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Water Economy and Governance in the Age of Urbanization

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Due to the severe effects of global warming, the earth is confronting various issues, including endangerment of lives. Most importantly, scarcity of water is one those issues confronted. It is not that the world does not have enough water – 70 percent of the planet is covered with water – but as we continue to fail to use available fresh water sources efficiently, we will not be even able to satisfy our survival needs. Water treatment and desalination technologies are coming to the fore, which has also made us consider water economy and the water–energy nexus. This nexus becomes especially crucial when megacities and urban areas are considered. In this issue of IGLUS Quarterly, we have tried to bring new perspectives for the water problem of urban areas and megacities by considering the water–energy nexus.

The issue opens with a short feature article that analyzes urban water management by touching upon the efficiencies of water use for domestic, industrial, agricultural, and municipal aspects. Prof. Heechul Choi and I have tried to present a general overview on the topic.

In the second article, Dr. Moon Son adds another level to the water–energy nexus, making it the water–energy–food nexus. He offers insights into the interchangeability of water, energy, and food sources, and also provides information about membrane and electrochemical technologies and their contribution to sustainable development and megacity design.

Given that 70 percent of the world is covered with seawater, desalination of sea water to provide potable water is a hot issue for countries that lack natural fresh water sources. For a better understanding of desalination, Sung-Ho Chae and Prof. Joon Ha Kim bring an overview on the current technologies and their effect on water economy of East Asian countries such as Japan, Korea, and Singapore. The article also analyzes the water industry background of China.

The next article is about Pakistan, which is one of the world's most water-stressed countries. However, the main issues are related to the management strategies and misuse of water sources rather than scarcity. Muhammad Saboor Siddique and Hammad Fazal present an overview of Pakistan's water challenge by analyzing the mismanagement strategies that have resulted in water quality deterioration, ground water depletion, deforestation, deglaciation, food insecurity, and increased poverty.

In the closing article of the issue, Dr. Abayomi Babatunde Alayande and Seyi Jemima Akinlolu-Raphael discuss the failed governmental planning and policies for water crisis in Nigeria. The article addresses water issues in Nigeria related to environmental policies and the environmental and health impact of water pollution, and offers suggestions to solve these issues.

We sincerely hope that you enjoy the articles of this first issue of volume 5 of IGLUS Quarterly, and we also hope that it contributes to the awareness of the severity of water stress in the world. We invite you to join the discussion at iglus.org. If you feel that there are innovative practices underway in your city/region and you would like to contribute to an upcoming edition of IGLUS Quarterly, we encourage you to contact us at umut.tuncer@iglus.org. For inquires and questions about the content of this issue, you may also contact me at numanyanar@hotmail.com.

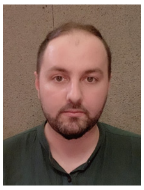
Numan Yanar **(Editor of the Issue)**

Urban Water Management and Quality-Based Water Use

Numan Yanar[a], Heechul Choi[a,b]

Abstract: *Urban waters are classified according to their use in domestic, industrial, municipal, and agricultural needs. It is important to manage them properly in order to efficiently use and distribute water, considering physical, chemical, and biological aspects. In this article we provide an overview for the efficient use of urban water and consider aspects of management for quality-based distribution. A brief discussion about urban water management design strategy, Xeriscape, is also provided.*

Authors' Profiles



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Urban water management and quality-based water use

Societal demands for wealth and high living standards have increased with developing technology and networking. Therefore, development of sustainable growth strategies of the governments is essential to provide the necessary wealth, not just for the present, but for the future as well.[1]

One critical issue that urbanization forces us to deal with is water management. Demand for water has increased rapidly as a result of growing urbanization combined with the severe effects of climate change and agricultural requirements.[2] According to the World Bank, these factors will have a severe impact on economies,[3] so its significance regarding water resources and water environment should not be ignored.

The report of the World Bank states that some cities may confront a two-thirds drop in water availability by 2050. This will lead to further problems, even in basic necessities like food and health. However, efficient use of water could make a difference for this serious situation. Good policies would increase the GDP of central Asian countries by more than 11 percent and reduce undesirable water shortages in the Middle East.[3] "Good" policies for urban water management include the efficient use and recycling of urban waters (surface water, groundwater, potable water, sewage and other types of waste waters), flood prevention, development and regulation of water efficient-sensitive management and design techniques, and protection of natural wetlands, waterways, and estuaries.[4] Effective urban water management will lead to the creation of more resilient, sustainable, and wealthier cities.

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Effective management of urban waters relies on efficient water use and recycling policies. Water recycling requires the treatment of wastewater/water by removing any solids, particles, and living small organisms. This is not just a process that provides potable water; it also has biological, chemical, and physical aspects for urban life. In this regard, health effects should be considered as biological aspects, while environmental effects are important for physical and chemical aspects.[5] Efficient use and recycling of urban waters can be analyzed according to domestic, industrial, agricultural, and municipal use.

Each person uses between 30 and 300 liters of water per day for domestic use.[6] Approximately 3 liters of this is consumed for the needs of the human body, which is difficult and unhealthy to reduce. However, for the remaining domestic consumption, it is important to use water efficient utilities and machines, through means such as preventing leakage of household appliances.

For industry cases, water is required for heat transfer, power generation, and processing. During these applications, recirculation, reduction, and reuse of water by measuring and monitoring the water quality carries great importance since the mismanagement of industrial wastewater not only creates high water consumption, but is also very harmful for the environment, with a significant footprint.[5, 7]

Water efficiency at the municipal level requires effective monitoring and management of distribution. Leak detection and repair, metering, rate systems, and regulations are the main concerns facing municipalities.[5]

Agricultural use of water creates the water–energy–food nexus and therefore is the most important factor in the efficient use of water. Agriculture accounts for 70 percent of the total water use of the world, although this figure is only 40 percent in many OECD countries.[8] However, this ratio has been changing in favor of domestic and industrial use in recent decades. Demand for water for domestic and industrial uses has been rising in parallel to economic development, increasing populations, and resulting urbanization. According to the United Nations' Food and Agricultural Organization (FAO), water withdrawal for household and industrial use quadrupled from 1950 to 1995.[7] This created a danger for agricultural water demand because of polluted urban supplies, which lead to high health risks such as epidemics. To prevent this, it is also important to develop efficient design and management strategies.

Urban Xeriscape is an efficient method to distribute water. Xeriscape involves creating landscape designs that can contribute to minimum water use by preserving the environment.[9-10] Enhancement of environmental quality and degraded environmental conditions for architectural applications have been the main objectives. However, those objectives have started to have transition towards efficient use of water and design and applications due to global warming and climate change concerns. Xeriscape has seven basic principles: appropriate planning and design, preparation and improvement of soil, preference of drought-tolerant plants, reducing the rate of lawn, efficient irrigation, use of mulch, and proper maintenance.[11-13] These principles provide effective water use by providing urban sustainability through distributing water according to its quality without wasting high-quality or potable water when it is not required.

Domestic, industrial, municipal, and agricultural uses of water are interconnected. Therefore, in order to keep same water wealth for our future, it is important to manage the efficiency of water through well-management methods, which includes recycling and quality-based water use.

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Water-Energy-Food Nexus for Sustainable Development and Megacity Design

Moon Son[a]

Abstract: *Water, energy, and food are closely related, interchangeable, and essential resources to our lives, and are also crucial for urban planning. As the population of a city gradually increases, the placement of these resources becomes increasingly important. The design and placement of these resources may be achieved by using their interchangeable characteristics or by securing a greater amount of each resource. To stably secure these resources, which is indispensable for sustainable urban development, membrane and electrochemical technologies have been actively developed and various technologies are expected to be developed in the future to meet the demands of megacities.*

Author's Profile

Dr. Moon Son is currently a postdoctoral researcher in the Civil and Environmental Engineering Department at Pennsylvania State University, USA, working with Dr. Bruce. E. Logan. Dr. Son focuses on the development of the membrane and electrochemical processes for water production, energy harvesting, and resource recovery. Dr. Son obtained his bachelor's degree in Environmental Engineering from Yonsei University and his PhD at the School of Earth Science and Environmental Engineering from Gwangju Institute of Science and Technology.
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Introduction

One of the most important aspects of megacity or urban design is the efficient placement of huge amounts of resources such as water, energy, and food to be used in cities. Over the past decades, extensive studies have been conducted to resolve issues related to water, energy, or food resources. However, each resource has been studied individually and only a few comprehensive studies have been reported, most likely due to the lack of awareness that each resource was interconnected. In fact, the water, energy, and food resources are interconnected and one may constrain the other.

The nexus

To understand the water-energy-food (WEF) nexus, it is necessary to understand the previous step – the water-energy (WE) nexus. The WE nexus begins with an observation of the interrelationship of water and energy. Although water and energy appear to be separate resources, they are in fact closely related.

Energy is needed to produce water. For example, water treatment or wastewater treatment plants produce clean water with a considerable amount of energy. In the United States (US), the amount of energy used for wastewater treatment is about 3 percent of total energy use. Considering the energy consumption for drinking water treatment and the process of distributing it to homes, the amount of energy consumed in water production could be even higher than 3 percent of total energy use. Thus, to achieve a successful nexus (whether it is WEF or WE nexus), it is necessary to reduce the energy used for wastewater treatment or reduce daily water usage. This means that the two resources need to be used in a balanced way.

Water is needed to generate energy. People often think only of the price when using energy at home, but they actually have to think of a power plant that produces that energy. Power plants are gigantic industrial complexes that consume huge amounts of resources themselves, one of which is water. A water-cooled heat exchanger is essential for cooling the massive amount of heat generated by a power plant. With regard to the Fukushi-

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ma nuclear power plant accident that happened in the not-too-distant past, the most important cause of the explosion in the power plant was that the temperature of the reactor was irreversibly increased due to the loss of coolant, resulting in missed timing of the cooling water inflow. As such, water is essential for industrial processes and for electricity production.

In fact, most of the energy currently used in US cities comes from fossil fuels (natural gas, coal, petroleum) or nuclear power, not renewable energy. According to the Lawrence Livermore National Laboratory, only about 12 percent of the total energy used in the US in 2018 was produced from renewable energy (solar, hydro, wind, geothermal, biomass). Interestingly, a huge amount of water was used as cooling water in the power plant. In California, the amount of water used in a power plant (4553 million gal/day) is close to that of water used for public/municipal water (6299 million gal/day). Therefore, in city planning, where enormous amounts of water and energy are consumed, its effective arrangement must be considered from the design stage. This is a water-energy nexus.

Food is the last resource to add to the nexus; that is, the WE nexus becomes the WEF nexus by adding food resources into the loop. Due to population growth and improved quality of life, the demand for food has increased exponentially, and the amount of water and energy in the food industry has soared. Correspondingly, the volume of water entering agriculture and animal husbandry has surged.

The WEF nexus does not just mean a cycle of resources, but a warning that if one resource becomes scarce, other resources may be threatened. Also, if one loop is broken, the whole cycle is threatened, so a balanced use of three resources is needed. Therefore, for a nexus to be successful, not only must the circulation of resources be smooth, but also the amount of resources must be abundant, without a break in the link (Fig. 1).

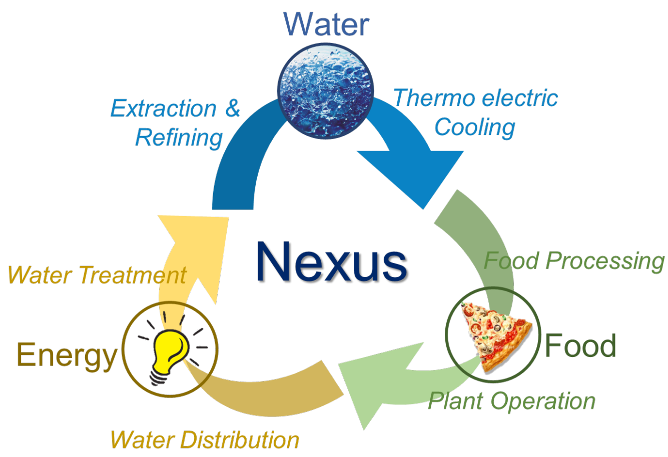

Figure 1. Schematic of the water-energy-food nexus

Sustainable development

According to the United Nations (UN), sustainable development is defined as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (Imperatives 1987). As the earth's limited resources have been used indiscriminately, sustainable development has emerged as the guiding principle for long-term global development.

In 2015, the UN has announced 17 goals that are deemed necessary for the sustainable development of humankind (Fig. 2, Nations 2015).

Figure 2. The 2030 agenda for sustainable development, adopted by all United Nations member states in 2015 (Nations 2015).

The nexus for sustainable development

Among the goals in the UN's 2030 Agenda for sustainable development are goals directly related to the WEF nexus: zero hunger (#2), clean water and sanitation (#6), and affordable and clean energy (#7). Although the UN has set three separate goals, the concept of the nexus is a combination of these three. Therefore, the successful operation of the nexus is a way to simultaneously achieve the three goals of sustainable development.

As mentioned above, there are two technical ways to achieve a successful nexus. One is to help circulation between resources, and the other is to increase the amount of the whole resource. Several technologies are available for this purpose, including membrane- and electrochemical-based technologies.

The membrane and electrochemical technologies for the nexus and city

Most cities use membrane technology for water reuse. For example, the water used in the toilet is filtered through membranes and reused. This is called grey water. In regions such as the western United States (including California), where water usage is greater than precipitation, seawater can be used as freshwater or agricultural water through seawater desalination. Membrane-based seawater desalination has not been a mainstream technology since decades ago due to its high energy consumption (> 10 kWh m^{-3}), but it has recently achieved remarkably low energy consumption (~ 4 kWh m^{-3}) due to the breakthrough technology on membrane development and energy recovery system. Therefore, most of the existing seawater desalination facilities adopt membrane-based method rather than conventional heat-based methods. Efficient water production due to the development of membrane technology reduces the amount of energy entering the water production process, thereby reducing the load on the entire nexus (Son et al. 2015, Son et al. 2017, Son et al. 2018a).

Membrane technology can also recover/harvest energy that is naturally extinguished in the nature. For example, water of different salinity naturally mixes where sea water and river meet. This salinity difference produces the same amount of energy as a water drop from a 200-meter-high dam. Therefore, when water of different salinity is flowed through the membrane, the water flows from the low salinity to the high salinity and energy can be harvested like hydroelectric power (Son et al. 2016, Son et al. 2018b).

Electrochemical technologies can also be used to produce ultrapure water or harvest salinity gradient energy (Kim et al. 2017a, Kim et al. 2017b). Another advantage of electrochemical technology is that it can produce energy using the enormous amounts of waste/low-grade heat (< 60 °C) produced in cities (Zhu et al. 2016). Although electrochemical technology has a relatively short history of technology development, it has attracted a lot of attention due to its compact design, which makes it easy to link with other processes.

Some new technologies can also be introduced if we focus on the circulation of resources rather than individual technologies. One of these technologies is based on the use of solar power to purify water through membranes and store purified water in highly elevated reservoirs. Although there is a loss of energy in the conversion process, hydropower generation is also possible in an emergency or in the isolated islands area, using water stored during the day. In addition to the mentioned membrane and electrochemical technologies, many other technologies are actively being developed to implement the nexus for sustainable development.

Nexus research is becoming increasingly important. Despite the lack of accessible resources, the amount of resources used in a city is increasing and it is necessary to worry about the efficient allocation of resources from the design of the city.

Conclusion

Water, energy, and food are resources that are closely related to each other and are interchangeable, encompassed by the WEF nexus. The success of the nexus depends on exchanging resources or increasing the total amount of resources. Membranes and electrochemical techniques for the nexus have been studied extensively and are expected to receive more attention in the future.

Due to the global lack of resources and growing demand for those, nexus-related research is expected to become more active, such as resource circulation and stable securing. Also, since the number and population of megacities are gradually increasing, the amount of resources used in a city is increasing exponentially. Therefore, it will be necessary to consider the concept.

ARTICLE

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Prospect of Desalination Industries for the Water Economy of the East Asia Region

Sung Ho Chae[a], Joon Ha Kim[a]

Abstract: *While the first desalination technology emerged a few decades ago, desalination has really only started gaining attention since the 1990s, when the climate change era substantially began. After thriving in the 1990s, East Asia countries started to engage in desalination passionately, which has led to a number of meaningful results being harvested and the desalination technology advancing greatly. Nevertheless, desalination still faces several challenges before it can become a dominant means of water supply. To better understand the status quo of desalination, this article starts with a brief history of modern desalination industries. We then investigate the technical levels of East Asian countries such as Japan, Korea, and Singapore and the water industry background of China, one of the biggest water markets in the world. The latter part of the current article compares desalination with water reuse and introduces the strategies that desalination should seek. We strongly hope that this article aids the decision-making of desalination stakeholders around the world.*

Authors' Profiles

Sung Ho Chae has a background of undergraduate-level chemistry disciplines from the Gwangju Institute of Science and Technology (GIST),Korea. He is currently a researcher and a PhD candidate at GIST and researching membrane theories and the pressure-retarded osmosis (PRO), a process of harvesting renewable energies by mixing seawater and freshwater. As an author, he wrote a textbook concerning PRO for the first time in this field and published high-quality peer-reviewed papers. Thanks to such contributions, the Korea Ministry of Education conferred him the 'outstanding researcher award' in March 2019.
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Prof. Joon Ha Kim is a professor at the Gwangju Institute of Science and Technology in Korea. He has a background in chemical engineering from Korea as well as California. He has researched on the academic area of environmental systems engineering, which associates complex environmental systems with control theories, modeling, and optimized solutions to mitigate the problems caused by the intrinsic complexities in the systems. Prof. Kim's main research areas are environmental systems engineering including open and closed systems. He specializes in data-mining and modeling of complex systems, desalination engineering and optimization, watershed modeling and water pollution management, membrane systems optimization in water treatment, and non-point source pollutants modeling and management. He has written highly cited articles in well-known peer-reviewed international journals in addition to his book publications.
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A new type of water market

A recent trend in the water market is already showing clear signs of remarkable growth in this field. According to Global Water Intelligence (GWI), the average annual growth rate of the global water market is anticipated to be 4.2 percent until 2025 (see Fig. 1). This number represents an even faster pace than global economic growth, which the International Monetary Fund predicted as 3.3 percent in 2019 and 3.6 percent in 2020 (as of April 2019). Such swift growth in the global water market has been attributed to the demand for 'new water resources'. In recent years, the demand for new water resources has soared because access to conventional freshwater resources has become increasingly limited. Control of conventional freshwater resources has become harder as the global climate has become chaotic and uncertain. For example, reservoir water can run out more quickly if the actual summer temperature is higher than forecast. On the other hand, the water quality in a river can be significantly degraded if unexpected rainfall

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results in non-point pollution. To deal with such kinds of contingency, new water resources are required for stable water supply. Shifting from old water resources to new ones can be interpreted as actions to mitigate damages caused by the uncertainty of water supply in the climate change era.

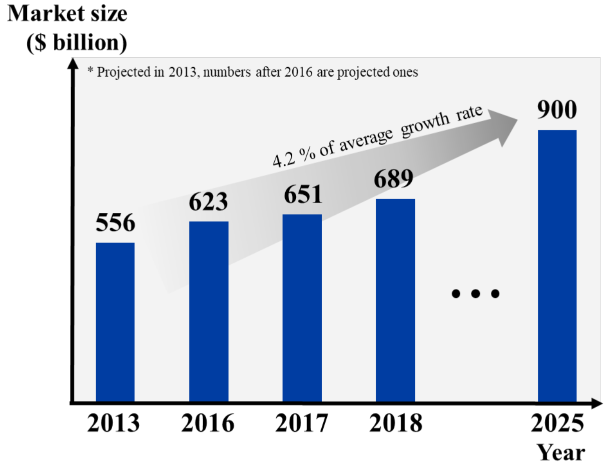

Figure 1. Annual growth of the global water market, projected by Global Water Intelligence (GWI) in 2013. The average annual growth rate of the global water market will be 4.2 percent until 2025. Such a pace is faster than the growth rate of the global economy projected by the International Monetary Fund.

(Recreated from the data of GWI)

Asia – a valuable market for desalination

Desalination is considered one of the most suitable water resources to aid the shift in the water market. Desalination is the process of producing fresh water by removing the salinity of saline water such as seawater. Although desalination was initially created a few decades ago to be used for various purposes, this technology was not able to be used as the main water supplying method due to its high energy consumption and relatively low economy. However, the efficiency of desalination has been greatly enhanced as time passed and its efficiency has increased accordingly. Over the past few decades, the most eye-catching growth in desalination industry has appeared in Asia. In the Middle East, countries that had no stable water supply systems have now implemented desalination plants. In the East Asia region, the desalination industry has been regarded as a strategic business worthy of being fostered. With such distinct needs, the international desalination industry could have been formed in Asia and a new type of water market emerged consequently.

Despite the importance of East Asia to the desalination market, there has been insufficient in-depth analysis of those countries, in contrast to the countless analyses for the desalination industries in the Middle East. Given that the recent advance of desalination technology has been considerably led by East Asian countries, analyzing the trend built by the countries in the region is highly instructive to better understand the formation of a new water market. In this context, this article is going to present the analysis on the growth of the desalination industry in East Asia.

Change of desalination technology

As mentioned above, desalination started to be used several decades ago. In principle, therefore, this technology is not a 'new water resource'. However, the hegemony of the present desalination field is totally different from that of the past. Desalination processes are divided into two parts according to the operating mechanisms. One is a process called 'thermal desalination', which involves extracting fresh water by heating up saline water. The other is a process called 'membrane-based desalination', which involves filtrating the unwanted solutes in saline water by pressurizing through a semi-permeable membrane. Most desalination plants that existed in the 1970s were thermal-based plants. Prototype membrane-based desalination processes were discussed theoretically in the form of hyperfiltration and reverse osmosis (RO), but their technological level only remained around sieve-like processes (L. Dresner et al., 1980). In other words, membrane-based desalination processes at that time were not capable of securing sufficient safe water. Furthermore, the energy consumption magnitude of membrane-based desalination processes was substantially higher than that of thermal desalination processes, which made the membrane-based desalination processes less economically attractive than the thermal desalination processes. According to previous studies, at that time, the specific energy consumption (SEC) of thermal desalination plants ranged from 15 to 18 kWh/m^3, while that of seawater RO was over 20 kWh/m^3 (M. Khayet, 2013; Khaled Touati et al., 2017). The lower energy consumption of the thermal plants could have been achieved because those plants could carry out mass production by circulating the residual seawater to produce sufficient fresh water. However, the situation turned to the other side as time passed by. The SEC of RO continually declined while that of thermal desalination processes did not. The biggest contribution to the decrease in the SEC of RO was the invention of energy recovery devices (ERDs) such as the pressure exchanger (Boris Liberman, 2004). Thanks to the role of ERDs, which reuse the energy remaining in brine after filtration, the SEC of RO became less than half of the previous one. In addition, advances in the membrane technology have not only cut down the energy consumption of RO but have also ensured safe water quality. As a result, the membrane-based desalination has become a more economical and practical option than the thermal desalination and has become the dominant process in the field. In the 1990s, the market share of membrane-based desalination processes completely overtook that of thermal desalination processes. The construction of thermal desalination plants rapidly declined and membrane-based desalination plants began to supersede thermal desalination plants. In the late 2000s, RO, the most representative membrane-based desalination process, held 70 percent of the global desalination market (C. Fritzmann et al., 2007).

Technical levels of East Asian countries

The success of membrane-based desalination motivated a number of developed countries to engage in the desalination market. The membrane-based desalination processes, once considered unattractive, turned into an efficient tool for dealing with climate change and an excellent business partner to pioneer the Middle East Asian market.

As the name suggests, the membrane is the most important component of a membrane-based desalination process. The performance of a given membrane strongly matters in terms of three aspects. The first aspect is water quality; a membrane with high performance is more likely to secure a better water quality. The second is productivity; the production rate of fresh water through the given membrane area directly links to the economics of a whole desalination plant. The third aspect is energy; if the given membrane cannot suffice the aforementioned two aspects, additional energy would be wasted to achieve the desired production of the desalination plant. The loss at the membrane filtration session cannot be compensated by what is done before and/or after this session. Thus, the good performance of a membrane must be firmly guaranteed.

Japan

In this context, Japan had outstanding merit for the membrane-based desalination market due to the strength of producing membranes with good quality. The most famous Japanese membrane incorporations are Hydranautics of Nitto Denko and Toray Industries. They are international companies headquartered in Japan and have almost 100 years of industrial background in the chemical and material engineering fields. Commercial RO membrane and membrane modules are the important products of those companies and both are main competitors with DowDuPont, LG water solutions, and Suez. The primary membrane product of Hydranautics and Toray Industries is the RO spiral wound module, the size of which ranges from 4 inches to 16 inches. The spiral wound membrane market showed an average annual growth rate of 10.04 percent during a period of 2014 (US$3.49 billion) to 2017 (US$4.65 billion) (Global Spiral Membrane Market Report, 2019). Due to such a compelling growth pace, the investment scale for the spiral wound module membranes is forecast to increase. In the meantime, a membrane type of hollow fiber is rising as a notable contender against the spiral wound membranes. Toyobo is one of the representative hollow fiber membrane makers in Japan and is vigorously researching ways to improve the quality of hollow fiber membranes for membrane-based desalination. Considering the irreplaceable role of membrane modules in the current desalination industry, Japan is positioning a very advantaging place in the desalination industry since two corporations out of five most spiral-wound-membrane-selling companies are located in Japan.

Korea (Republic of)

Unlike Japan, Korea has extensive experience in the EPC (engineering, procurement, and construction) field for desalination plants. Among the many EPC incorporations in Korea, Doosan Heavy Industries & Construction was the most remarkable because it had been a leading company in the field of the thermal desalination plant construction between the mid-2000s and the early 2010s (see Table 1). However, as the market for thermal desalination plants fell, the share of Doosan Heavy Industries & Construction also rapidly decreased. In recent days, many corporations – such as Doosan Heavy Industries & Construction, Daewoo E&C, GS E&C, and Hanhwa E&C– have sought to hold the hegemony of the newly risen membrane-based desalination EPC market, but no company has fully dominated this field yet. While the turmoil occurred in the Korean desalination EPC market, the competitiveness in a membrane market of Korea grew up apparently. Notably, as LG Water Solutions acquired H_2O Innovations of the United States in 2014, the Korean portion in the global membrane market suddenly grew. LG Water Solutions plans to improve the membrane performance of H_2O Innovations further by applying the cutting-edge chemical technologies, which are sourced by LG Chem, a parent company of LG Water Solutions. In this context, although enough time would be necessary to adapt to the global membrane market, Korea has the potential to be a dark horse in the desalination market if experiences from the EPC field and cutting-edge technologies for membranes are appropriately combined.

	Project Name	Country	Award	Capacity
Reverse Osmosis (Membrane-based desalination)	Fujairah (Hybrid)	UAE	2001	170,470 m^3/d
	Shiuaibah Ph.3 Expansion RO	Saudi Arabia	2007	150,020 m^3/d
	Shuwaikh RO	Kuwait	2008	136,380 m^3/d
	Jeddah Ph.3 RO	Saudi Arabia	2009	240,030 m^3/d
	Ras Al Khair Ph.1 (Hybrid)	Saudi Arabia	2010	309,130 m^3/d
	Busan Gijang RO	Korea	2011	45,460 m^3/d
	Escondida Water Supply	Chile	2013	220,000 m^3/d
Multi-Effect Distillation (Thermal desalination)	Benghazi North	Libya	2004	5,000 m^3/d
	Zawia	Libya	2005	5,000 m^3/d
	Yanbu Ph.2 Expansion	Saudi Arabia	2011	68,190 m^3/d
	Marafiq Yanbu	Saudi Arabia	2011	54,550 m^3/d

Multi-Stage Flash (Thermal desalination)	Farasan Power & Desal MSF Unit	Saudi Arabia	1978	2,270 m^3/d
	Yanbu Power & Desal MSF Unit	Saudi Arabia	1982	27,280 m^3/d
	Assir Ph.1	Saudi Arabia	1985	95,470 m^3/d
	Jebel Ali Station 'E'	UAE	1986	109,100 m^3/d
	Shuaibah Ph.2	Saudi Arabia	1993	454,600 m^3/d
	Al Taweelah A2 IWPP	UAE	1998	227,300 m^3/d
	Az Zour South Ph.3	Kuwait	1999	130,920 m^3/d
	Umm Al Nar Station 'B'	UAE	2000	284,130 m^3/d
	Fujairah (Hybrid)	UAE	2001	284,130 m^3/d
	Sabiya Stages 1&2	Kuwait	2004	227,300 m^3/d
	Sohar IWPP	Oman	2004	150,020 m^3/d
	Ras Laffan 'B'	Qatar	2005	272,760 m^3/d
	Sabiya Stage 3	Kuwait	2005	227,300 m^3/d
	Shuaibah Ph.3 IWPP	Saudi Arabia	2006	895,562 m^3/d
	Shuweihat S2 IWPP	UAE	2008	454,600 m^3/d
	Qurayyah Add-on CCPP MSF Unit	Saudi Arabia	2009	6,000 m^3/d
	Rabigh Power No.2 MSF Unit	Saudi Arabia	2010	9,820 m^3/d
	Ras Al Khair Ph.1 (Hybrid)	Saudi Arabia	2010	727,360 m^3/d
	Yanbu Ph.3	Saudi Arabia	2012	550,000 m^3/d

Table 1. Desalination plant constructions carried out by the Doosan Heavy Industries, tabulated in chronological order. This company has undertaken many thermal desalination plant (especially multi-stage flash) constructions.

Source: Doosan Heavy Industries & Construction

Singapore

While Singapore does not technically belong to the region of East Asia, that country's technical achievements cannot be excluded when it comes to the water industry level in Asia. Therefore, we will peek inside a small part of Singapore's water industry. Singapore is a city-state with a population of 5.6 million people. Due to its dense population and small territory, this city-state does not have sufficient natural water resources for all of its citizens. To achieve a better water system across the state, Singapore has employed four other water supply strategies: rainfall catchment, water reuse, importing water from Malaysia, and desalination. The smallest of these, in terms of the amount of water supplied, is desalination plants, which only provide 10 percent. However, the Singaporean Government is continually investing in infrastructure related to the desalination plants because the water importing contract with Malaysia will expire after 2060 (those two countries agreed on a 99-year contract that was signed in 1962). Since the dependence of Singapore water supply on Malaysia is considerable (35–40 percent), alternative technology needs to be prepared for the stable water supply in Singapore (Ivy Ong, 2010). Most of the desalination projects in Singapore are run by the Public Utilities Board (PUB), which is a statutory board of the Ministry of the Environment and Water Resources. PUB plays a role as not only an agency managing the water resource of a whole state but also a platform combining the R&D centers of universities (as of 2017, 26 R&D centers were engaged in) and the monetary power of incorporations (more than 150 companies, as of 2017) for implementing practical and efficient water supply systems in Singapore. With the management of government, the technical levels of Singaporean water and desalination industries increased greatly and Singapore became one of the core countries in the desalination field. The Singaporean Government's investment in the water industry will continue in the future as well so that the desalination industries in Singapore will be boosted (see Table 2).

China

In terms of technical advances, China is still highly dependent on foreign technologies – which come from countries such as Japan, Korea, and Singapore – to implement desalination plants. However, the United Nations predicts that 255 million people will be added to China's urban population by 2050 (United Nations Department of Economic and Social Affairs) and demand on the urban water supply systems in China will skyrocket accordingly. For now, the Government of China plans to efficiently manage the existing urban water supply systems to keep up with increasing population trends. The representative case of such an attempt can be found in the South-North water transfer project in China. For the project, several routes have been built to bring water from the water-abundant south (Yangtze river region) to the drier north, which led to the groundwater source of the north (industrialized region such as Beijing) being over-exploited. However, new urban water resources will be inevitably needed someday since such a kind of water transfer is very sensitive to external variables (such as climate and pollution). In this context, water reuse and desalination technologies are considered as good measures that can be taken to counter the increase in urban water demand in China.

Rivalry to water reuse

Desalination became an attractive technology when it

	Tranche 1 (2006~2011)	Tranche 2 (2011~2016)	Tranche 3 (2016~)
Investment scale	S$300 million	S$140 million	S$200 million

Table 2. The overall investment plan of the Singaporean National Research Foundation to Environment and Water Industry Program Office to drive public and private sector R&D in water industry fields. Thus far, S$470 million (approximately US$344 million) has been invested, with more to come.

Source: PUB homepage

transitioned from the thermal one to the membrane-based one. Nonetheless, this energy-intensive process needs to be more efficient and optimal in order to survive in the water market. In particular, desalination should find distinct advantages over water reuse technology.

Water reuse literally indicates a technology that reuses impaired water for people's daily use after applying suitable cleanings. Generally, wastewater treatment plants are regarded as the sources of the impaired water and the impaired water is re-supplied to the public after cleaning. The biggest advantage of water reuse technology is that it guarantees the sufficient supply of water source differently from the groundwater. Furthermore, the cost and the footprint for additional plant installations are relatively small if the water reuse plants are configured in the vicinity of a wastewater treatment plant. This is caused by the water reuse processing, based on the water pre-cleaned by wastewater treatment plants (that is, secondary and tertiary treated water). Due to such advantages, the capacity of advanced water reuse systems (tertiary water reuse systems and water reuse systems including membrane filtration parts) is forecast to be even higher than seawater and brackish water desalination plants by 2022 (see Fig. 2).

Nevertheless, membrane-based desalination processes have some strong points. These processes can be utilized as a tool for the 'further' water treatment. The groundwater in urban regions can be concentrated as it is exploited over a long time. Usual water treatment does not work for such concentrated groundwater, so extra-particular water treatment should be applied in that case. In such cases, brackish RO processes are usually employed to filtrate the concentrated groundwater. In addition, the utilization of membrane-based treatment is frequently required, in addition to desalination processes. For example, wastewater treatment plants configure a RO or a nanofiltration process in the terminal part of a whole process from time to time. This is because membrane pores in such processes are small enough to reject the particles that remain even after prior cleaning processes.

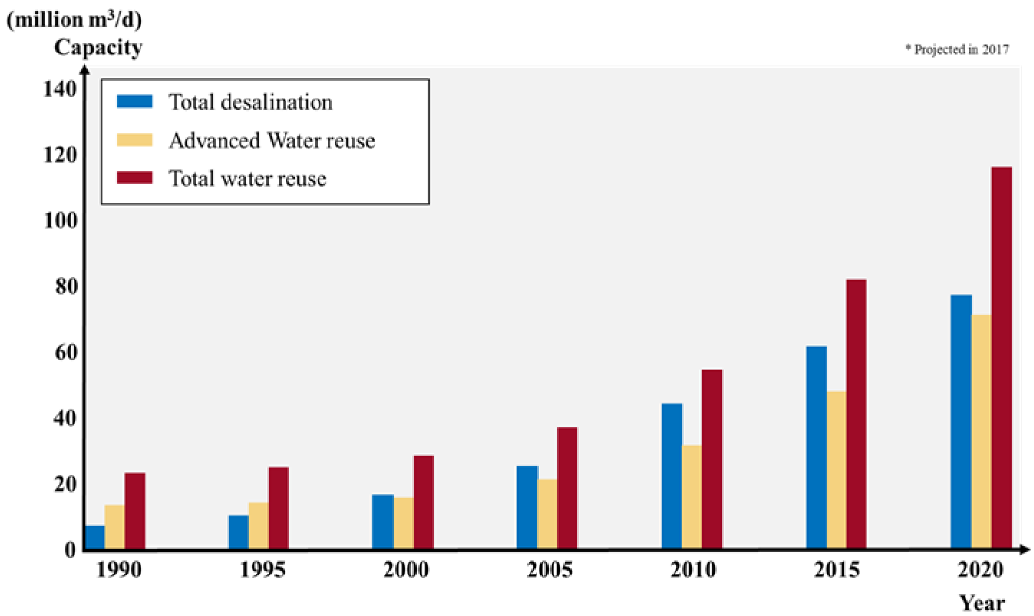

Figure 2. Comparisons among the global capacities of total desalination plants, advanced water reuse plants, and total water reuse plants. The capacity of advanced water reuse plants was higher than that of desalination plants in the 1990s, but that trend has reversed since the 2000s. GWI projects that the capacity of advanced water reuse plants will again catch up to that of desalination plants around 2022.

(Recreated from the data of GWI)

However, such advantages are not sufficient to appeal the necessity of desalination processes over the water reuse to stakeholders. Desalination plants are still more energy-intensive and site-specific than water reuse plants. To firmly stand as a more attractive water resource, there is a need for market strategies that are clearly distinctive from the water reuse technology.

Prospects for the desalination market in East Asia

With the end of the thermal desalination age in the Middle East, the overall trend of new water markets has changed. According to GWI, in 2016 the total annual contracted capacity of water reuse was more than twice than that of seawater and brackish desalination: 6.7 million m^3/d and 3.0 million m^3/d, respectively. Furthermore, annual contracted capacity at water reuse plants using more advanced technology overtook desalination in 2012 and stood at 4.9 million m^3/d in 2016. Water reuse technology will continue to grow at a faster rate over the next few years, with newly contracted advanced water reuse capacity growing at 9.4 percent compared to 7.3 percent for desalination.

Although slightly behind the water reuse in a whole water market, the recent pace of the desalination market is notable. However, this technology has many inherent limitations to be one of the global main water supply means. Therefore, the stakeholders of the desalination field should seek its survival strategies for the whole water market. The East Asian desalination market should have other markets than just the Middle East. One of such 'another way' might be able to be found in the convergence with other water treatment field, as with the case of aligning a RO process at the last part of the wastewater treatment plant, which is mentioned above.

To conclude, the short-term prospects of the desalination field, especially in Asia, look promising. However, to make a firmer ground for desalination, the utilization scope of membrane-based desalination processes should be widened. For example, many previous studies found that relatively newly emerged energy-generating systems based on the salinity gradient mechanism such as pressure-retarded osmosis (Sung Ho Chae et al., 2018) and reverse electrodialysis are effective to reduce the energy consumption of RO. Since those processes use the same kind of solutions and membrane, RO processes can be readily paired. Likewise, additional attempts should be made to carry the current pace of the desalination market constantly. In this context, it seems like that 'outside-the-box' approaches are more than suitable for the bright long-term future of the desalination market in East Asia.

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Pakistan's Water Sector: Security and Challenges

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Abstract: *Water security is highly linked with food, climate and human security challenges for the sustainable development of any country. This report briefly describes the situational analysis of Pakistan's water sector and related securities. Pakistan is among World's 36 most water stressed countries. Per capita availability of water has declined up to about 860 cubic meters, making Pakistan a water-scarce country. In addition, Pakistan has only 30 days storage capacity which adversely affect the agricultural productivity, despite having World's largest irrigation system. Uncontrolled groundwater extraction for advanced industrial and agricultural activities not only deteriorates the water quality, also depletes water table in the region. To secure future water, a comprehensive conservation and management strategy is required to deal with regional climatic changes.*

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Pakistan's water sector: security and challenges

"Water is not for life … Water is life." This quotation from the United Nations (UN) Secretary General, highlighted the status of water as a need that connects all aspects of human life. Additionally, water contamination, either by industrial or human sources, not only affects the health of general public but also claims lives and has wide-ranging consequences. While a shortage of water is a vital issue for human life, excess water from storms and floods is also problematic as it can devastate an entire ecosystem.

Situational analysis

Water-related challenges are among the key problems Pakistan currently faces. The country has changed drastically from being a water-copious country to one facing water stress. From 1990 to 2015, the availability of water per capita in Pakistan dropped from 2150 cubic metres to 1300 cubic metres. Pakistan is currently ranked 36th in a list of the world's most water-stressed countries [1].

By 2025, the amount of water per capita is expected to decline further to about 860 cubic meters, which would make Pakistan a water-scarce country [2] (1000 cubic meters/capita is the minimum volume of water required to avoid health and food implication of water scarcity). Despite significant developments in water source and sanitation facilities, approximately 27 million people in Pakistan do not have access to safe drinking water and about 47 million people do not have access to adequate sanitation facilities [3]. Irregular supply of water and its increased demand are collectively resulting in a shortage of water throughout the country. Rapid urbanization

[a] Water and Sanitation Agency (WASA), Rawalpindi, Pakistan

and industrialization, increased population growth, and water-intensive agriculture practices are among the major factors contributing to Pakistan's growing water demand. Water demand escalates every day and is expected to reach 274 million acre-feet (MAF) by 2025, whereas the projected 191 MAF is stagnant for the supply sector, resulting in a supply-demand gap of approximately 83 MAF [4].

Climatic changes, hydrological cycles, and Pakistan's geography further compound concerns over this widening gap between water supply and demand. However, poor water infrastructure, inadequate lining of canals and insufficient storage capacity further intensify the situation of water scarcity. Pollution of available resources by dumping contaminated agricultural run-off, along with untreated domestic and industrial wastewater in natural water bodies, also results in limited freshwater availability.

Taking into consideration the situation, the Pakistan Government has made several attempts, at both federal and provincial levels, to describe its commitments on the road to combat with these water-related issues. In April 2018 the Government approved its first ever National Water Policy (NWP), which provides national targets for safe drinking water, management of water resources along with their storage and treatment. The NWP also provides a framework for the promotion of sustainable consumption, urban water conservation and behavioural changes to reduce water wastage through awareness campaigns. Moreover, to enable itself economically to achieve sustainable development and poverty reduction targets by 2030, Pakistan has joined the alliance of upper middle-class countries by prioritizing the Sustainable Development Goals (SDGs) of UN's 2030 Agenda. Regarding Goal 6 (clean water and sanitation), Pakistan has focused on ensuring the availability of safe drinking water for all by 2030 and investing in sufficient water infrastructures, providing appropriate sanitation facilities, and raising hygiene awareness at every level.

Water availability: threats and challenges

Water availability in Pakistan is mainly from river flows, glaciers, precipitations, and huge reserves of ground water in the Indus Basin. These water sources have a marked temporal variability, which makes the resource management a complex task. Likewise, ground water availability and aquifer recharging are highly dependent on dry and wet years. The Indus River System and its tributaries, being a single source of water supply, feed Pakistan mostly through glacier melting. The availability of water in the Indus System is very seasonal-based, producing annual river flows of approximately 85% during the period of June to September [5]. These peak flows also overlap with the concentration of monsoon rainfall. In the plain areas of Sindh and Punjab, rainfall may vary from 150 to 1500 mm per year [6]. Extreme weather conditions can result in floods and droughts that severely deteriorate the country's agriculture and livestock, as well as its water infrastructure.

Limited water storage is mainly due to excessive losses to the Arabian Sea, resulting into canal water shortage. Tarbala, Mangla and Chashma are major reservoirs in Pakistan that have a total design capacity of 15.75 MAF but this has decreased to 13 MAF because of sedimentation [7]. It has been predicted that 40% of Pakistan's total storage capacity will be lost by 2020 because of sedimentation [8]. Additionally, only 10% of annual river flow can be stored in the reservoirs, compared to the standard of 40 per cent. These dams can store water for only 30 days of average demand [3], compared to 220 and 1000 days for India and Egypt, respectively. However, as far as Pakistan's live storage capacity is concerned, only 121 m^3 of water is available per person, which is only higher than Ethiopia.

From snow and glacier melting, the Indus River System receives approximately 146 MAF of annual river flow, 48 MAF of which escapes below the Kotri Barrage (a much higher amount than downstream requirements) to the Arabian Sea. These losses are due to limited storage facilities and are likely to increase at a higher rate because of increased global warming and glacier melting. Pakistan, with the largest irrigation system in the world, lost its two-thirds of currently diverted water because of poor transmission and seepage in its canal system [8].

Agricultural productivity remains extremely low, despite having such a large irrigation system. Water supply is connected to the canal command area and farmers consume water even when it is not required. Therefore, up-stream growers have four or five times more water than users at the tail-end for every season [9]. These circumstances result in the low productivity of farms against per cusec of available water. For example, cereal crops in Pakistan are only one-sixth as productive as those in China and one-third of Indian crops [7].

Several inefficiencies and inequalities were reported for water supplied to the domestic sector. In Punjab, the largest province, only 51 per cent and 18 per cent of urban and rural populations, respectively, have tap water access [10]. This indicates that most of the population use expensive water sources like underground water and tanker systems for their basic needs at the domestic level.

Groundwater extraction, especially for irrigation purposes, has almost doubled, from 25.6 to 50.2 MAF, over the last four decades [11] because of unpredictability allied with surface water supplies. This means that groundwater is contributing to half of the total canal water available for farmland. Furthermore, domestic and industrial sectors also rely on groundwater resources for drinking and process water, respectively. Unmonitored groundwater extraction in the domestic sector also increased because of inadequate water supply in the cities. For instance, in Faisalabad (Pakistan's third most populated city), the majority of households shifted to groundwater resources because of a lack of monitoring and inefficient water supply by Water and Sanitation Agency (WASA), Faisalabad [12].

River flows and precipitation patterns in Pakistan recharge most of the groundwater aquifers, resulting in the provision of access to this water resource, even for a very long time (40 years). Approximately 55 MAF of water is recharged annually to groundwater resource in the Indus Basin System, most of which (30 MAF) occurs in the fresh water zone [13]. However, no matter how huge these reserves are, the excessive pumping may lead to the depletion of this valued resource. This is exactly what happens in different regions through the country. Excessive and unmonitored extraction of groundwater through 1 million tube wells installed across the country leads to reduced water quality and falling water table. For instance, despite the availability of the River Ravi and an extensive canal system, the water table of the Lahore region has decreased by up to 0.5 meters annually over the last 30 years [14]. The situation is even worse in Balochistan, where there is no canal system to recharge the water table. In Pishin District, the water table has been depleted down to 1000 feet [15].

Unsustainable groundwater extraction is not only depleting the resources, it is also causing the intrusion of saline water into fresh water resources. Therefore, it reduces the accessibility and deteriorates the quality of groundwater as per the World Health Organization (WHO) standards.

Deteriorating water quality across the country is also a very serious concern. Water contamination in Pakistan is mainly due to by-products of various industrial and agricultural activities such as textiles, fertilizers, dyeing, leather, sugar processing, cement, food processing and pesticides. Approximately 90 per cent of these industrial and agricultural effluents, along with municipal sewage, are dumped directly into the open drains and rivers [16]. These effluents not only remain in fresh water bodies, but also are percolated from unlined drains and polluted underground water aquifers. Additionally, the absence of proper monitoring of effluent disposal in fresh water bodies results in the deterioration of drinking water quality, which also adds to health concerns. For instance, increasing ground water contamination has put Pakistan's 50 million population at the risk of arsenic poisoning [17].

Climate change and global warming have been the major challenges the world started to face since the start of this century, and it is also an emerging threat for water sustainability in Pakistan, as in most countries. The Indus Basin, which depends heavily upon the Himalayan Glaciers, is also vulnerable to shifts in weather patterns. The Climate Change Task Force in Pakistan claimed that from 1901–2000, the average temperature increased by

0.6 ^{0}C. Parallel to that, 25% of mean precipitation has also increased in the last century [7]. Additionally, the variability of monsoon rainfalls will also increase because of climatic changes, resulting in an enhanced number of extreme events like droughts and floods. Flood data for the past 50 years in Pakistan shows that the number of these extreme events (floods) per decade has increased with the increase in average temperature [18]. Similarly, droughts have also had huge impacts on the regions of Indus Basin, making Balochistan and Sindh most vulnerable.

According to the Global Climate Risk Index of 2017, Pakistan ranked seventh out of 181 countries [19]. Maplecroft ranked Pakistan 16th out of 170 countries, putting it in the "extreme risk" category, on the Climate Change Vulnerability Index 2017. Through multiple factors climatic change will adversely affect the water situation in Pakistan. For instance, more water for irrigation is required during prolonged dry and warmer seasons because of increased temperature. In addition, higher atmospheric temperatures have meant that more water is demanded by farm animals for their hydration needs, industries for their cooling processes and individuals to cope with higher temperature. Also, the increasing population and urbanization will ramp up water demand, driven by climatic changes.

Increasing atmospheric temperatures may cause **de-glaciation**, resulting in increased water flows in rivers, but these flows would decrease thereafter, creating situations ranging from extreme floods to extreme droughts. Unregulated escape of water flows below Kotri Barrage leads to a rise in sea levels. Intensified rainfalls (monsoon season) in the Indus Basin not only increases the sedimentation due to increased run-off, but also reduces the capacity of reservoirs. As a result, these extreme events will be more severe and frequent in the near future, which will have a negative impact on the sustainability of the water and agriculture sector.

Transboundary disputes, especially on Indus System Rivers with India, intensify the vulnerability of river supply. Both countries signed the Indus Water Treaty for the peaceful management of water in 1960. As a result, eastern rivers were allocated to India while western rivers (Jhelum, Chenab and Indus) are reserved for Pakistan. Despite the signed terms and conditions, disputes over treaty emerged when India started altering water flows in the western rivers, as was the case with the Kishanganga Project of the Jhelum tributary [20]. The Indian government is working on the development of 17 different hydro-power projects on the Chenab River and 16 similar projects are in progress on Jhelum River [21]. India diverts about 33% of water river flow to the Kishanganga Dam from the Neelam River, which affects the Neelam-Jhelum hydropower project in terms of water availability.

Being a lower riparian state on Kabul River tributaries, Pakistan also has transboundary disputes with Afghanistan, as the Afghan government is constructing hydro-power projects on the Kabul River. Because of the arid nature of the region, growing water demands of both countries can potentially create a serious water conflict. Pakistan and Afghanistan share nine rivers with annual average flow of about 18.3 MAF, 16.5 MAF of which is from the Kabul River [21]. Hydro-power projects and storage constructions in future by the Afghan government may decrease 17% of average annual river flows towards downstream. Therefore, an official agreement is required for the peaceful sharing of water resources between two countries.

The conclusion drawn from all of the above scenarios is that the mismanagement of Pakistan's water sector results in water quality deterioration, ground water depletion, deforestation, deglaciation, food insecurity and increased poverty. Water practices at both the agricultural and domestic sectors are not in accordance with water resources and Pakistan's conservation strategy [15] in terms of water requirement and quality. Therefore, to secure water for future, analysis of existing water resources along with a comprehensive conservation and management strategy is required. In addition, the tools of public awareness, excessive plantation, investments in water infrastructures, efficient irrigation systems, upgrading of academic curricula for sustainable development, strict policy implementations and research and development in the water sector can all help stabilize the situation of water scarcity in Pakistan.

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Nigeria Water Crisis: A Function of Failed Governmental Planning and Policies

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Abstract: *While Nigeria is fortunate to have an abundant supply of ground and surface water, and some coastal cities have access to abundant seawater, most people in the country lack access to safe drinking water. This problem is natural and anthropogenic in origin. The natural causes are mostly linked to climate changes and require global efforts. However, the anthropogenic causes are almost inherent in the lifestyle of the people, such as irresponsible disposal of domestic, municipal, and industrial waste in and around water bodies. This article is based on secondary information that focuses on some causes of water pollution in Nigeria and the health repercussions, and also suggests some possible strategies to combat the problem of poor quality water.*

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Introduction

Nigeria is located in the western part of Africa, surrounded by the Republic of Niger and Chad to the north, the Atlantic Ocean to the south, the Republic of Cameroon to the east, and the Republic of Benin to the west. The population is around 200 million people, making it the most populous nation in Africa and the seventh largest in the world.

Water resources

Water is life and life is water. Water covers more than 70 percent of the earth's surface and modern civilization started from sufficient water supply. In Nigeria, water plays a central part in the economy and development. Many of the states are named after rivers and the water from these rivers is used for domestic and industrial purposes, farming, and electricity generation. Nigeria has access to surface, underground, and sea water, which are unevenly distributed throughout the country. High precipitation is observed in the southern part of Nigeria, which has almost nine months of rainfall per year, compared to between three and four months of rainfall in the northern part of the country. Seasonal water shortages are always experienced in the northern and the middle belt region of the country during the time of the year when there is less or no rainfall and underground waters dry up. Even in the southern region, where rain falls for three-quarters of the year, there is still a water shortage problem. Cities like Lagos, Ibadan, and Port Harcourt in the south cannot provide high-quality drinking wa-

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ter. Overall, less than one-fifth of Nigeria's population has access to safe drinking water, and an average of two-thirds of the population have access to basic water supply (Organization & UNICEF, 2017). Unfortunately, this problem only affects the masses, as rich Nigerians can afford to supply and treat their own water.

Causes of water shortage

Although the northern area experiences natural causes of water shortage, this is not the main problem because there are enough surface waters that have the capacity to meet the region's need. The cause of lack of access to safe drinking water in Nigeria is man-made; for example, water pollution.

Water pollution in Nigeria occurs in both developed and underdeveloped places. This is as a result of the poor sanitation and hygiene culture perpetrated by the citizens and failure of the authorities to provide even basic facilities. A study conducted in the Lagos metropolis found that potentially toxic concentrations of heavy metals have been found in its water systems (Ehi-Eromosele & Okiei, 2012). Most industrial wastes in the country come from the mining, pharmaceutical, textile, paint, food, and petroleum industries.

Most people in Nigeria are not aware of the danger of collecting water through shallow wells and water downstream of effluent discharge points. Even when they are aware, the cost of digging deep wells below the table water is unaffordable for the general public and collecting downstream water is sometimes the only available option. In most cases, people depend on water sourced from downstream and shallow wells for their household supplies. Only a small number of people, in urban areas, have access to potable water supplied by the government or water treatment systems, leaving the general population at the mercy of the contaminants in surface and underground water. While one might consider that underground water is safer for human use, poor wastewater disposal puts the general public at risk. This is because most homes produce their water from the underground and, at the same time, dispose of their waste into the same ground (septic tank).

Considering increased industrialization in Nigeria, the quantity and the variety of industrial waste making its way to the water bodies have doubled. Likewise, dramatic increases in population and the rate at which houses are built close to each other have not made it possible to create appropriate distances between the wells and the septic tanks. Hence, cross-contamination of the shallow wells is a major challenge faced by those who can afford to produce both their waste and dispose of their waste. Also, improper industrial and municipal waste disposal have an adverse effect on human lives and the environment in urban areas. In rural areas, waste is usually dumped in and around surface water since the people cannot afford to produce their own water and manage their waste; surface water is both where they source their water and dispose of their waste. Surface water pollution has been a major cause of water pollution in Nigeria as a result of population growth and poor waste disposal methods. Waste is usually dumped into and around streams in Nigeria (Nzeadibe, 2009).

Nigeria will not be able to catch up with global sustainable development unless drastic measures are implemented. Despite an annual budget of US$500 million being spent on water sanitation programs, Nigeria still does not have access to safe drinking water. Nevertheless, the negligence, wrong practices, and a lack of accountability have led Nigeria to this present situation. Funds are disbursed yearly to different states of the country, which have the autonomy to spend and allocate some of these funds to the local government. Unfortunately, there is no clear tracking of the budgeted funds and expenditures. These yearly allocated funds fall in the hands of some selected few, who end up embezzling the funds without anyone holding them accountable (Wade, 2018). Nigeria has no well-developed water or wastewater regulatory agency that can monitor the utilization and optimization of these funds. Other sectors (transport, energy, etc.) also lack functional agencies.

Environmental policies

While numerous policies have been set out in the water sector, they have achieved little or nothing. Examples include the Federal Environmental Protection Agency

(1988), the National Policy on Environment (1989), and the National Environmental Reference Laboratory (1990). Most recently, in 2003, a presidential Water Initiative: Water for people, Water for Life program was launched, with ambitious targets to increase water access (including a 100 percent target in state capitals), 75 percent access in other urban areas, and 66 percent access in rural areas (Idu, 2015). However, nothing was done to implement the goals. In June of 2016 the new government approved a Water Resources Roadmap (2016–2030) with the ambition of providing 100 percent water supply to all the citizens; establishing a policy and regulatory framework; developing and implementing national water supply and sanitation; and identifying alternative sources for funding water supply and sanitation through the collaboration with development partners, states and local government authorities, communities, and the private sector (Umezulike, 2017). Nigerians wait in hope that this Water Resource Roadmap will not go down the drain as the previous ambitious policies have. In the same vein, although Nigeria embraced the millennium development goals (MDG) some years back, it has not shown any significant achievement. Now, the country has joined the bandwagon of sustainable development goals (SDG), but is still far from pursuing the objectives and the goals of the program.

Environmental and health impact of water pollution

A lack of access to quality water for both drinking and household use affects the health of the people and the economy (Adewolu et al., 2009). Water pollution also has a direct impact on the environment and the ecosystem. For example, in the Niger Delta area of Nigeria, pollution as a result of oil spillage is a major threat, which has led to a decline in agricultural activities and loss of biodiversity. When these waters are polluted, some of the pollutants find their way to the food chain from animals that drink from them and to humans through meat and fish consumption.

The disposal of industrial and municipal waste into and around surface water and underground water systems impacts human health and disrupts ecological systems. Over the years, many diseases have been spread through water pollution. For instance, Nigeria still suffers from epidemics of typhoid, diarrhea, dysentery, and cholera, all of which are microbial in origin. The effect of these microbial infections on Nigeria's economy cannot be overstated. Few Nigerians who are aware of such dangers take it upon themselves to filter and boil their water before consumption. However, these filtration technologies are expensive and are therefore not readily available to the masses. Likewise, the energy cost for filtering and boiling water is high, if available at all.

A way to go

For Nigeria to solve the problem of water pollution and shortage, the management policies to be dealt with. In the same vein, the way water is managed in Nigeria must change; the stakeholders need to be widened to the general public and international organizations with clear roles to ensure better accountability.

Because Nigerians rely on water bodies for daily use, there is an urgent need to protect them. Presently, Nigeria has no reliable system for monitoring water quality. Hence a database for water quality around the country should be created that records physical, chemical, and biological characteristics. Constant monitoring and the maintenance of such records would show the level of pollution and signal the potential risk. This information would help provide solutions before major disease outbreaks. The environmental laws, especially as they relate to water bodies, should be strengthened. Polluters of water bodies should be charged and the standards for industrial and agricultural effluent discharge need to be enforced. All industrial and agricultural waste must be treated before discharged and must comply with regulatory standards.

Water distribution is also a problem in Nigeria. Supplying treated water to the masses at an affordable rate would reduce the pressure on those people to produce their own water in an unhygienic way. Similarly, there is a need for a robust wastewater treatment system in the country as water pollution is linked to unacceptable disposal of domestic, municipal, and industrial waste.

Finally, it is essential that public awareness is raised regarding the use of water from shallow wells and the irresponsible discharge of waste into and around water bodies. Enlightening the masses would greatly reduce the anthropogenic causes of water pollution. The use of water filters with no or very low energy consumption and boiling if necessary should be encouraged.

Conclusion

This article has briefly discussed the water situation in Nigeria and some of its root causes. The major cause of water pollution and shortage in Nigeria is not natural, but self-imposed by the people as a result of mis-management policies. Nigeria is one of the few countries where the citizens are responsible for their own waste treatment and water supply, which enables people to practice whatever they deem fit. Nigeria needs a complete overhaul in terms of re-planning its cities and putting basic structures in place for newly developing cities. While the federal government cannot do it all, they can play an active role in fragmenting this sector. Each small community could provide its own solid waste management, wastewater treatment, and water supply with strengthening laws, policies, and regulations regarding sanitation. Access to safe drinking water should not be a luxury available only to the rich, but a fundamental right of every citizen.

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