sustainable urban water management through three fields of resiliency, efficiency and quality (ARCADIS, 2016). Also, the City Blueprint Approach (CBA) developed by the KWR Water Cycle Research Institute in the Netherlands consists of pressure indicators, status indicators, and governance indicators

3. Research Methods

This paper aims to develop a sound and sustainable model of water circulation city by considering the complex and diverse elements—both natural and artificial—of urban water circulation. By introducing appraisal elements of sustainable urban water management that are actively conducted overseas, this study attempts to develop suitable urban water circulation models for Korea, taking into consideration its domestic laws, institutions, environment, technology level, and civic awareness.

In this paper, a number of urban water circulation factors and policies are examined through literature review and the case studies of Germany, the United States, and Australia. First of all, to study decentralized rainwater management, which is the basic concept of water circulation, I investigate Germany's water circulation policies that rainfall runoff water management plan was established at the urban planning stage and rainwater charges were imposed according to the principle of burdening the cause. In addition, I examine the water circulation policies of the United States that first introduced the concept of LID, which is the most widely used in South Korea. Beyond the concept of LID limited to land use plans and hydrological flows, I research the WSUD in Australia, which includes various urban water cycles such as managing rainwater, securing water, and reusing water.

Next, various efforts, achievements and limitations of policies to promote water circulation city in Korea are also investigated. I examine domestic laws related to water circulation and water circulation projects, and analyze the limitations of domestic urban water circulation through research papers on water circulation policies and techniques. Following the analysis, the paper proposes a differentiated water circulation city model for Korea, catering to its specific local contexts and conditions. Four issues are given particular attention: institutional issues, project planning issues, governance issues, and evaluation indicator issues. The outcome of this study is expected to contribute to the establishment and revitalization of the water circulation city in Korea.

4. International Case Studies on Urban Water Circulation

Developed countries such as Germany, the United States, and Australia have been paying attention to water circulation cities to ensure safety in disasters and to preserve biodiversity and natural resources. Recently, to adapt to climate change and hand over the intact natural environment to the next generation, measures have been prepared to create a more water-sensitive urban infrastructure. Representative examples include Germany's Decentralized Urban Design (DUD), the United States' Low Impact Development (LID), and Australia's Water Sensitive Urban Design (WSUD). Although the terms used by each country are different, they have the same purpose in terms of implementing a more sustainable city by more actively carrying out water circulation management in urban areas (Kim et al., 2015).

4.1 Germany

Germany is one of the countries with advanced environmental technology along with eco-friendly spatial planning. In particular, Germany has applied technologies and systems related to decentralized rainwater management in terms of spatial planning. Germany directly or indirectly stipulates decentralized rainwater management in related laws such as the Water Management Act. The Water Management Act on federal level requires each local government to set its own regulations on rainwater treatment. Each local government stipulates that rainwater discharged from buildings or pavement surfaces should be handled by the land user. After these regulations were enacted, it became mandatory to installation of decentralized rainwater in the region for land connected to public sewage pipes (Kim et al., 2018).

Germany's environmental plan has the main significance that it affects planning decisions for nature protection and landscape management when planning a basic construction plan based on the current status survey of target areas for each spatial hierarchy. Among the environmental plans, the landscape ecological plan corresponding to the land use plan has the characteristics of a spatial management environmental plan. The current status survey related to water circulation, such as water balance, groundwater level, and soil pavement in the area, is conducted in detail in the plan. And based on this survey, considerations of land use plans and grounds for planning decisions are presented. When establishing a spatial plan and an environmental plan, the direction and content of the plan are determined based on the environmental information of the region (Kim et al., 2015).

In addition to spatial and environmental plans, rainwater tax has been used in order to indirectly induce decentralized rainwater management by using economic means. Rainwater tax is a concept of imposing taxes on rainwater separately from sewage, and the existing sewage tax is divided into wastewater tax and rainwater tax. The wastewater tax is calculated according to the amount of water used, while the rainwater tax is calculated according to the impermeable area such as the building area and the pavement area. This tax system has been served as an opportunity to raise awareness of environmental preservation as well as transparency and fairness in tax imposition. This system has made it possible to prevent the spread of impermeable paved surfaces, and has become a factor in changing unnecessary impermeable surfaces to permeable surfaces. This indirectly has induced the use of rainwater reservoirs and facilities, rooftop greening, and water permeable surface pavement materials suitable for the target areas when constructing almost all new building and expanding and renovating existing buildings (Kang, 2018).

4.2 The United States

In the late 1990s, questions about the effectiveness of the existing management system in which protecting the ecosystem and achieving water quality goals began to arise, and the need for a new water circulation policy increased. Accordingly, in Maryland, a manual on Low Impact Development (LID) design technique, an urban management technique that can minimize the negative impact of urban and environmental effects by development activities, was first created and spread throughout the United States. Recently, the LID technique has expanded its concept to the term Green Infrastructure (GI) and promoted water circulation management (Kim et al., 2015).

The United States' water circulation policy uses mixture of LID and GI techniques. In addition to simply ensuring good rainwater drainage, it has established itself as an urban management paradigm that regulates land use or manages permeable layer to maintain its natural hydrological function before development. To encourage the expansion of GI, federal agencies, state governments, local governments, other organizations and private sectors make together efforts to apply the concept of GI when establishing development permits, planning procedures, technical support, and financial plan.

Seattle has established a system that can identify the location of the Green Stormwater Infrastructure and provided location verification services on its website. In addition, if a green rainwater infrastructure is not installed when a new building is completed, the completion permit is not granted, and when a rainwater garden is installed, the city supports $4 per ft square. Large-scale buildings and public facilities are obligated to have a 10-year management period and ordinary residents have a 4-year management period, and if poor management is confirmed, subsidies are retrieved (Lee et al., 2019).

4.3 Australia

Australia has tried to ensure the health of the ecosystem and urban environment through desirable water management. The Water Sensitive Urban Design (WSUD) policy is urban planning and design that considers water circulation including for water management, defense and conservation. WSUD's principles are to protect natural water systems, integrate water networks and rainwater treatment, protect water quality, reduce runoff and peak flow rates, and minimize drainage facility development costs. WSUD is a technique that seeks to improve the environment through elements across cities based on basic water circulation systems such as water retention and storage, infiltration, and evaporation. In a broad sense, all urban elements constituting the water circulation system can be defined as WSUD elements.

Rainwater is stored and retained through rainwater tanks, rainwater barrels, and green rooftop at the building. Rainwater dropped to roads and street spaces is discharged by infiltration trenches, Bioretension Basin, Bioretension Swale, porous pavement, etc. These facilities remove pollutants and reduce rainwater runoff rates. Rainwater treated by these facilities will reach wetlands, artificial wetlands, ponds, lakes, etc., or will be recycled as landscaping water, toilet water, etc. Through these processes, the city becomes a safe city that can improve the ecological environment and prevent flooding in addition to rainwater management (Kim et al., 2014).

The water management plan applying these WSUD techniques is not a sub-plan of the land use plan, but has the same hierarchy as the city's overall plans such as land use plan, transportation plan, and energy plan (Hong et al., 2010).

Various urban water circulation management techniques have been developed and applied worldwide for the purpose of "establishing an eco-friendly water management plan", and the main concepts and policies are shown in the following table.

Table 1. Major concepts and policies for urban water circulation management.

Item	Concepts	Major contents
1. Germany	DUD (Decentralized Urban Design)	- Planning of rainfall runoff management at the urban planning stage - Decentralized rainwater management based on ecological architecture. - Imposition of rainwater tax in accordance with the principle of burden on the cause.
2. The United States	LID (Low Impact Development)	- A combination of land development methods managed in the area where rainfall runoff are generated and technology to maintain rainfall-runoff patterns in natural conditions. - Maintaining natural hydrological characteristics, securing green infrastructure, creating natural spaces, reducing non-point pollution, and imposing rainwater tax according to the impermeable area.
3. Australia	WSUD (Water Sensitive Urban Design)	- Planning multi-purpose rainwater management such as urban flooding, drought, and environmental preservation to cope with climate change at the urban planning stage - Securing water (seawater desalination and treated wastewater reuse) and saving water

5. Analysis of Urban Water Circulation Policies and Projects in Korea

In the process of water circulation, water circulation is divided into natural water circulation and artificial water circulation because of human water use. Natural water circulation refers to a circular process that starts with precipitation in the atmosphere, goes through soil, groundwater, river, sea, etc. and evaporates back into the atmosphere. Artificial water circulation flows into various facilities for human use from the moment rainwater falls, circulates within the facility according to its use, and eventually flows back into the river and lake, and the sea, affecting the natural water system.

Urbanization brings about major changes in the water circulation system, and as a result, the vicious cycle that causes various problems is repeated, but existing water circulation measures have limitations in responding problems. Existing water circulation management is focused on direct outflow reduction through LID, post-treatment for the purpose of urban non-point pollution management, and natural water circulation centered on rainwater management, so there is a limit to recover fundamentally water circulation. It is time to promote a comprehensive water circulation policy through proactive management suitable for the era of integrated water management.

5.1 Distributed Laws and Policies of Urban Water Circulation

In the early days of urban formation, sufficient supply of water was prioritized (Water Supply City), and after that, to solve the problem of public hygiene, sewage infrastructure was established (Sewered City) and the focus was on defending to prevent flooding (Drained City). Since then, as standards of living have improved, awareness of environmental conservation, recreation and amenity has increased, interest in managing non-point pollutants and creating water-friendly spaces has increased (Waterways City). In addition, many countries are striving to implement Water Cycle City to preserve biodiversity and natural resources. Recently, in order to adapt to climate change and solve various urban problems, the concept of Water Sensitive City using LID and GI has emerged (Choi, 2018).

In Korea, urban water circulation policy began to be promoted in the Ministry of Environment's non-point pollution management policy. After unifying water management, Water Environment Conservation Act for water circulation management was revised, and the department in charge of water circulation management was transferred to the Ministry of Environment. Accordingly, an opportunity for a different change than before was created, but system and specific contents of the policy have not yet been established.

Similar terms related to water circulation, such as rainwater management, eco-friendly development and low impact development, are used, and various laws related to water circulation are divided and managed according to management areas by policy as shown in the following table.

Table 2. Laws related to water circulation in Korea.

Item	Ministry of Environment	Ministry of Land, Infrastructure and Transport	Ministry of the Interior and Safety
1.Purpose	- Rainfall management in initial stage - Decentralized rainfall management - Non-point pollution management	- Eco-friendly development - Sustainable development	- Rainfall management for disaster prevention
2. Laws	- Framework Act On Water Management - Water Environment Conservation Act - Act On Promotion And Support Of Water Reuse - Sewerage Act - Natural Environment Conservation Act	- National Land Planning And Utilization Act - Act On Urban Parks And Green Areas - Building Act - Green Buildings Construction Support Act	- Countermeasures Against Natural Disasters Act

On the other hand, a new paradigm for the use of rainwater has been proposed due to the enactment and revision of Water Supply and Waterworks Installation Act and Act On Promotion And Support Of Water Reuse. But the water circulation effect is insufficient because it is limited to simply reuse rainwater. In particular, there is no separate legal definition of urban flooding due to distortion of water circulation, and urban flood countermeasures are individually promoted by various ministries in accordance with individual laws such as Countermeasures Against Natural Disasters Act, Sewerage Act, River Act and Framework Act on The Management of Disasters and Safety. Therefore, the linkage and efficiency between legal plans and projects are insufficient.

Some local governments, such as Seoul, Daejeon, and Suwon, also enact and operate basic ordinances related to water circulation. The ordinance includes LID, non-point pollution source management, rainwater management facilities, groundwater recharge, and water reuse. But due to the absence of superior law, individual laws are cited according to the needs of local governments, so there is a limit to the effectiveness and continuity of self-government laws.

Therefore, for comprehensive and systematic urban water circulation management, it is necessary to enact integrated law that encompasses environmental policies and urban planning and establishes basic principles, concepts and scope of urban water circulation.

5.2 Focused on Restoring the Natural Water Circulation

Urban water circulation includes not only the natural circulation process of water resources caused by rainfall, but also artificial water circulation processes used and discharged in cities such as water supply and sewerage. Natural water circulation refers to a natural circulation system of water resources (such as evaporation, infiltration, and runoff) caused by precipitation within a certain watershed. The soundness of natural water circulation is evaluated by quantitatively comparing the degree of distortion in water circulation characteristics between before and after urban development. Artificial water circulation means a water circulation system that is flowed into from outside the system, utilized and managed as urban water, and discharged in order to maintain basic functions of the city. Han et al. (2010) presented the soundness of artificial water circulation by evaluating the actual amount of water-intake reduced compared to the amount of urban water demand. It is possible to improve the soundness rate through diversification of water supply source, water saving, and water reuse.

In Framework Act On Water Management, sound water cycle is defined as a state in which its normal functions continuously perform to maintain the ecosystem and human activities. Therefore, for sound water circulation, the normal function of water should be considered, including both the natural and artificial systems. The water circulation system is very complex and sophisticated, so it cannot be solved by dealing with only one element; a systematic and holistic approach is needed (Kang, 2018). In order to realize a sound water circulation through sustainable integration management, it is necessary to comprehensively consider water use, water safety, and water environment (Kim, 2020).

The Water Environment Conservation Act stipulates that mid- and long-term water cycle goals are included in Comprehensive Plan to Manage Non-Point Pollution Sources. In addition, the mid- and long-term water cycle goals are defined as Impervious area ratio and Water cycle ratio (referring to the ratio of rainwater permeation, retention, and evaporation to the total rainfall). Despite the wide variety of impermeable characteristics depending on the types of surfaces in the city, there is a limitation in that evaluation is made by a dichotomy between impermeable and permeable (Kang, 2020). In addition, since urban water problems can also conflict with various stakeholders from various perspectives such as water supply, urban planning, infrastructure, environment, and amenities, the overall urban water circulation system needs to be reviewed, including both natural and artificial water circulation (Farooqui et al., 2016).

However, the water cycle ratio defined in the Water Environment Conservation Act is limited to the natural water circulation by performing water circulation evaluation using only hydrological data (infiltration, evaporation and outflow amount) of the relevant urban basin. Although hydrological data is the most dominant factor in evaluating water circulation in the basin, the actual water circulation evaluation requires a combination of various information such as water quality and land use conditions of the target basin as well as hydrological characteristics. In addition, information on population and water usage in urban basins related to the social environment are not considered in the existing water circulation evaluation techniques (K-water, 2021).

5.3 Focused on Reducing the Non-Point Pollution

Despite the implementation of many water circulation projects, the effects have not yet been clearly revealed. There are two reasons: first, the Ministry of Environment's policy to deal with water circulation in the past was focused on non-point pollution management, and second, the water circulation project promoted by the urban planning department remained in a simple landscape project without water management function. When the purpose of water circulation project is limited to improve water quality, most of projects fail. The water circulation project should be carried out with the goal of restoring river water by strengthening penetration and moisturizing capacity in the basin, thereby improving water quality, securing water ecological soundness, and creating a waterfront environment (Kang, 2020).

Rapid urbanization has caused a decrease in green area, an increase in impermeable area, a decrease in groundwater level, and a deterioration in river water quality. Vulnerabilities in urban water problems, such as flooding, drought, and heat islands due to urbanization and climate change, are increasing. It faces serious challenges, such as the deepening climate crisis, the declaration of carbon neutrality, the structural change in the water supply and demand, and the continued growth of future generations. Accordingly, there is a need for a comprehensive water management plan that can simultaneously restore water circulation, secure alternative water resources, and relieve urban heat islands. To manage rainwater circulation, reduce non-point pollution, and effectively respond to water disasters and urban water problems, it is required to implement a proactive water circulation policy that considers integrated water management.

A number of studies were conducted, from land use planning and design using LID techniques to derivation of planning elements and effectiveness analysis. To review the technical feasibility of the water circulation technique, effect analysis and business feasibility evaluation have conducted through hydrological models. However, most cases have approached to solve individual problems such as non-point pollution, rainwater treatment, and focused on the development of technologies and techniques by each element. There is a limit to approach comprehensively within the framework of the entire plan (Choi et al., 2010).

6. Development of Water Circulation City Model

6.1 Institutional Issues

To respond to climate change and changes in water management conditions and reflect the increased citizen needs, it is necessary to implement a changed water circulation management policy from follow-up measures to prevention in advance. Laws and systems related to water circulation should be established to continuously implement water circulation management policies required by the times and the people and secure the ability to execute. A unified standard is needed, such as setting the concept, scope of management, and policy goals for water circulation management that can encompass both the natural water circulation and the artificial water circulation. In particular, in cities, distortion of water circulation caused by infrastructure such as water supply and sewage and impermeable layers is a major factor in increasing flooding and heat island phenomena, so policies considering artificial water circulation are required.

Risks in urban water management, such as floods, droughts, and heat islands, are continuously increasing due to climate change and distortion of the water circulation system caused by urbanization. Under the current legal system, it is difficult to expect a recovery of the overall urban water circulation by implementing water management project with single-purpose. To cope with complex urban water problems caused by distortion of water circulation, ordinances for water circulation management by local governments are enacted and operated. But due to the absence of superior laws, there is a limit to the effectiveness and continuity of self-government laws.

For comprehensive and systematic urban water circulation management, superior laws covering environmental policies and urban planning should be enacted. It is necessary to establish a special law for urban water circulation management. The goal of water circulation management should be set up to integrate and manage the multi-function of water circulation such as water quantity and reuse, water quality and ecology, water disasters, and water energy. To achieve this goal, it is necessary to divide the roles between the state and local governments, establish a system for coordination and cooperation between various ministries, and improve the water circulation management organizational system.

For the water circulation plan to be linked to the urban space plan, it is necessary to mandate prior consultation with the Minister of Environment on the water circulation part before establishing an administrative plan and permission for development projects. In order to minimize changes in water circulation and damage in water environment due to development activities, the project implementers need to establish plans such as the application of LID techniques and consult in advance. By reflecting the pre-consultation system implemented by some local governments in the superior special law, it will be possible to secure the executive power of local government officials and expand it nationwide.

It is also necessary to introduce economic means such as rainwater tax and subsidization. The rainwater tax system can promote financial stability for rainwater management and enable sustainable operation in urban water circulation (Choi, 2018). The owner of a facility that interferes with the penetration of rainwater and causes distortion in water circulation should be asked to fulfill social responsibility to secure the soundness of water circulation. In addition, through the introduction of the rainwater tax system, financial conditions can be prepared for the water circulation recovery project of local governments.

Effective compensation measures need to be prepared for the water circulation management policy linked to land use. In Overseas, there are real estate subsidies and commission reductions when applying LID technology, simplification of developer licensing procedures using LID methods, high-density development permits, and subsidy systems (K-water, 2021). It is necessary to induce the installation of water circulation facilities by defining support methods such as tax reduction, subsidy support, and floor area ratio relaxation.

6.2 Project Planning Issues

Since the water circulation project so far has been centered on LID techniques for water quality management (non-point pollutant management), there is a limit to improving comprehensive water circulation such as water quantity and reuse. And in most projects the effect of responding to disasters such as urban flooding, drought, and heat islands is insufficient. It is necessary to expand the concept into an urban water circulation project model that includes the entire water field such as water quality, quantity, aquatic ecology, and reuse, and promote integrated and multifunctional water circulation projects.

In order to promote a multi-purpose project, the concept of water circulation management should be changed from surface management centered on LID facilities to integrated management linking green space (green infrastructure) and artificial water circulation facility (gray infrastructure). In addition to rainwater and surface management, the entire water circulation system (water supply and sewage, urban drainage system, underground water, river water, etc.) should be set up as a management range, and customized techniques should be selected according to urban maturity and space size. In particular, it is difficult to plan a comprehensive water circulation compared to a new development area due to restrictions in securing an optimal place in the existing city area, so it is necessary to consider integrated planning techniques with urban regeneration projects. Water circulation projects should be promoted by considering the spatial characteristics of cities, such as new development areas and urban regeneration areas, and focusing on utilization of multifunctional spaces like open spaces in cities.

Active water reuse is necessary to restore the soundness of urban water circulation. Reuse of water is considered as the essential component for sustainable water resources not only in areas where water is scarce but also in areas where water is abundant. In developed countries, reuse of graywater and treated waste water is intensively fostered as a third water industry. Since water reuse leads to a reduction in tap water consumption and sewage generation, it can not only reduce pollutants in the short term but also restore water circulation in the long term. The MULTI-ReUse project, which started in Germany, is a project to overcome practical limitations through the development and implementation of new procedures in which treated waste water can be used for multiple purposes. A modular treatment system of treated waste water suitable for the needs of each consumer was developed, aiming to produce industrial water, agricultural water, groundwater recharge, and drinking water as a consumer for reuse of treated waste water (K-water, 2021).

In addition, it is necessary to revitalize water reuse through technology linked to various alternative water resources such as water intake, rainwater, and groundwater. In order to actively respond to drought and water pollution, reduce maintenance costs, and supply sustainable water, it is necessary to actively introduce distributed vertical water supply system that can be located close to consumers.

6.3 Governance Issues

To efficiently realize the institutional improvement and project planning in the water circulation, changes in life style through civic practice, community approach, and governance must be accompanied. A community approach centered on resident participation and partnership is essential to solve urban problems based on collaborative governance that emphasizes networks, cooperation and partnerships, joint production, resident orientation, and community culture among participants (Ban et al., 2009).

Until now, the water circulation project has been limited to a one-time pilot project due to a lack of understanding and public consensus on the necessity and policy of water circulation management, and there is a limit to continuous policy and project promotion. The government operates the National-Basin water Management Committee centered on experts, but it is difficult to represent interests in various regions under the existing system due to different water circulation characteristics and pending issues. It is necessary to break away from the existing centralized water management governance system and realize water circulation management in which various stakeholders in the region directly participate.

Citizen participation is a major success factor in water circulation management, and the participation of various subjects enables the search for ideas and solutions suitable for the region. Citizen participation in the overall policy process should be guaranteed through regional-centered governance establishment and operation, and regional customized policies should be discovered. Through the enactment of special laws related to water circulation, it is necessary to divide the roles between the state and local governments, strengthen the responsibilities and roles of local governments in water circulation management, and establish the role of administrative and financial support of the state.

Through urban water circulation governance, local governments need to form and operate an urban water circulation committee in which citizens and experts participate. A governance system should be established so that citizens can actively participate in the water circulation policy and project evaluation, deliberation, consultation, and decision-making process.

6.4 Evaluation Indicators Issues

The water circulation management indicator is limited to rainwater management, so it cannot accurately represent the water circulation of the entire city. Water circulation indicators need to be approached in a comprehensive range of water balance levels such as water use, water saving, water demand and supply management. Lee (2012) subdivided the indicators related to urban water circulation into urban water infra circulation (water supply and sewage), urban hydrological circulation (natural water circulation), and urban artificial circulation (stream, lake, artificial river, pumping, etc.). A reasonable urban water circulation plan should be established based on water balance analysis and demand management in the basin.

The fundamental problem with urban water circulation is that it hinders natural water circulation by the continuous adverse effects of climate change and the increase in impermeable area due to urbanization. In addition, an artificial system consisting of major water infrastructure such as water and sewage facilities is pointed out as a factor that increases water circulation distortion.

For the overall evaluation of natural water circulation and artificial water circulation, it is necessary to introduce the concept of urban water metabolism. Farooqi et al. (2016) established a framework for evaluating urban water metabolism by quantifying the flow of natural water and artificial water passing through urban areas. In the existing city where linear metabolism is dominated, resources and energy are input and released immediately after being used, showing the structure of input and output (production and consumption). On the other hand, circular metabolism, which is applied in water circulation cities, establishes the circular structure of input, output and input (production, consumption and reuse). In other words, sustainable circular urban metabolism can be achieved when integrally considering the flow between various resources and materials and applicable planning techniques, away from the level of simply introducing various planning techniques (Lee et al., 2013).

To realize circular metabolism in the city, it is most important to find a way to maximize the city's potential. This way does not mean simply introducing or applying one-dimensional planning elements, but rather signify a multidimensional process in which elements from various fields such as energy systems, waste management, water resource supply, and sewage treatment are connected. So, it is possible to utilize the most of the potential of the city's resources, and this virtuous cycle results in minimizing the amount of input the city needs and reducing the absolute amount of output, carbon emissions, and air pollution (Choi et al., 2011).

In order to establish sustainable water circulation management indicators, the material relationship for each element constituting the urban water circulation should be redefined and linked. In the process, not only water circulation (including natural water circulation and artificial water circulation), but also various urban components such as energy, carbon emission, and environmental pollution should be linked to each other. Considering the circular metabolism of all resources and energy in the city, sustainable water circulation management indicators can be established.

7. Conclusion

7.1 Summary of study

This study aims to develop a sound and sustainable water circulation city model by considering the complex and diverse elements of urban water circulation as a whole. The literature review and the case studies on Germany's Decentralized Urban Design (DUD), the United States' Low Impact Development (LID), and Australia's Water Sensitive Urban Design (WSUD), are examined. Various efforts, achievements and limitations of urban water circulation policies in Korea also investigated.

In Korea, various factors of the urban water circulation are not integrally considered in water circulation urban policies, and various laws are distributed and managed according to the managing sectors of each policy. Urban water problems can also conflict with various stakeholders from various perspectives, such as water supply, urban planning, infrastructure, environment, and urban amenity. So it is necessary to review the overall urban water circulation system, including both natural and artificial water circulation, but most policies have reviewed focusing on restoring natural water circulation. In addition, projects have promoted for individual purposes such as rainwater management and non-point pollution management, so there is limit to approaching in terms of integrated water circulation management such as water disasters, water reuse, and water saving.

Following the analysis, the paper proposes a differentiated water circulation city model for Korea, catering to its specific local contexts and conditions. Four issues are given particular attention: institutional issues, project planning issues, governance issues, and evaluation indicator issues.

For comprehensive and systematic urban water circulation management, a superior special law covering environmental policies and urban planning should be enacted. It is necessary to expand the concept into the urban water circulation project that includes the entire water field such as water quality, quantity, ecology, and reuse, and promote integrated and multifunctional water circulation projects. In order to efficiently realize the improvement of institutional system and the project model in the urban water circulation, governance system in which various stakeholders in the region directly participate must be established. Sustainable water circulation management indicators should be set up by considering the circular metabolism of all resources and energy in the city by linking various urban components such as energy, carbon emissions, and environmental pollution in addition to water circulation.

The outcome of this study is expected to contribute to the establishment and revitalization of the water circulation city in Korea.

7.2 Policy recommendation and Limitation

Globally, water circulation projects have been implemented to solve the distortion of water circulation due to urbanization, and many problems are still pointed out despite some successful cases. There are successful cases in individual buildings or small-size businesses, but large-scale applications at the basin level show limitations in measuring quantitative effects. The cause of these limitations can be found in the lack of accumulated research results that can implement it and measure results compared to huge goals.

The water circulation project should include not only reducing non-point pollution and managing rainwater, but also creating a pleasant environment and landscape in addition to integrated water management. Recently, researches on alleviating the heat island phenomenon, reducing fine dust, reducing carbon emissions, and utilizing water resources have attempted, leading to a need to establish a new concept for urban water circulation overall. Kang (2020) predicted that in the past, the water circulation policy started from non-point pollution management, but in the future, it will expand to urban planning to create a pleasant urban environment as well as urban river management, which will eventually lead to policies to secure new demand and supply sources for urban water resources.

To realize a sound water circulation through sustainable integration management, a passive water circulation plan that is applied only to cities is insufficient. It is necessary to expand the scope of water circulation by widening the range from city to basin units, and to comprehensively consider water use, water safety, and water environment in terms of integrated water management (Kim, 2020).

Water is a key factor in responding to the climate crisis, and water management in terms of carbon neutrality is required. According to the UN's "2020 World Water Development Report", the water management sector accounts for more than 90% of climate change adaptation. To respond to climate change and implement carbon neutrality through water circulation, it is need to introduce not only LID-based rainwater management and non-point pollution management but also water circulation soundness recovery by water reuse and water circulation optimization through real-time collection and analysis of water data. In the future, research is needed to establish a water circulation system that considers various factors such as overcoming the climate crisis, achieving carbon neutrality, linking with urban regeneration new deal projects, and linking with smart cities.

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