The Construction of Water-Sensitive Urban Design in the Context of Japan

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Abstract. Water Sensitive Urban Design (WSUD) is a critical sustainable development theory in the urban water environment, which is attracting more and more attention worldwide. Meanwhile, as an island country, Japan attaches great importance to water resources and water environment, and have achieved fruitful result in urban water management. Based on the framework of WSUD, this research introduces Japan's practical experience from the perspectives of water source protection, flood control, and waterfront space landscape, aiming to summarise Japan's experience and provide a new perspective. By explaining the thoughts of water sensitivity design contained in Japanese practice, this research expands the scope of WSUD, provides a meaningful research framework for Japanese researchers, and provides compelling cases for researchers on water-sensitive design around the world.

1. Introduction

WSUD is proposed in the late 1980s as a pattern of urban planning [1]. However, the definition of Water Sensitive Urban Design (WSUD) has been evolving, but there is still no unified definition [2]. The fundamental element is sustainable social development and sustainable management of the urban water environment. Its essential purpose is to protect water sources while providing resilience to the city's ecological environment and ultimately achieving coordinated urban construction patterns and urban water cycles. Under challenges such as climate change, urban population explosion, and water pollution, WSUD theory provides the possibility of simultaneously achieving urban development, protecting water sources, recovering urban ecosystems, and responding to climate change [3]. The WSUD theory is regarded as the critical theory of future urban development and urban water environment management in Australia, the United States, France, Singapore, and other countries [4, 5].

2. Literature Review

Since its introduction, there have been many studies on WSUD. Although WSUD is initially considered to manage the water resource system the main problem was solving rainwater management problems [6], with the improvement of related planning and management systems and the latest development of hydrological management measures and technologies, the scope and connotation of WSUD have gradually expanded. At present, comprehensive protection of the urban water environment and sustainable management of hydrological systems have been fully involved.

Recently, research on WSUD mainly involves three directions: natural geography, ecosystem, and socio-economic. Relevant research in the natural geographic mainly includes non-human intervention factors that affect hydrological conditions, such as terrain and slope, and elevation [7]. Ecosystem
research involves soil, greening, water quality, water quantity, rainwater recharge\cite{8}, ecological diversity\cite{1}, climate, and runoff control\cite{9}. At the socio-economic level, previous research mainly involved urban transportation\cite{10}, urban site development and construction\cite{7}, public awareness, public participation and the construction of a hydrophilic lifestyle, supervision and maintenance, risk assessment\cite{11}, and social stability, etc. Meanwhile, most researches in WSUD concentrated on smaller scales\cite{12} such as urban space, sites, feature planning, design projects, blocks, urban areas, and segmented watersheds\cite{13}. There are few studies on the national scale, and research subjects are mainly Australia and other countries.

Although there has been a lot of researches and practices on WSUD in Japan, the constant evolution of the WSUD concept has made little reviews incorporate works in Japan into the WSUD framework. Therefore, this paper will review Japanese research under the WSUD framework from three aspects: resources, disasters, and design, aiming to provide readers with a comprehensive understanding of the WSUD in the context of Japan.

3. Water Source and Urban Water Supply

With the development of the economy and the acceleration of urbanisation, more attention has been paid to the water source area and the surrounding ecological environment. Among them, soil erosion is the first problem to be solved, and the greening of the water source area can play a useful role in soil and water conservation. Simultaneously, due to its geological structure's particularity, the forest soil has a specific purification effect on some harmful components in natural rainwater and plays a role in purifying the water in the water source.

3.1. Water Resource Environment in Tokyo

Tokyo is the capital and the largest city in Japan. The total area is 2,191 km$^2$ (as of October 1st, 2016) and accounts for 0.6% of Japan's total area. Tokyo has a population of 13.63 million people (as of January 1st, 2018), which is about 10% of Japan's population. The population and the bases of economic activities are concentrated in Tokyo and extend to its suburban areas. Therefore, taking Tokyo as a research area can show the organisation of urban water management in Japan.

Japan has always attached great importance to protecting natural water sources and the ecological environment regarding Tokyo's future water supply system. It is hoped that while promoting environmental protection, the total amount of water supply can be maintained, and the water quality can be improved. A set of water sources, water quality, and environmental protection measures is proposed, including promoting the rainwater infiltration machines installation, improving the waterfront environment, new water quality standards, and "water source forests." Among them, the water source forests are the most direct intervention in the water source area.

The conservation and maintenance area of Tokyo Water Supply Forest is shown in Figure 1, with a total area of 21,624 hectares. The water source forest's primary function includes rainwater storage, water source conservation, sediment loss prevention, and water quality protection. For environmental protection and ensuring water supply source, the maintenance and conservation of water source forests are essential and need to be further promoted.
3.2. Water facilities in Tokyo

Until the early 1960s, Tokyo still used the Tama River as its primary water source. Subsequently, in response to the rapidly growing water demand, Tokyo began to use the Tone River water system and developed and constructed the Tone River water source. Currently, 80% of the water resources for Tokyo come from the Tonegawa and Arakawa River systems, and around 20% comes from the Tama River system. Moreover, in recent years, abnormal weather has frequently been occurring worldwide, and climate change will significantly impact water supply in the future, such as water resources and water quality.

To solve the water supply problem, the Ministry of Land, Infrastructure, Transport and Tourism (MLIT) and the Water Resources Agency of Japan developed new water sources in Tokyo, namely the "Basic Plan for Water Resources Development in the Tone River and Arakawa Rivers". Several projects like the Urayama Dam, Kita Chiba Waterway, and Takizawa Dam are completed recently.

In this system, raw water is taken from the Tone and Tama rivers and pumped to the Higashimurayama water purification plant. Simultaneously, the raw water from the Tama river water can be replenished to the Asaka water purification plant through natural flow, allowing the mutual exchange of raw water. Typically, water from the Tone and Tama rivers will be used for water supply, and a necessary amount of water from the Tama River system, such as the Okochi Reservoir, will be used to store water. Nevertheless, the highest water demand might encounter the Tone and Tama river water quality accidents in the summer. Under these drought circumstances, water from the Tama River is used to ensure raw water's efficient operation.

From the WSUD perspective, this water supply system directly changed Tokyo's water cycle path and has become an essential part of the Tokyo metropolitan area's water system. Tokyo's water facilities have achieved the dual goals of water conservation and water supply through regional and seasonal water resource deployment.

3.3. Water supply and water demand in Tokyo

Tokyo Metropolitan Government Bureau of Waterworks is in charge of the whole of Tokyo's water management project, which is one of the most famous large-scale water operators. The Bureau of Waterworks supplies water to the 23 wards and 26 cities and towns in the Tama area. The service area covers 1,239.27 km² for 13,401,324 residents' daily water demand. The total water distribution amount per year of Tokyo is 1,541 million m³ as of October 1st, 2017 [14]. Currently, the amount of raw water held by the Tokyo Metropolitan Government is 630 million m³/day in 2018.
Figure 2. Daily Average Water Use and Population Served (Wards and 29 Cities/Towns)

Water demand is one of the critical factors that determine the service capacity of the water supply system. It will fluctuate with changes in population movements, lifestyles, climate conditions, and socio-economic conditions. Tokyo has experienced water demand growth with population growth. During the period of rising growth, uncertain social and economic development trends, climate change, natural disasters, and other conditions may potentially impact water supply-demand, and future water demand may have unexpected changes. Tokyo's average water consumption and serving the population in the past 20 years are shown in the graph (Figure 2).

Given that water supply facilities will continue to be used for 50 to 100 years, it is necessary to look at water supply demand for as long as possible to ensure stable water supply. When renewing the water purification plant, the ageing water purification plant will be sequentially renewed on a series-by-series basis after establishing an alternative one. For this reason, the Bureau of Waterworks will consider the population trends for the next 25 years when forecasts water demand in the "Tokyo Waterworks Facility Reconstruction Basic Concept".

In general, Japan's experience has shown the vital influence of water sources, water supply facilities, and water demand, and has responded from the perspectives of forest conservation, water resource allocation, and demand estimation. These topics are the research directions of WSUD in recent years, from land resources to engineering construction. To build an urban environment where people and water are in harmony, research on water sources and water supply is the basis for further planning and design.

4. Flood Control and Disaster Prevention

Under the Disaster Measures Basic Act, River Act, and Flood Protection Act, Japan has formed a system from "crisis response" to "emergency measures and recovery," and then "disaster prevention" around the occurrence of a flood. The system covers measures from patrolling rivers, reporting damage status, delivering flood warnings, emergency restoration measures, post-disaster recovery measures, and then to river improvement, provision of the river information system, and construction of disaster prevention stations.

4.1. Super Levee development project

Along the major rivers flowing through urban areas with a high density of population and property, absolutely no embankment collapse is allowed. Wide levees named "high-standard levee" or "super levee" are constructed along these rivers since 1987 [15]. Super levees are high and wide (300-500 m) levees on which urban buildings and traffic facilities are developed. They also serve as the redevelopment of urban areas, which justifies the construction cost by increasing the developed lands' value (Figure 3).
Super levees are the ultimate defence against a usual flood in alluvial lowlands. The idea of super levees goes from the fact that even in an extreme flood, damage can be minimised if levees do not break. Moreover, broader levees can effectively deal with water overtopping, water seeping, and earthquakes. Hence super levees are by far better than conventional levees. Furthermore, a gently sloped super levees help to connect the community to the river smoothly.

The community side of super levees can also be used effectively, such as residential land and parks. Super levees also provide space for a scenic and comfortable living environment. People can approach the riverbank more naturally, without stepping over a clear dividing line. Harmony between the natural environment and the urban environment helps community residents stay close to nature. Thus, super levees make it possible to build a safe and scenic community integrated with the river.

As a direct measure to deal with the flood, the super levee project directly combines urban space and flood prevention engineering measures, which can realise the functions of flood resistance and disaster reduction and provide a brand-new kind of urban form as a meaningful WSUD exploration in urban design.

4.2. Rainwater storage and infiltration facilities
Where prevention of flood disasters by improving the river channel is difficult because of progressive urbanisation, developing rainwater storage and infiltration facilities by the river administrator, specifying the urban rivers and catchments, developing catchment flood disaster countermeasures, and other practical measures as comprehensive flood control measures.

Considering the hydrologic cycles and water environments in the river and its basin, rainwater storage and infiltration technology is not only for flood control but also for water conservation and restoration of sound water circulation system. The effects of rainwater storage and infiltration cover groundwater recharge, spring restoration, an increase of river flow during regular times, effective use of rainwater, improvement of water quality, improvement of heat island phenomenon, conservation of the ecosystem. [16].

Besides, to ensure the Tokyo metropolitan area's safety, an underground artifactual waterway is constructed in Kasukabe City, which is one of the largest underground water facilities globally (Figure 4). By connecting the five main rivers, including Nakagawa, Kuramatsu, and Tone, and directly drains water into the Edogawa River, floods in the Tokyo urban area can be prevented. The facility is 6.3 kilometres long and consists of five silo-shaped water storage spaces of different sizes in 50 meters underground.

Figure 3. Concept of Super Levee

Figure 4. The Metropolitan Area Outer Underground Discharge Channel
Japan is a flood-prone country, which makes WSUD measures to flood a vital topic. The comprehensive flood control measures in urbanised areas serve as a comprehensive policy, while the Super Levee and rainwater facilities are the unique creation and practice of Japan in WSUD. With the rising global climate change, Japan's urban design experience in dealing with flood disasters is worth promoting and reference.

5. Conclusion
In this research, we take the Water-Sensitive Urban Design (WSUD) as the research framework, introduces relevant Japanese practices in the three main aspects of water source protection, flood control and waterfront landscape. In general, Japan adheres to the WSUD principles and combines natural conditions, engineering technologies, and cultural traditions into the practices, forming WSUD with distinctive Japanese characteristics.

Specifically, Japan emphasised forest conservation in terms of water source protection and adjusts the water environment at the urban scale through water supply facilities and water demand. On this basis, in response to the occurrence of flood disasters, Japan adopted comprehensive flood control measures and created a series of valuable engineering measures, such as super levees and rainwater storage facilities. On a more microscopic scale, Japan achieved a more natural landscape by creating nature-oriented rivers with regional material and various sections and guided the design of waterfront space through regulations.

There are plenty of researches in the field of water environment covering all relevant topics, and we only outline a limited part related to water-sensitivity, and there will inevitably be some omission. At the same time, we focus on specific engineering practices and omit a series of policy decision in Japan. In general, we hope to outline the picture of WSUD in Japan for readers and will further enrich the relevant parts in future research.

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