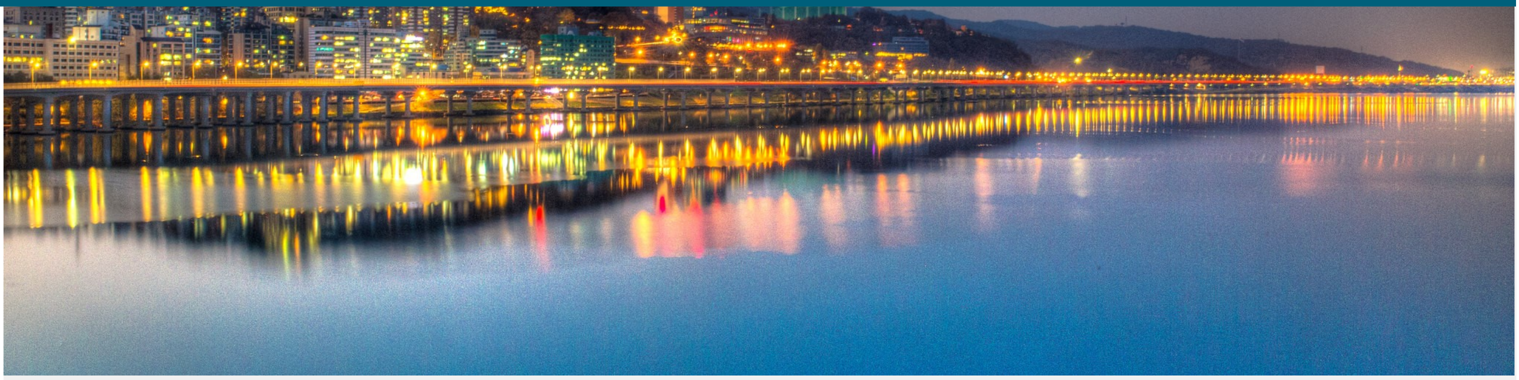
A Smart Water Nation?
Water Technology and Management in South Korea



ICDK Outlook No. 04, September 2020

Ministry of Higher Education and Science Denmark

Published by Danish Agency for Science and Higher Education
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Cover photo Hangang River HDR
Taken from Carmine.Shot www.flickr.com

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Publication can be downloaded at idck.um.dk and ufm.dk/publikationer.

ISBN (electronic publication): [978-87-93706-86-6]

NORDISK MILJØMÆRKNING
5041 TRYKSAG 0457

Contents

Abstract, preface and summary

This outlook provides a brief but in-depth overview of South Korea's strengths and innovative approaches to smart water management technologies. The objective is to assist Danish researchers and R&D-intensive companies to identify potential opportunities for collaboration with South Korea in water research and development activities.

South Korea's water stress level is nearly 58 per cent, despite rainfall being 1.5 times higher than the world average. This is due to the country's mountains and steep riverbanks, the fact that most rain comes during the summer and high population density. Water management has thus, been a priority since the 1960s in South Korea. As a result, the country has accumulated knowledge, achieved tangible results and built water infrastructure, which now serves 96.8 per cent of the population (versus 17.1 per cent in 1961).

As newer challenges of South Korea arise such as aging infrastructure, increasing energy costs and underutilisation of concepts like grey water, the agenda for South Korea to become a smart Water Nation has been pushed forward. This, paired with the government's devotion to adapting for the Forth Industrial Revolution, creates opportunities for the country to leverage its existing advanced water treatment technologies, ICT-based water management system, and high level of internet connectivity.

To quote Professor Jung Jinyoung at Yeungnam University, "South Korea is a small country with a high population, where the water management is a vital task. Thus, based on its strength in ICT-based technologies, South Korea is emphasising the necessity to become a frontrunner in smart water."

The outlook is consist of five chapters and the short description of each chapter is listed below:

Chapter 1 provides a general introduction of water policies and governmental structures along with important features of water management in South Korea.

Chapter 2 explains the progress South Korea has made towards Smart Water Management across three categories.

1. **Smart networks**: Combined and integrated water network systems
2. **Digital solutions**: Hydrological data information management system, river flow management system, rainfall radar flood prediction system, supercomputer-based river analysis network and hydro intelligent toolkit
3. **Intelligent equipment**: Smart water meters, desalination and advanced water treatment system

Chapter 3 provides a map of South Korea's business and research ecosystems and its strongholds. This is where interested parties in Denmark or elsewhere can look to find opportunities for competition or collaboration.

Chapter 4 shows South Korea's strengths, weaknesses and opportunities in smart water management and provides recommendations to parties in Denmark based on author's experiences in Korea.

The authors of this report have identified several areas where Danish stakeholders could find collaboration opportunities:

Strategy

- Share experience of how to gain public trust on water quality.
- Share Low-Impact Development examples in Denmark to inspire Korean developers.
- Collaborate on utilising ground water as a new water resource.

Technology

- Share experience with energy positive wastewater plants in Denmark.
- Collaborate on various technologies prioritised by the Korean government.

Research

- Research cooperation on applied technologies, TRL 5- 9.
- Leverage synergy from Korea Water Cluster by collaborating with Korean SMEs on R&D to business.

Please contact ICDK Seoul if you have an interest in learning more about the potential possibilities of future cooperation with Korean partners.

This report refers to diverse types of water resources and bodies and tries to give examples and the approaches for embracing diverse water technologies. The water resources mentioned in this report includes both *renewable water* resources as well as *non-conventional water* sources, cf. textbox for definitions.

Renewable water resources are the total volume of a country's water resources, both surface water and groundwater, which is generated through the hydrological cycle.

Non-conventional water sources are the other sources of water apart from natural freshwater such as the production of freshwater by desalination of brackish or saline water. These also include the reuse of urban or industrial wastewaters, mostly in agriculture, but increasingly in industrial and domestic sectors.

1. A water stressed country with a successful water management system

The United Nations classifies South Korea as a *water stressed country.* With a water stress level of 58 per cent South Korea is placed in a group with much warmer countries in parts of Africa and the Middle East, including Morocco, South Africa and Afghanistan.[1] The classification is surprising at first glance, considering that South Korea on average has 1,274 mm of rainfall annually (based on records from 1978-2007). This is about 1.5 times higher than the world average of 880 mm. However, due to the country's high population density and natural factors, South Korea not only has to manage floods during the summer months, but also has to store water ahead of seasonal shortages in the cooler drier months.

Despite such challenges, South Korea's approach to water management is considered as one of the most successful in the region and the world[2]. The country has successfully managed its water and achieved economic growth despite unfavourable water conditions.

Water and sewage supply ratio

From the 1960s to the 1990s, the ratio of water supply for the total population in South Korea rose exponentially from 17.1 to 78.4 per cent and was at 96.8 per cent in 2017. Likewise, the sewage system doubled its supply ratio from 35.7 in 1991 to 70 per cent of the population in 2000 due to steady investments in sewage infrastructure, and was at 93.6 per cent in 2017[3].

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[1] Definition: A situation in which the water resources in a region or country are insufficient for its needs.

[2] Asian development bank, Asian Water Development Outlook, Strengthening water security in Asia and the Pacific (2016)

[3] Korean Statistical Information Service (2019)

Water quality in public water bodies

In 1991, South Korea experienced its worst water-related industrial accident when Phenol leaked into the Nakdong River, one of the four major rivers in the country. The widespread public outcry for change made the government implement comprehensive measures for water management of the four major rivers (from 1998 to 2005) and a basic plan of water environment management (from 2006 to 2015) in 1996. As a result of the government's action, the biological oxygen demand (BOD) concentration in the public water bodies fell significantly. This is an imperative indicator of water quality.

Water supply and usage

The major sources of drinking water in South Korea are artificial reservoirs created by dams (49.9 per cent) and river surface water (39.7 per cent). Other water sources are also used for drinking water like river underflow water (6.9 per cent) and ground water (2.6 per cent)[4]. South Korea has some of the world's most advanced water treatment facilities and management systems. Its tap water quality was ranked eighth in the world in 2003[5]. Despite of its documented safety, only five per cent of South Korea's population drinks the tap water, citing concerns over aging water pipes and taste. Most households, schools, companies and even public offices have water purifiers or drink bottled water[6].

South Korea uses its surface water for many purposes other than drinking, including agriculture, industry and hydropower generation. Agriculture is still the biggest user of water in South Korea. This includes water for rice fields, farming, and livestock and totals 15.2 billion m^3 per year. Household use comes in second, at an estimated 7.6 billion m^3 every year. Water for industrial purposes comes in third at 2.3 billion m^3 of water every year[7].

Due to the monsoon season and the topographical characteristics of the peninsula, dams are commonly used to control surface water and for hydropower generation. There are four main Korean rivers: Han River, Nakdong River, Geum River, and Yeongsan River. Also, there are 61 national rivers, 3,771 local rivers and 25,000 small rivers located throughout the country.

Water management at national and local level

Until recently, several Korean ministries and agencies at different levels have overseen water related issues in South Korea. Until 2018 the two main ministries for

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[4] Ministry of Environment, Statistics of water supply (2015)
[5] UNESCO Political inertia exacerbates water crisis, says World Water Development Report First UN system-wide evaluation of global water resources (2003)
[6] MK news media (2014)
[7] Statistics Korea, Water resources usage (2007)

water quality and quantity management were the Ministry of Environment (MoE) and the Ministry of Land, Infrastructure and Transport (MoLIT).

South Korea's National Assembly found that the management structure was fragmented and caused unbeneficial overlaps, excessive use of the national budget and inefficient water supply and quality control. Therefore, in May 2018 legislation was passed unifying water management under the MoE's sole responsibility. The South Korea Water Resources Corporation (K-water), the public agency overseeing water management, was also transferred under the MoE, along with the Water Resources Policy Bureau and Four Main Rivers Flood Control Offices.

South Korea's provincial water supply infrastructure was built in the 1970s and 1980s and is now in need of a rapid maintenance overhaul. The MoE launched a project in 2001 to improve the country's weary water supply systems, however, the effects have been limited[8]. Water leakage accounted for 10.5 per cent of water use in 2017, which is little improved from 2010 (10.8 per cent). In general, the process of replacing and upgrading water pipes has not kept pace with the need for maintenance of the infrastructure[9]. The water leakage rate in Seoul is three per cent lower than Amsterdam (four per cent) and New York (seven per cent). However, the rate in other regions, such as Jeju Island, has reached 44.4 per cent, which is considerably higher than international rates[10].

1.1 Comparing water key features with Denmark

A direct comparison between South Korea and Denmark across a few selected water key features, tells a story that Denmark has something to offer in terms of among other things consumer behaviour and water security strategies at national, regional and local level.

Worth noting is the almost two times higher precipitation in South Korea and yet a water stress level almost three times higher compared to Denmark. Also worth noting is the large tap water price difference of 2.32 EUR/m^3, which seems to directly impact daily water use per capita, where a citizen in South Korea on average use approximately 100 L more than a citizen in Denmark.

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[8] Enforcement of strong incentives to replace aged water pipes (2001)
[9] Statistics Korea, Water supply leakage ratio (2017)
[10] OECD, Survey on Water Governance for Future Cities (2014)

WATER KEY FEATURES COMPARISON

South Korea	Denmark
• Precipitation 1,224 mm/yr	• [14]Precipitation 703 mm/yr
• 59% of total precipitation from June to August	• 34% of total precipitation from June to August
• Renewable water resources per capita 1,453 m^3	• Renewable water resources per capita 1,114 m^3
• [11] Price of tap water 0.53 EUR/m^3	• Price of tap water 2.85 EUR/m^3
• [12] Daily water use per capita 280 L	• Daily water use per capita 188 L
• [13] SDG 6.4.2 Water Stress 58% (2014)	• SDG 6.4.2 Water Stress 21% (2014)

1.2 South Korea's Water Industry structure

South Korea's water industry has a unique structure under which the industry is distinctively driven by the public sector, including the central government, local governments and public corporations. This can be seen in the figure below[15].

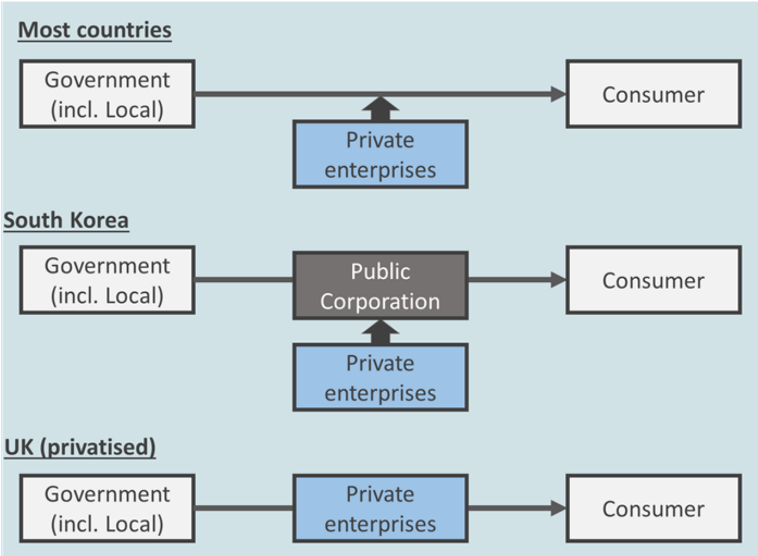

Figure 1 Water industry structure comparison

Through this public-driven industrial structure, the government can control the

[11] Ministry of Land, Infrastructure and Transport, Korea Water Resources Corporation, Water and Future (2018)
[12] K-indicator, Water consumption per capita (2019)
[13] Unwater, Progress on level of water stress (2019)
[14] Climate data for cities worldwide (2019)
[15] Water Journal (2018)

national budget and effectively manage the entire water industry ecosystem. At the same time, however, this structure can risk limiting the competitiveness of private companies and make it difficult for international companies to enter the industry ecosystem.

The Korean government is continuously trying to understand pros and cons of the present setup. The government is committed to find the optimal structure for the water industry and is also recognizing the need for being more open towards international collaboration. One result is an attempt to reallocate a substantial portion of the sewage industry into private companies, while keeping the water supply in the public sector. Thus, the changing regulatory framework conditions can constitute a risky business environment for foreign companies. However, foreign companies that fully understand the unique dynamics of the South Korean structure and policy objectives for the future can enjoy the same competitive advantage compared to business environments in countries with more privatised structures.

Korea Water Cluster

The large scale public-private partnership Korea Water Cluster (KWC) illustrates the Korean efforts in improving conditions for the private water industry. KWC was initiated in 2015 and located in the southwest section of Daegu Metropolitan City covering a total area of 645,000 square meters. It is funded by the MoE and Daegu City government with a significant budget worth approximately EUR 225.7 million[16].

"The KWC area consists of facilities that support the water industry, a test-bed, and a water industrial complex. This complex will support companies throughout the full technology life cycle, from idea to testing to commercialisation," said Professor Jung Jinyoung during an ICDK Seoul interview. "KWC finally opened in July 2019 with space for 50-60 companies. So far, 24 domestic companies including one big conglomerate have moved into the KWC area." The KWC is open to international water companies with interests ranging from construction to management. The network and infrastructure provided by KWC make it a potential stepping-stone into the Asian market.

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[16] Choi et al., Issues and development plan for Korea Water Cluster, Environmental Engineering Research (2016)

2. A Smart Water Nation: Advanced Research and Technology

Aging water infrastructure, a growing population and increasing energy costs are the biggest challenges for water managers in South Korea. Smart Water Management (SWM) is the key to overcome these challenges as it enable managers in the water utility sector to accurately know the status of their systems and deploy resources intelligently and efficiently. Conventional methods related to infrastructure repair, water quality alerts and flood management are shifting to data-driven, preventative maintenance.

According to Professor Jung Jinyoung from Yeungnam University and a representative of Korea Water Cluster, South Korea has the right ingredients to become a smart water nation. "South Korea is a small country with a high population, where the water management is a vital task. Thus, based on its strength in ICT-based technologies, South Korea is emphasising the necessity to become a frontrunner in smart water. Additionally, the current government's interest in the Fourth Industrial Revolution provides the key driver for the adoption of smart water projects in this country."

The digitalisation of the Korean water sector is expected to receive significant support for R&D activities in the coming years. For the right Danish researcher or company with state of the art and/or complementary technology or solutions these areas could lead to new interesting collaboration opportunities.

In September 2018, the MoE and Korea Environmental Industry and Technology Institute announced that a total of EUR 161.6 million (Gov. 102.1 million, Private 39.5 million) will be invested in projects to develop Environmental technologies based on Fourth Industrial Revolution technologies from 2019 through 2025. The three main components of these projects are described below.

1) Development of optimal management technology for new and trace pollutants: The projects consist of eight technology tasks including measurement and analysis techniques for trace pollutants, prediction of the behaviour of trace pollutants related to their removal from the treatment process and optimal treatment of water and sewage. The goal is to develop automatic analysis technologies for 263 types of new and trace pollutants.

2) Development of low-energy, high-efficiency core materials and treatment technologies: The projects entails domestic development of low-energy key equipment for water treatment, including aerators and sludge treatment systems. The project's ambition is to develop domestic technologies and reduce energy use by 20 per cent.

3) Development of intelligent water supply and water management technology with the goal of reducing water and sewage maintenance costs by 14 per cent while increasing public trust and satisfaction. The project includes development of technology to detect leaks using IoT, measure water quality and quantity in real-time, automatically control and optimise operational systems for waterworks and wastewater treatment plants and create a tap water information service based on big data.

In order to demonstrate tangible innovations related to SWM, the Presidential Committee for the Fourth Industrial Revolution, appointed Busan as a National Pilot Smart City in 2018. The political prestige project aims at developing a new 2,194 m2 area expected to house 9,000 people and be a showcase for solutions related to logistics and water technologies in particular[17].

In the following chapters ICDK Seoul further highlights South Korean developments within three key components of SWM[18] with the intention of assessing strengths, weaknesses and not least opportunities for collaboration:

1) **Smart networks**: A way of collecting real-time information from multiple sources, enabling responsive management of the system.
2) **Digital solutions**: A combination of algorithms and real-time data that provides solutions for predictive maintenance, preventing overflows and assessing real-time status.
3) **Intelligent equipment**: Self-optimising pumps, sensors and advanced treatment technologies that can minimise the time spent on manual monitoring

[17] ICDK Outlook rapport: I-Korea 4.0: Innovation Initiatives in Smart Cities and Healthcare, ISBN: 978-87-93706-52-1
[18] Xylem, What is smart water management (2018)

and maintenance.

2.1 Smart Networks

South Korea is today building a reputation in the area of SMW, based on the same ICT technologies that have already made the country famous thanks to multinational electronics conglomerates such as Samsung and LG.

In a report from the International Water Resources Association (IWRA), three out of 10 cases of outstanding SWM are from South Korea[19]. One such example is Paju City. To alleviate public concerns over water quality and to escalate the consumption rate of tap water, the city has since 2014 integrated ICT throughout the entire water supply process and enabled citizens to check the status of their water quality and the supply network in real-time. After just three years, 36.3 per cent of Paju City residents were drinking the tap water and public trust in the system rose substantially[20].

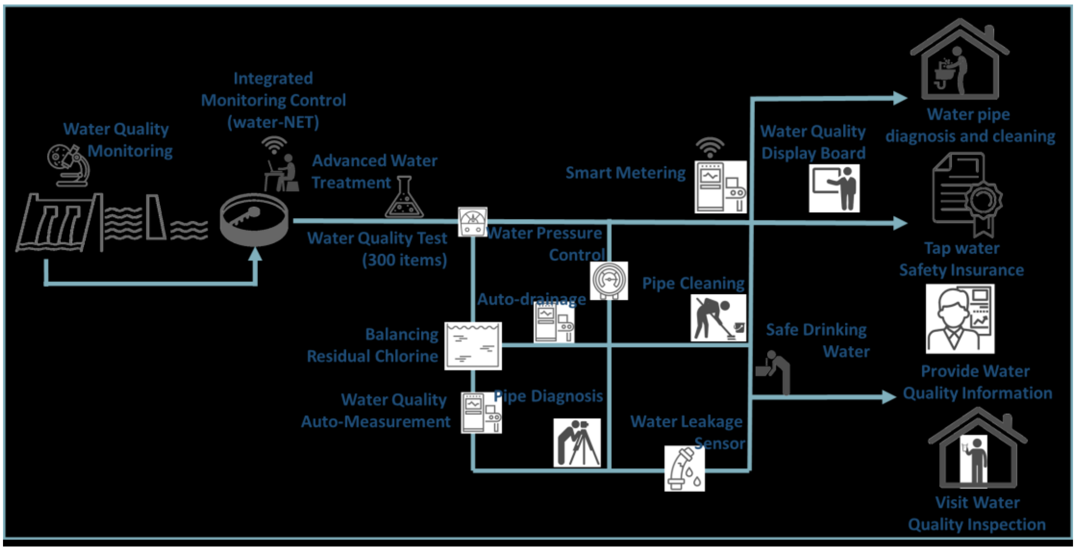

Figure 2 Schematic of Water networks system in Paju city

Another success story comes from Seosan City, which launched a smart water meter system in 2016. The city ambitiously set a target of reducing water leakage and improving the overall rate of non-revenue water. Smart water meter technology helped reduce water leakage by 190,000 m^3. This will save the city an estimated EUR 524,000 over the next eight years, which is substantial in a city of 175,000 people. Now water managers from water utilities can also provide prompt response to complaints by using a shared, central database[21].

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[19] International Water Resources Association, Smart water management case study report (2018)

[20] Paju Municipality, Paju News (2017)

[21] International Water Resources Association, Case study of Seosan smart water management

Table 1 Smart devices of Seosan Smart Water Management system

Digital Meter	The digital meter convers measured flow data into electrical signals and transmits them on a time basis - Measuring flow data - Detection function i.e. overload, backflow, leakage - Data communication
Remote Transmitter	The remote transmitter collects data from the meters every hour and transmits the data every four hours. - Direct radio path with base station by 1-Watt high-power transmission - 19 Ah capacity battery enables 8 years of run-time - LCD display for meter reading
Base Station	Wide area wireless transmission coverage with approx. 1.5 km
Monitoring System	The monitoring system shows the connection status and end-user meter gauge on a real-time. The gauge reading can be acquired and analysed. The monitoring system also calculates supplied water volume and provides information on leakage within the water supply network.

2.2 Digital Solutions

South Korea was an early adopter of smart networks for assessing the status of water networks as well as for predicting and preventing problems. It has already collected a large volume of water-related data that can be used for optimising models that underlie digital solutions.

K-water has been the main entity developing these solutions, with support from the MoLIT as well as the MoE[22].

Hydrological Data Information Management System

In 2007, South Korea introduced the Hydrological Data Information Management System (HDIMS), installing real-time monitors at multi-purpose dams, weirs and flood control reservoirs. The HDIMS allows water managers to collect and manage high-quality hydrologic data, enabling them to make more accurate decisions more quickly. The system now helps officials to prevent or mitigate damage from water related disasters like flood and drought. It also helps make recovery quicker.

[22] Ministry of Land, Infrastructure and Transport & K-water, Nature for Water (2018)

River Flow Management System

South Korea's high reliance on surface water makes it imperative to secure adequate water from flowing bodies. This means water managers must accurately measure and predict both supply and demand for water. This requires simultaneously collecting water consumption data from multiple sources. The next important component in this system is weather and effluent analysis technology. In 2011, K-water, together with MoLIT, developed a River Flow Management System by integrating different models into one system that combines the rainfall-runoff model, agricultural reservoir prediction model, dam-weir model, water budget analysis and water quality model. The system provides results based on a comprehensive evaluation of each body of water bodies and supports water managers in their decision making.

Rainfall Radar Flood Prediction System

In 1974, South Korea installed and operated its first Flood Prediction System in the national capital area, then slowly expanded it to other cities. Now there are sixteen sites with prediction systems all around the peninsula. They operate simultaneously to achieve support water management.

South Korea's Flood Prediction System can predict both the size and timing of floods using automatically observed water level data, precipitation data from regional hydrologic monitoring stations and rain radar. The Korean government began installing rain radar systems in 2004 as awareness of scattered and frequent cloudbursts increased. Unlike conventional weather radar, rain radar can provide accurate rainfall information and predict sudden cloudbursts three hours in advance, within its 100 km observational radius. The rain radar fires dual-polarisation waves on horizontal and vertical planes in concentrated 100 km zones to maximise accuracy and calculate the size of raindrops.

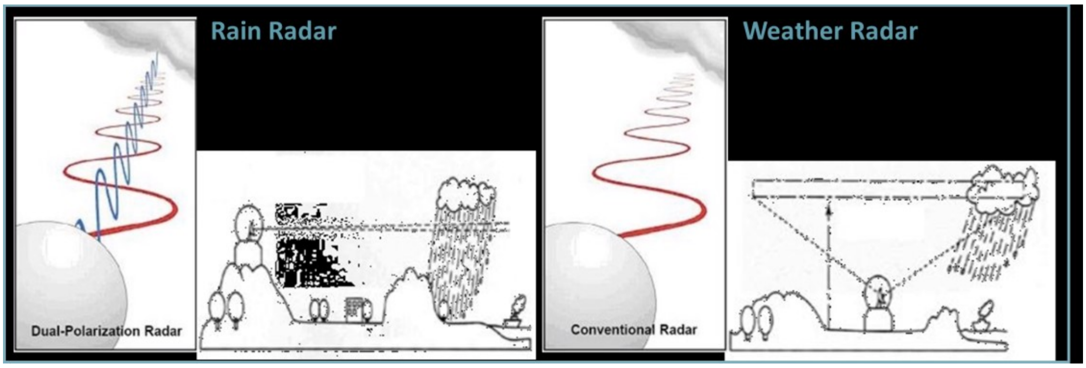

Figure 3 Conventional weather radar and dual-polarization rain radar that South Korea deployed in response to climate change (photo credits: MoLIT and The Washington post)

The government is developing an even more advanced system that aims to predict rainfall six hours in advance and with higher accuracy by integrating ICT and surveillance drones. The government has further plans to provide safety education and other smart services to the public by applying IoT and Virtual Reality to the system in the future.

Supercomputer based River Analysis Network (SURIAN)

The SURIAN system is a real-time water quality forecast system that predicts and provides water quality estimate data for scientific water management. The system links the K-water Precipitation Prediction Model (K-PPM), Hydrologic Simulation Program-Fortran (HSPF), Reservoir Water Quality Model (CE-QUAL-W2) and Coupled Three-dimensional Hydrodynamic and Particle Dynamics Model (ELCOM-CAEDYM) to obtain more accurate water quality forecast data and improved user accessibility by providing information to various network platforms. One application of this system is a new prediction model for blue-green algae that was introduced in 2017 and has been in the optimization process since 2018.

Hydro Intelligent Toolkit for Integrated Water Resources Management Decision Support (K-HIT)

To address frequent water-related disasters, South Korea has placed great emphasis on developing water management systems that leverage multiple data sources and types.

The most prominent example is K-HIT, a convergence technology toolkit that combines five formerly separate algorithms for real-time hydrological data acquisition, precipitation forecasting, flood analysis, reservoir water supply and hydropower generation.

According to the developer K-water, this system has proven effective at reducing damage from seasonal floods and preventing droughts by releasing stored water during the dry season. K-water says that the toolkit demonstrably mitigated flood damage in 2012, 2013, and 2015.

In addition to the digital water solutions described above, water managers in South Korea have also developed a variety of purpose specific systems. The government has also launched initiatives to gather water information so that it can be incorporated into databases for both real-time and big data analyses. This is part of an overall Fourth Industrial Revolution push[23].

2.3 Intelligent Equipment

To further its push to become a Smart Water Nation, the Korean government has

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[23] ICDK Outlook rapport: I-Korea 4.0: Moon Jae-In's strategy to bring South Korea into a new digital era, ISBN: 978-87-93706-31-6

invested in the development of core water technologies and launched a dedicated research group under the MoE[24]. The technologies of interest are smart water meters, desalination and purification.

Smart Water Meters

Gochang city is the first city in South Korea to deploy smart water meters city-wide. In collaboration with IoT firm Freestyle Technology, the city installed smart water meters in around 24,000 homes in 2017. According to the Gochang Waterworks, smart water meters enable the waterworks to provide accurate usage and billing information to residents. The smart water meters further help prevent damage from leaks by reducing non-revenue water costs by 19 per cent compared to the previous year[25].

Desalination

The Korean peninsula is surrounded by saline water on three sides, while fresh water is rather limited due to the mountainous terrain. This has forced South Korea to specialize in several desalination technologies. Among these technologies, the most common are the evaporation type and reverse osmosis type[26].

Until 2010, South Korea was world renowned for developing the core technologies underlying Multi-Stage Flush (MSF) Evaporation systems for desalination. However, since evaporation based systems require significant energy, resulting in high carbon emissions, the global trend has been to move away from these in favour of osmosis. To maintain its competitive edge, South Korea started a state-funded research project on the reverse osmosis membrane in 2007. The efficiency of reverse osmosis technology in South Korea has reached 3.8 – 4.0 KWh/m^3 of water, which puts it just below the global standard of 3.5 kWh/m^3.

The Korean government continues to support R&D on new technologies. This has led to innovations such as the hybrid forward and reverse osmosis system developed at the Korea Institute of Machinery and Materials (KIMM) in 2014[27]. Research on optimising and increasing the efficiency of evaporation technology continues as well, as this technology is still commonly used outside of South Korea[28]. Research is also underway to find ways to extract useful metals including lithium and magnesium from seawater during the desalination process.

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24 Smart Water Grid Research Group
25 ZDnet, South Korea's IoT in full swing (2018)
26 K-water, Desalination (2019)
27 Hangyerae news media (2014)
28 Hwang et al., Comparative analysis of seawater desalination technology in Korea and overseas, J. Korean Soc. Environ. Eng. (2016)

In 2018, Doosan Heavy Industries signed a Memorandum of Understanding (MoU) with SAP, agreeing to work together to speed up the transformation of their desalination technology into an ICT-driven technology[29]. This will move Doosan a step closer to smart water management by enabling system fault prediction, real-time status monitoring, remote management, and simultaneous membrane control[30].

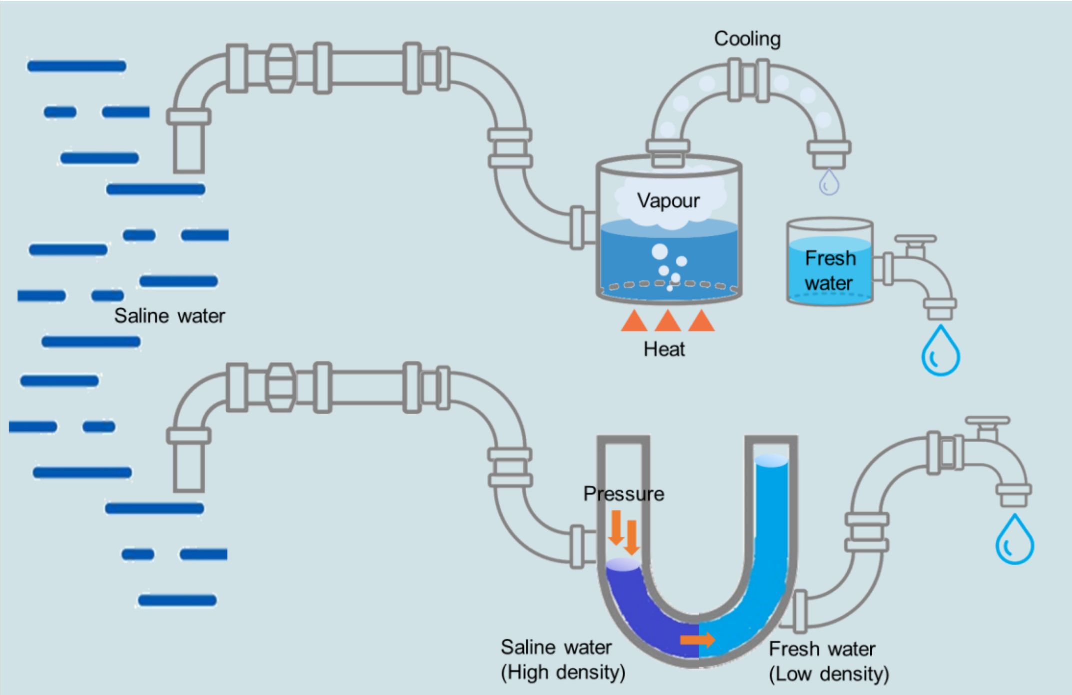


Figure 4 Two types of desalination technologies in South Korea

Purification

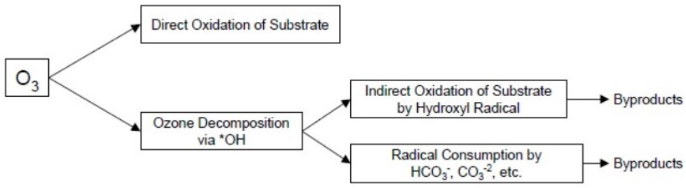
Purification, or advanced water treatment, refers to adding processes to the general water treatment system, such as activated carbon treatment, ozone treatment, bio-treatment, membrane filtering and advanced oxidation. The purpose of these systems is to remove tastes, odor-causing substances, trace organic pollutants, ammonia nitrogen and pathogenic microorganisms that are not completely eliminated during the general water treatment process.

Through the Water Quality Management Improvement Plan enacted by the Prime Minister's Office in 1994, South Korea has invested EUR 356.3 million and deployed around 20 advanced treatment systems around South Korea's four major rivers[31].

Table 2 Mechanism of typical advanced treatment method in South Korea

Activated carbon	Characteristics	An amorphous carbon manufactured from woods, lignite, anthracite, palm shell, etc.

[29] Business post (2018)
[30] National Science & Technology, Desalination membrane pollution monitoring (2019)
[31] Ministry of Environment, Assessment of advanced water treatment system (2006)

<table>
<tr><td></td><td></td><td>Granular Activated Carbon (GAC) used for column filtration and Powder Activated Carbon (PAC) used for aggregation process at water treatment system together with a coagulant.
Biological Activated Carbon (BAC) has same backbone of activated carbon but additionally functionalised by microorganisms to enhance the properties of removing organic matter from the water.</td></tr>
<tr><td></td><td>Mechanism</td><td>Removal of contaminants by physical and chemical adsorption as well as biological mechanisms</td></tr>
<tr><td>Ozone</td><td>Characteristics</td><td>Remove odor and taste, Sterilization, Avoid trihalomethane (THM), Higher effectiveness on microorganism sterilization</td></tr>
<tr><td></td><td>Mechanism</td><td>


1) Direct reactions of dissolved ozone to organic and inorganic matters
2) Indirect reactions of OH radical produced by ozone decomposition.
</td></tr>
</table>

The efficacy of advanced treatment systems has been well proven in South Korea, leading the MoEto announce that 70 per cent of water treatment systems will be upgraded to Advanced Treatment System by 2025[32].

[32] Munhwa news media (2019)

3. Industry and Research Strongholds

According an article in the Journal of water policy and economy from 2018, there are 17,348 water-related companies in South Korea. Of these, 97 per cent are small and medium-sized, 1.2 per cent are mid-sized, and 0.9 are large companies. A large majority of these companies, 72.7 per cent, are related to water supply, while the others deal in sewage (9.2 per cent), dams (6.2 per cent), hydropower (5.4 per cent), desalination (0.4 per cent), and other sectors (6.1 per cent).

Unlike many other industrial sectors in South Korea, where there are a proliferation of SMEs, but they have little actual share of the market, SMEs in the water sector are actually responsible for 68% of total sales revenue. Total sales revenue in the water industry totalled EUR 11 billion in 2019 according to the Korean Environmental Corporation[33].

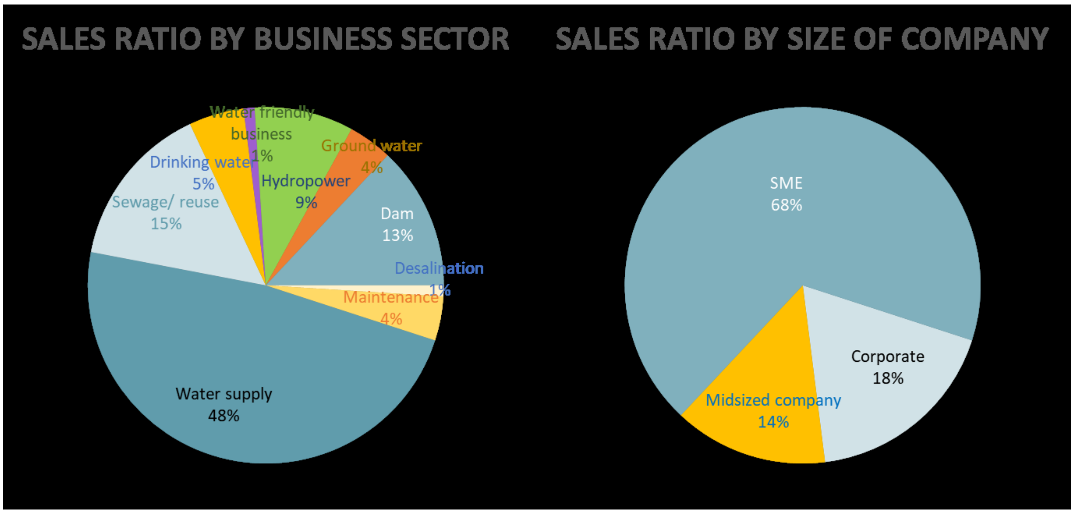


Figure 5 Ratio of revenue on different water industry sectors in South Korea in 2016[34]

In 2018, K-water conducted an industry-wide assessment of South Korea's water

[33] Korea Environment Corporation (2019)
[34] Lee N. S., Status of domestic water industry ecosystem and development tasks, Journal of Water Policy and Economy, vol.30, pp.55-66 (2018)

sector to foster collaboration in both domestic and international markets. In the *Water Industry Ecosystem Map*, K-water and the Ministry of Environment are placed at the centre, whereas companies are distributed from the centre, based on number of activities with the government, rate of collaboration and revenue size.

Figure 6 Water Industry Ecosystem Map with relevant companies and entities (photo credit: K-water)

The seven water-related companies below, has been selected by the MoE for their particular strong R&D capabilities according to 1) quantitative performance such as sales, patents, papers, 2) technological impact on civil society, and 3) social economic impact of the technology[35].

- Doosan Heavy Industries & Construction: the leading company in the seawater desalination plant market
- Korea Institute of Civil Engineering and Building Technology: Optimal system for reducing odour of sewage in urban sewage
- NovoTec Co.: Control of sediment in sewer pipes and repair techniques
- Econity Co.: Advanced membrane modules with high efficiency for the wastewater treatment
- EMC-water Co.: A system that eliminates high concentration pollutants in sewage by utilising iron oxidation reactions
- WARECO Co.: Evaluation of deterioration level and improvement technology of deteriorated pipeline
- POSCO E&C: Development of a global industrial (steel) waste water advanced

[35] Water Journal (2018)

treatment and re-use process demonstration technology.

South Korea's water research institutes are mostly government-affiliated, with some other local government agencies, non-profit organisations and government agencies. Areas of research from those institutions are mostly on management, operation, infrastructure and investigation as well as monitoring[36]. According to analysis by the MoE and the Korea Environmental Industry & Technology Institute (KEITI), the proportion of research into core technologies (TRL 1-4) in South Korea is low. Instead, research institutes in South Korea have focused more on applied technologies (TRL 5-9). The KEITI report analyses 17 government research institutes that conducted water research projects from 2013 to 2015. (See table below).

Institute	Number of projects by the level				Sum
	Basic	Applied	Development	Others	
Korea Institute of Science and Technology (KIST)	15	11	5	9	40
Korea Institute of Construction Technology (KICT)	1	4	16	4	25
Korea Advanced Institute of Science and Technology (KAIST)	1	-	7	-	8
Korea Institute of Energy Research (KIER)	1	-	6	-	7
Korea Institute of Machinery and Materials (KIMM)	5	-	1	-	6
Korea Testing Laboratory (KTL)	-	-	3	2	5
Korea Institute of Materials Science (KIMS)	2	2	1	-	5
Korea Research Institute of Chemical Technology (KRICT)	-	2	2	-	4
Gwangju Institute of Science and Technology (GIST)	2	1	-	-	3
Korea Environment Institute (KEI)	1	-	1	-	2
Korea Atomic Energy Research Institute (KAERI)	-	-	1	1	2
Korea Institute of Ocean Science and Technology (KIOST)	-	-	1	-	1
Korea Research Institute of Standards and Science (KRISS)	1	-	-	-	1
Korea Institute of Geoscience and	-	1	-	-	1

36 Ministry of Environment and KEITI, Case analysis on water research institutes in South Korea (2015)

Mineral Resources (KIGAM)					
Electronics and Telecommunications Research Institute (ETRI)	-	1	-	-	1
Korea Electrotechnology Research Institute	-	-	1	-	1
Ulsan National Institute of Science and Technology (UNIST)	-	-	-	1	1
Total	29	23	49	17	118

The table illustrates that development-level research are most common in South Korea and furthermore that KIST is the single most active research institution conducting one third of all water related projects and approximately half of the basic (TRL 1-4) projects. The top three institutions of KIST, KICT and KAIST all have experience with international research collaboration.

KIST's primary focus areas cover:

- Water cycle management: Climate change and management, non-point pollutant source control, New pollutant control
- Water treatment system development for sustainable water cycle: membrane, osmosis, Anamox, MBR, biological treatment
- Novel nano materials and Environment assessment: sorption material, catalyst
- Energy efficient environmental technology development: Bio diesel, Visible light catalyst, Biogas

KICT's primary focus areas cover:

- UAV/USV water quality monitoring in upper stream of Dam
- Particle Dispersion Modelling for precise analysis on water quality incident
- Floating intake and emergency discharge system with the siphon phenomena

KAIST's primary focus areas are:

- Water resource management system (Water life cycle) development
- Precious metal capture from water
- Membrane process for sustainable water production
- Carbon based nanomaterials for water treatment
- Fate and transport of nano materials in aquatic systems

4. Strengths, Weaknesses & Opportunities

South Korea has developed advanced treatment technologies, including desalination and purification out of necessity, driven by its topological and climate characteristics. Innovators in South Korea have combined these technologies with the country's other technological strengths in internet connectivity and ICT to develop digital water solutions as well as smart management tools. The government has supported these efforts based on its Fourth Industrial Revolution initiatives, supporting South Korea's potential to be a frontrunner in Smart Water Technologies.

At the same time, however, aging water infrastructure and exceptionally high levels non-revenue water outside of the capital region threaten South Korea's position globally and its overall water security. Outdated infrastructure, for example, forces the use of chlorine disinfection in waterworks all over the countries. This gives tap water a distinctive odour and taste, which lowers the number of people drinking tap water while increasing distrust in water quality.

The concept of greywater[37] first appeared in water legislation in 1991, however greywater reuse remains undeveloped in South Korea[38].

ICDK Seoul has assessed South Koreas strengths and weaknesses in the table below in order to assist Danish researchers or companies in identifying the opportunities with the biggest potential for collaboration.

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[37] Definition: water from the kitchen, bath and/or laundry, which generally does not contain significant concentrations of excreta (WHO, UNEP, Guidelines for the safe use of wastewater, excreta and greywater) (2006)

[38] Ministry of Environment, Policy research on efficiency of water reuse (2011)

Strengths	Weaknesses
Technology for alternative water resources; Desalination, purification ICT and 5G technology Government's strong support on 4iR/water related R&D projects	Public trust for drinking water Chlorine disinfection* Zero discharge system Old infrastructure Water leakage Lack of reuse of grey water**
Opportunities	**Threats**
New water resources: ground water Strategy of gaining public trust Low-Impact Development Energy positive wastewater plant*** *Combined Water Tele-Monitoring System for hazardous chemical spill* *Stable Isotope tracing technology* *Sediment research for algae by-product* *Algorithm for algae analysis*	Topological characteristics High deviation of precipitation Dam dependency (limiting water circulation)
*Chlorine Disinfection: The trend of drinking water is now moving from 'Safe water' to 'Oishi water (Oishi means delicious in Japanese)'. In order to reach level of tasty water, S. Korea necessarily get rid of Chlorine disinfection. **Reuse of Grey Water: The practice of circulating grey water has been implemented since 2014. In Pohang city, the grey water supplied to the industrial water after undergoing a process. Likewise, for the first time in the country the grey water reused for semi-conductor manufacturing water in Asan city.[39] ***Energy Positive Water Treatment Plant: The subject is actively researched in South Korea for generating energy to cover energy consumption from the water treatment plant and generate excessive energy for other usage.	

ICDK Seoul recommends Danish researchers looking for excellence and funding opportunities to focus on SWM areas such as smart networks, digital solutions, and intelligent equipment and the top performing institutions of Korea Institute of Science and Technology (KIST), Korea Institute of Construction Technology (KICT), Korea Advanced Institute of Science and Technology (KAIST) and Korea Institute of Energy Research (KIER). Furthermore, MoLIT and K-water in 2018 highlighted a need for increased R&D activity within Water Tele-Monitoring System for hazardous chemical spill, Stable Isotope tracing technology, Sediment research for algae by-product, and Algorithms for algae analysis, which could be potential areas of future funding opportunities[40]. In the case of Danish companies, ICDK Seoul sees big potentials in offering Korean stakeholders knowledge of complementary technologies

[39] Munhwa news media (2019)
[40] Ministry of Land, Infrastructure and Transport & K-water, Nature for Water (2018)

and solutions addressing the weaknesses of *Public trust for drinking water*, *Chlorine disinfection*, *Zero discharge systems*, *Old infrastructure, Water leakage*, and *Lack of reuse of grey water.* The National Pilot Smart City project in Busan would be an ideal showcase for Danish technology and solutions providers.

About ICDK Outlook

ICDK Outlook is written by the Danish Ministry of Higher Education and Science's Innovation Attachés.

The Innovation Attachés are a part of Innovation Centre Denmark which is a partnership between Denmark's Ministry of Foreign Affairs and the Ministry of Higher Education and Science. Together the two ministries manage eight centres in Brazil, China, India, Israel, South Korea, Germany and the USA. ICDK Outlook is a concept where the attachés provide new knowledge and inspiration about opportunities or trends within a given topic with relevance for stakeholders within higher education, research and innovation. Find out more about Innovation Centre Denmark on www.icdk.um.dk, where you also can find all ICDK Outlooks.

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