Chapter 10
Water Resources Management in South Korea

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Abstract This chapter covers the following key topics: an overview of the current state of water resources availability and use characteristics of rivers, large reservoirs, water quality management, water-related natural disasters, and the future water resources management in South Korea. The average annual rainfall in the past 30 years is about 1300 mm, which is greater than world's average annual rainfall, but the spatial and temporal variance is large. Most rivers show characteristics of short lengths and steep slopes, releasing a significant amount of water. These features make the downstream region relatively more vulnerable to massive floods during the wet season. The significant annual fluctuations in water level make water resources development and management difficult. In comparison, South Korea has a larger river regime coefficient than other countries. Therefore, many of these reservoirs are built to store water during the wet season and supply water during the dry season. In the 1960s, South Korea's rapid industrialization has led to a severe deterioration in water quality in most rivers. Since the 1980s, many environmental infrastructures have been built to improve water quality. Therefore, future water resources management strategies in South Korea should focus on (a) establishing a safe and robust foundation for flood control, (b) supplying clean and sufficient water for people and nature, and (c) enhancing sustainable water quality and ecosystem management.

Keywords Water resources availability · River characteristics · Water quality management · Water-related natural disasters · Future water resources management

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10.1 Introduction

The Korean Peninsula is located in the Far East. Korea was divided into North Korea (Democratic People's Republic of Korea) and South Korea (Republic of Korea) along the Military Demarcation Line after the Korean War. In 1948, the South Korean government was formally established. South Korea's total area is 100,222 square kilometers, and its total population was 51.6 million in 2016. In Fig. 10.1, the map of East Asia and the Korean Peninsula is presented.

In the past 30 years, the average annual rainfall was 1300 mm, with a broad range from a high of 830 mm to a minimum of 1756 mm. However, the rainfall varies spatially and temporally, which means it fluctuates across the whole country and throughout the entire year. The rainy season typically lasts from June to September, and about 68 percent of total annual rainfall occurs during this season.

Most rivers have short lengths and steep slopes releasing a significant amount of water. These features make the downstream region relatively more vulnerable to massive floods during the wet season. The Miracle on the Han River refers to the period of rapid economic growth in South Korea following the Korean War (1950–1953). During the nation's economic growth, land use transformed from agriculture to other industrial production. Most people who live in areas near the river became very vulnerable to flooding.

Fig. 10.1 Map of East Asia and the Korean Peninsula

10.2 Water Resources Availability and Current State of Water Use

Over 75.9 billion cubic meters per year (BCM/year) of water is available through the nation. The average water availability is 1488 cubic meters per capita per year. The five major rivers in South Korea are the Han River, the Nakdong River, the Geum River, the Yeongsan River, and the Seomjin River. Out of the five river basins, the average water availability in the Han River and the Nakdong River is relatively low due to the high population density. Figure 10.2 shows water availability in five major rivers.

The yearly average available water is 132.3 BCM. 75.9 BCM (57 percent) is for water use, and the rest is lost through evapotranspiration Fig. 10.3. Out of 75.9 BCM, about 54.8 BCM (72 percent) becomes runoff in the wet season, and 21.2 million cubic meters (MCM) (28 percent) becomes runoff during the rest of the year. The water supply comes from the river (12.2 BCM), the reservoir (20.9 BCM), and the groundwater (4.1 BCM), and the rest flows into the sea (38.8 BCM). Table 10.1 shows the water supply from the reservoir:

The available water is 75.9 BCM per year, of which 4.1 BCM are groundwater supply. The groundwater supply has been increasing, but for the past 4 years,

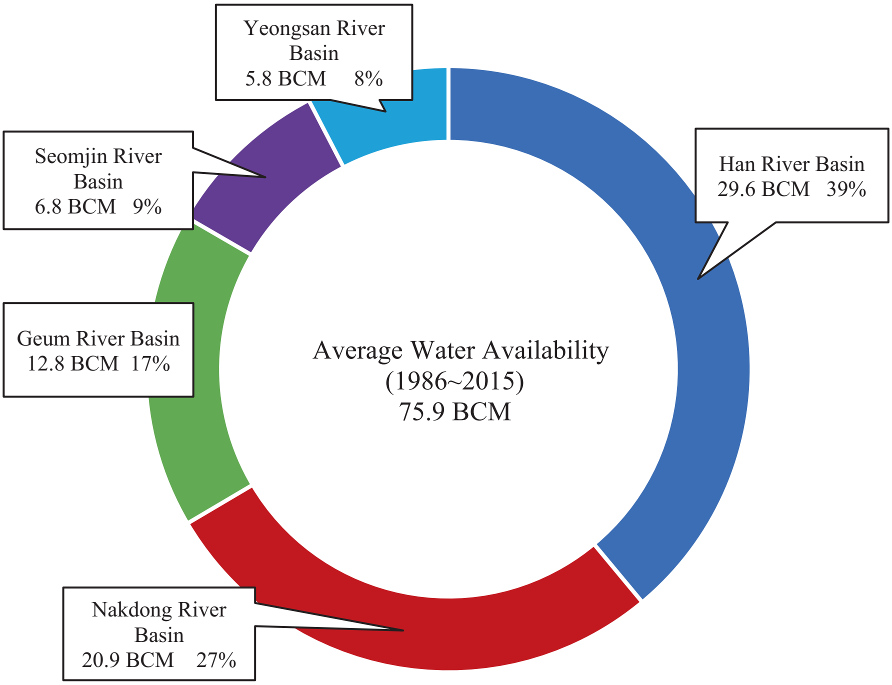

Fig. 10.2 Annual average water availability in five major rivers (MOLIT 2016)

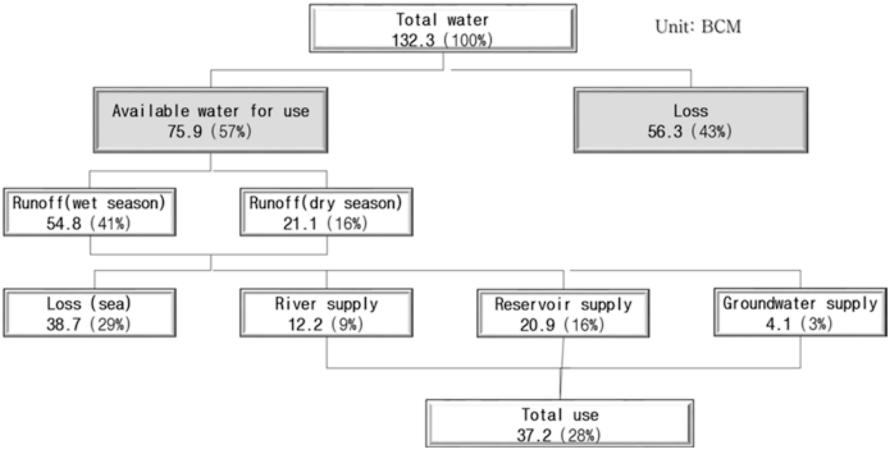

Fig. 10.3 Present state of water use in Korea (MOLIT 2016)

Table 10.1 Main reservoir and weir supply (MOLIT 2016)

	Total storage (MCM)	Effective storage (MCM)	Water supply (MCM/year)	Count
Multipurpose reservoir	12,923.0	9111.0	11,220.2	21
Hydropower reservoir	1844.0	992.8	1335.0	15
Water supply reservoir	609.0	536.3	880.5	54
Estuary bank	1259.3	807.1	2930.0	12
Irrigation reservoir	3142.4	3009.10	4093.0	17,401
Weir (Four Rivers Restoration Project)	626.3	173.4	463.6	16
Flood control reservoir	2709.7	–	–	2
Total	23,113.7	14,629.7	20,922.3	–

groundwater use has been relatively steady. The alluvial aquifers are distributed mostly in large rivers (i.e., Han River, Nakdong River). All the alluvial aquifers cover an area of 27,390 square kilometers (27 percent of the total land area of South Korea). The thickness of aquifers ranges from 2 to 30 centimeters (Fig. 10.4).

The total water supply for domestic, industrial, and irrigation use was roughly 5.1 BCM in 1961 and increased dramatically until 2014, when it was five times greater than in 1961 (251 MCM) (Fig. 10.5, Table 10.2).

Domestic water supply has been increasing, but the water supply per capita has been decreasing. Industrial water supply has been steady since 2000, when the economic growth rate was stabilized. Since 2000, as the agricultural area decreased and the irrigated paddy ration increased, the irrigation water supply started to stabilize.

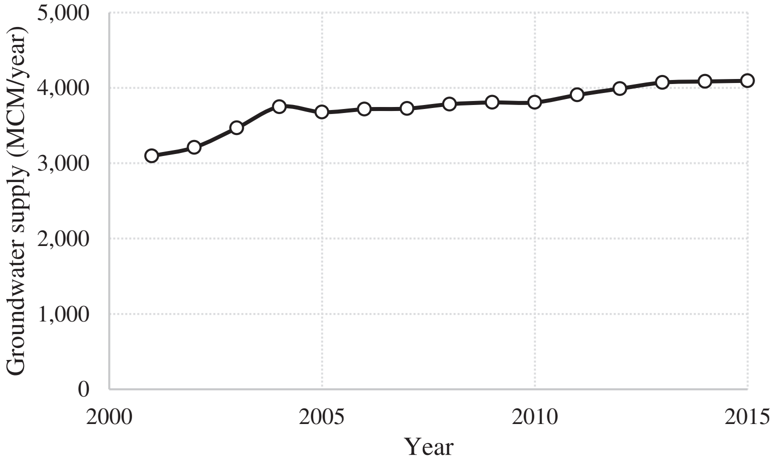

Fig. 10.4 Groundwater supply (unit: MCM/year) (MOLIT 2016)

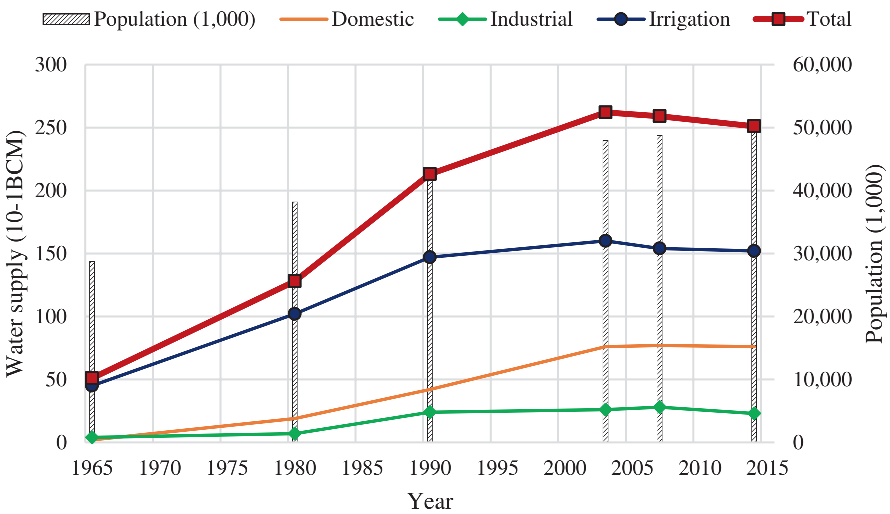

Fig. 10.5 Domestic, industrial, and irrigation water supply (MOLIT 2016)

Table 10.2 Water supply in South Korea (MOLIT 2016)

Water supply (10^{-1} MCM)	1965	1980	1990	2003	2007	2014
Domestic water	2	19	42	76	77	76
Industrial water	4	7	24	26	28	23
Irrigation water	45	102	147	160	154	152
Total	51	128	213	262	259	251
Population (1000)	28,705	38,124	42,869	47,892	48,684	50,747

10.3 Characteristics of Rivers

Since two-thirds of South Korea is covered by mountains, most rivers have small drainage areas and short river lengths with a steep slope and a large amount of sediment. Most major rivers start from the Taebaek Mountains, which stretch across North to South Korea along the Eastern coastline. Eastern South Korea has a steep-sided hill with a short river length, while Western South Korea has a flat plain with a long river length. The Han River has the largest drainage basin with the highest average annual runoff, while the Nakdong River is the longest river (Fig. 10.6). Ten major rivers in South Korea are presented in Table 10.3.

The annual fluctuations in water level are the primary driving forces that make water resources development and management difficult. Table 10.4 is the list of river regime coefficient expressed in the maximum and minimum water flow ratio of major rivers. South Korea has a higher river regime coefficient than many other countries (Table 10.4). Runoff reaches the estuary very rapidly, within 1 to 3 days, right after a massive storm in flood season. Therefore, many reservoirs are built to store this runoff and supply water during the dry season.

The instream flow is the minimum required flow to maintain normal river functions and conditions, considering domestic, industrial, and irrigation supply, the environment, hydropower, navigation, etc. It is officially noted for the crucial control points in rivers.

10.4 Large Reservoirs

Due to climate and river runoff characteristics in South Korea, numerous multipurpose reservoirs have been built for storing water during the wet season and supplying it during the dry season. Multipurpose reservoirs are constructed for water supply, flood control, navigation, irrigation, hydropower, etc. Even though reservoirs play a critical role in water resources management, the construction of reservoirs has decreased dramatically in South Korea since the 2000s due to environmental problems, issues around submerged areas, the lack of remaining suitable locations, etc. In 2016, 20 multipurpose reservoirs were being operated. The Soyanggang reservoir has the largest storage capacity of 2.9 MCM, while the Chungju reservoir has the largest hydropower generation capacity of 410,000 kilowatts. Table 10.5 is a list of major multipurpose reservoirs.

10.5 Water Quality Management

Soon after the industrialization in the 1960s, the urbanization of South Korea progressed rapidly (Table 10.6). The large reservoirs and "wide area water supply systems" are built to satisfy increasing water demands. In South Korea, wide area water

Fig. 10.6 The five large rivers in South Korea

Table 10.3 Ten major rivers and streams in South Korea (WAMIS)

Name	Basin area (km^2)	Length (km)	Average annual rainfall (mm)
Han River	25,954	494	1301
Nakdong River	23,384	510	1186
Geum River	9912	398	1272
Seomjin River	4.96	224	1412
Yeongsan River	3468	137	1318
Anseong Stream	1656	60	1269
Sabgyo Stream	1650	59	1235
Mangeong River	1504	81	1254
Heongsan River	1133	63	1138
Dongjin River	1124	51	1278

Table 10.4 River regime coefficients

River name	River regime coefficient
Han River	90
Nakdong River	260
Geum River	190
Seomjin River	270
Youngsan River	130
Thames River	8
Seine River	34
Rhine River	18
Nile River	30
Mississippi River	3

Table 10.5 Main reservoirs in South Korea (K-water 2016)

River name	Reservoir	Catchment area (km^2)	Height (m)	Length (m)	Total storage (MCM)	Flood control capacity (MCM)	Water supply (MCM)
Han River	Soyanggang	2703	123	530	2900	500	1213
	Chungju	6648	97.5	447	2750	616	3380
	Hoengseong	209	48.5	205	86.9	9.5	119.5
Nakdong River	Andong	1584	83	612	1248	110	926
	Imha	1361	73	515	595	80	591.6
	Hapcheon	925	96	472	790	80	599
	Namgang	2285	34	1126	309.2	269.8	573.3
	Milyang	95.4	89.5	535	73.6	6	73
	Gunwi	87.5	45	390	48.7	3.1	38.3
	Gimcheon-Buhang	82	64	472	54.3	12.3	36.3
	Seongdeok	41.3	58.5	274	27.9	4.2	20.6
	Boheonsan	32.6	58.5	250	22.11	3.49	14.87
Geum River	Daechung	4134	72	495	1490	250	1649
	Yongdam	930	70	498	815	137	650.43
Seomjin River	Seomjingang	763	64	344.2	466	32	350
	Juam (main)	1010	58	330	457	60	270.1
	Juam (auxiliary)	134.6	99.9	562.6	250	20	218.7
Miscellaneous	Buan	59	50	282	50.3	9.3	35.1
	Boryeong	163.6	50	291	116.9	10	106.6
	Jangheung	193	53	403	191	8	127.8

Table 10.6 Urbanization rate (UN 2014)

Year	1960	1970	1980	1990	2000	2010	2050
South Korea (percent)	27.7	40.7	56.7	73.8	79.6	81.9	88.0
World (percent)	32.9	36.0	39.1	43.0	46.6	50.6	66.0

supply systems are defined as a system that delivers raw water or treated water to more than two regions by central or local governments. Also, urbanization caused water contamination and many dry streams.

The Environmental Conservation Act was issued, as the water contamination became a social problem in the early 1970s. By establishing the Environmental Office in 1980, water quality policy was actively enforced. When the Environmental Office expanded to the Environmental Agency after the 1990s, many environmental acts and national plans were established. After the phenol spill happened in the Nakdong River in 1991, the public became highly interested in source water and drinking water safety. In 1994, another water pollution accident occurred in the Nakdong River. This made the water quality policy more regulated by expanding the Environmental Agency to the Ministry of Environment. The total pollution load management system, which restricts the total amount of pollutant load from each basin, was introduced in 1999. The Water Quality Environmental Conservation Act was revised as the Water Quality and Ecosystem Conservation Act in 2005. This includes not only the reduction of water contamination but also the conservation of the water environment and the hydro-ecological system.

By increasing the number of environmental infrastructures, the water quality has been improved, but the enhancement rate has been slowing down recently. The biochemical oxygen demand (BOD) is below 3 mg/l for 95 out of 114 sub-basins in South Korea (MOE 2016). Although the total phosphorus (TP) concentrations have been improving, most regions exceed the Organization for Economic Co-operation and Development (OECD) standard level of TP (0.035 mg/l). The downstream of industrialized areas is still highly contaminated. In 2017, the new administration considers moving the Office of Water Resources from the Ministry of Land, Transport and Maritime Affairs to the Ministry of Environment. One of the reasons is to reinforce the integrated water resources management (IWRM). The Ministry of Land, Infrastructure and Transport was renamed the Ministry of Land, Transport and Maritime Affairs in 2017 when Moon's new administration began.

IWRM is a process that promotes the coordinated development and management of water, land, and related resources to maximize the resultant economic and social welfare in an equitable manner, without compromising the sustainability of the vital ecosystem (GWP 2000). The reasons why IWRM should be introduced in South Korea are as follows: (a) the rainfall varies spatially and temporally, which means that it fluctuates across the whole country and throughout the entire year; (b) the national water management is separated by number of agencies (i.e., the Ministry of Land, Transport and Maritime Affairs; the Ministry of Environment; the Korea Hydro & Nuclear Power Co.; the Ministry of Agriculture, Food and Rural Affairs; and the K-water), which manage the domestic and industrial water supply, water quality management, flood control, hydropower generation, and the irrigation water supply; and (c) laws and systems are unsatisfactory for coordinating the upstream areas with the downstream areas and integrating water quantity and water quality. Implementing IWRM is expected to resolve the problems, for example, the separated water management, water quality and ecosystems in rivers, and unbalanced water supply-demand between regions.

10.6 Water-Related Natural Disasters

Floods and typhoons represent 66 percent of the most severe water-related natural disasters. Flood damage accounted for 59 percent of the water-related natural disaster damage costs. Typhoon damage was the second most costly, accounting for 28 percent. In South Korea, the average water-related disasters cost about 1.8 billion US dollars per year, which is greater than the OECD average. Table 10.7 shows the five worst water-related disasters.

The Imjin River had several major floods (1996, 1998, 2011, and 2013), which caused property damage and human loss. The Imjin River flows from North to South Korea, but the majority of this basin belongs to North Korea (63 percent of the total Imjin River basin). Therefore, South Korea has less control over the Imjin River. North Korea constructed several reservoirs in the upper Imjin River, and they released a huge amount of water downstream several times without warning to South Korea, causing massive damage. The ongoing political tensions between South and North Korea make it difficult to control floods in the Imjin River altogether. The Gunnam flood control reservoir was built in the lower Imjin River to prevent further damage. Even with the construction of the Gunnam flood control reservoir, it is insufficient to control floods in the lower Imjin River because of the short distance between reservoirs in the upstream and downstream, which gives short response time to the downstream reservoir.

In the 2000s, several typhoons struck South Korea, causing serious damage. Typhoon Rusa was the strongest storm on August 23, 2002. A record of 870.5

Table 10.7 Top five heavy rainfalls and typhoons in South Korea (1999–2015)

Rank	1	2	3	4	5
Year	2002	2003	2006	1998	1999
Natural disaster	Typhoon Rusa	Typhoon Maemi	Heavy rainfall and typhoon Ewiniar	Heavy rainfall	Heavy rainfall and typhoon Olga
Date	8/30–9/1	9/12–9/13	7/9–7/29	7/31–8/18	7/23–8/4
Maximum wind velocity (m/s)	Jeju: 43.7 Yeosu: 29.1	Jeju: 60.0	Gunsan: 31.0		Wando: 46.0 Muan: 41.0 Gwangju: 39.6 Masan: 37.0
Maximum daily rainfall (mm)	Gangneung: 870.5 Donghae: 319.5 Sokcho: 295.5	Namhae: 456.3 Goheung: 304	Hongcheon: 255.5 Namhae: 264.5 Sancheong: 229.5	Ganghwa: 481.0 Boeun: 407.5 Yangpyeong: 346.0	Cheorwon: 280.3 Chuncheon: 237.2
Damage cost ($1000)	5,448,148	4,371,790	1,713,418	1,308,717	1,123,817

Rank 1 indicates the most severe event (MOLIT 2015) millimeters of rainfall in 24 hours was the highest ever recorded since 1904. As a result of Typhoon Rusa, the Janghyeon and Dongmak reservoirs collapsed.

In 2010, frequent localized heavy rainfall inundated the urban areas. Over recent years, urban planning has changed a lot to prepare for urban flooding and to reduce the urban inundation. The design criteria for sewer systems and pump stations were extended from 10-year to 30-year design frequencies. The design frequency for urban rivers was also extended from 50 years to 80 years.

The Korean government amended the Natural Disaster Countermeasures Act to include special disaster areas. The special disaster areas can be declared for all severely harmed areas so that the victims can focus on recovery. The Korean government also revised the River Act to designate the river sections and to introduce emergency action plans for dams.

10.7 Future Water Resources Management

Two-thirds of the total annual rainfall occurs during the rainy season (July–September) and causes floods and droughts, alternately, throughout the year. These climate characteristics make water resources management extremely challenging in South Korea. Therefore, future water resources management strategies should focus on (a) establishing a safe and solid foundation for flood control; (b) supplying clean and sufficient water for people and nature; and (c) enhancing sustainable water quality and ecosystem management.

In order to establish a safe and solid foundation for flood control, it is recommended to analyze climate change impact on floods, plan basin-wide flood reduction strategy, improve the floodplain management plan, and increase the urban flood mitigation capability. In order to supply clean and sufficient water for people and nature, it is recommended to develop a reliable water system through supply and demand management to maintain stable water supply to impoverished water regions and to build a water resources infrastructure based on local characteristics and economic efficiency. In order to enhance sustainable water quality and ecosystem management, it is recommended to establish a national basin-wide environmental management plan, to implement a water quality and environmental monitoring system, and to strictly regulate pollutant sources.

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