H₂Open Journal

Check for updates

© 2022 The Authors

H_2Open Journal Vol 5 No 2, 221 doi: 10.2166/h2oj.2022.076

Jakarta water supply provision strategy based on supply and demand analysis

N. Ardhianie [a,*], D. Daniel[b], P. Purwanto[a] and K. Kismartini[c]

[a] Doctorate Program of Environmental Science, School of Postgraduate Studies, Universitas Diponegoro, Semarang 50275, Indonesia
[b] Department of Health Behaviour, Environment, and Social Medicine, Gadjah Mada University, Yogyakarta, Indonesia
[c] Department of Public Administration, Universitas Diponegoro, Semarang 50275, Indonesia
*Corresponding author. E-mail: nilaardhianie@gmail.com; nilaardhianie@students.undip.ac.id

NA, 0000-0002-9573-794X

ABSTRACT

Robust water service delivery systems require an understanding of resource dynamics as a basis for planning sustainable solutions for Jakarta, the capital with challenging water service provision performance. A significant gap needed to be closed with a service coverage of 64.06% and non-revenue for water at 45.06%. However, there is no detailed information on Jakarta's water supply and demand, which is essential to understand the resources situation. This study estimates Jakarta's total water supply and demand for 5 years. Furthermore, we analyze the natural and socio-economic factors shaping the current supply and demand using thematic analysis based on the DPSIR (Driver, Pressure, Status, Impact, and Response) framework. This paper contributes to two building blocks in the system strengthening approach to water and sanitation, i.e., (1) the sector policy strategy and (2) planning, monitoring, and review. Key drivers, pressures, status, impacts, and responses were critical to informing the system-wide understanding of the problem and suggesting evidence-informed explanations for a better water supply provision strategy in Jakarta.

Key words: Jakarta, supply and demand, urban water planning, water provision

HIGHLIGHTS

- Jakarta does not have a thorough supply and demand analysis available for the public.
- DPSIR (Driver, Pressure, Status, Impact, and Response) analysis to show the ways in which water and society are interlinked.

INTRODUCTION

The United Nations General Assembly explicitly recognized the human right to water and sanitation. It acknowledged that clean drinking water and sanitation are essential to realizing all human rights through Resolution 64/292 in 2010 (The Human Rights to Water & Sanitation 2010). In November 2002, the Committee on Economic, Social, and Cultural Rights of Indonesia adopted General Comment No. 15 that defined the right to water as the right of everyone to sufficient, safe, acceptable, and physically accessible and affordable water for personal and domestic uses (United Nations 2002). However, many households in Jakarta, the capital of Indonesia, do not have access to piped water or sewer networks (Figure 1).

Jakarta, a delta on the North Coast of Java Island, faces an extraordinarily complex water supply challenge. In 2020, the megapolitan with a population of 11 million required roughly 1.2 billion cubic meters of water, and the piped water system can support less than half of it. Most of the population relies on groundwater and uses it without any treatment for their daily needs, except for drinking, where people usually boil it before drinking. The water quality test by the Environment Agency in five areas in 2018 showed that 64.6% of the samples were contaminated with detergent and *Escherichia coli* above the quality standard threshold (Dinas Lingkungan Hidup Jakarta 2018), all samples from rivers in Jakarta are polluted, 1% light polluted, 20% moderate, and 79% highly polluted (Dinas Lingkungan Hidup Jakarta 2021) which is also supported by other studies (Irawan *et al.* 2015; Padawangi & Douglass 2015; Kooy & Walter 2019).

One of the reasons for high-level groundwater contamination occurs because the current sewer network only covers 4% of the city (KPPIP 2019). All Jakarta's surface water is heavily polluted by greywater from households, commercial buildings and discharges from industries, chemicals from agricultural soil, solid waste, and fecal

This is an Open Access article distributed under the terms of the Creative Commons Attribution Licence (CC BY 4.0), which permits copying, adaptation and redistribution, provided the original work is properly cited (http://creativecommons.org/licenses/by/4.0/).

Downloaded from http://iwaponline.com/h2open/article-pdf/5/2/221/1046139/h2oj0050221.pdf
by guest

Figure 1 | Location of Jakarta in Indonesia's map.

matter from overflowing or leaking septic tanks (Apip *et al.* 2015). Another study revealed a complex mixture of organic contaminants comprising more than 100 structurally heterogenic compounds was detected in a river affected by discharges from a large industrial manufacturing center and municipal sources. It is estimated that 5–17 tons of pollution from municipal sources are carried by just one urban river, the Ciliwung, into the Jakarta Bay each year. These various contaminants might seep and contaminate the groundwater (Dsikowitzky *et al.* 2017).

The heavy reliance on groundwater also poses serious environmental risks such as land subsidence, damage to buildings, increased risk of flooding, and seawater intrusion (Neise 2019). Jakarta sinks about 1–15 cm a year, while some northern parts sink by as much as 28 cm a year (Abidin *et al.* 2011). Thus, Jakarta is the fastest sinking city in the world (BBC 2019).

The provision of clean water via piped water in Jakarta started long ago. The practice of providing water through a centralized system dated to the colonial period when Jakarta was still called Batavia, and the government established the Water Leidinggen Bedriff van Batavia (local water supply enterprise) in 1918 (Kooy 2014). The era of modern management began in 1957, marked by the operation of the Pejompongan I Water Treatment Plant, which treated water from the Jatiluhur Dam and flowed through an open channel of 70 km (Nasution 2016). Since 1997, the piped water system has been managed under a concession agreement between PAM Jaya, the water utility owned by Jakarta Provincial Government and two private operators (PAMJAYA 2020). Since 1997, the piped water system has been managed under a concession agreement between PAM Jaya, the water utility owned by Jakarta Provincial Government and two private operators (Nasution 2016).

To provide piped water access to all residents, the authorities need to develop a comprehensive master plan or strategic planning based on a detailed and accurate analysis of demand and supply for the megapolitan. Equal access to water and sanitation services requires a political choice on the part of the State, coupled with well-considered planning, budgeting, and financing, not just for capital cost but also for operation and long-term capital maintenance (De Albuquerque & Roaf 2012). An instruction by the Regional Secretary in 2021 stated that the process should start in 2021 (INSEKDA NO 1/2021 2021). The planning should be based on analysis of the availability and the needs so that the imbalance between water demand and supply can be identified, and solutions to close that gap can be conducted. Water balance across various space and time scales is needed to facilitate water management planning and ultimately ensure human and environmental health (Vörösmarty *et al.* 2000). This need is critical in a region with rapid population growth and where the sustainability of water supply is uncertain (Loucks & Van Beek 2017).

Soentoro (2011) analyzed the raw water problem in Jakarta using DPSIR (Driver, Pressure, Status, Impact, and Response) and concluded that the rapid growth of urban and industrial demand could not be fulfilled due to limited local raw water and inadequate funding to build new regional raw water infrastructure. This leads to finding the most accessible solution: to use groundwater, including issuing permits from the government to use groundwater. However, after several decades, the policy has depleted the aquifer, and to overcome the problem, an integrated approach should be applied. Still, its success depends on the political will of the government.

The complexity of the problem Jakarta currently faced, i.e., underinvestment, limited involvement of government, especially in terms of technical performance, resource management and despite Indonesia having a regulation on how to develop strategic planning or a master plan, showed a lack of system approach in the

Downloaded from http://iwaponline.com/h2open/article-pdf/5/2/221/1046139/h2oj0050221.pdf
by guest

city water delivery system. Research by WaterAid in four countries showed a similar result to Jakarta. When monitoring was a weak area, it accentuated deficiencies in planning and financing, weak coordination, unclear institutional arrangements, insufficient resource allocation, and lack of prioritization of resources (WaterAid 2020). Given the characteristics of the water and sanitation system that are multiple connections, dependencies and relations among different actors and factors and the interconnected nature of financial, institutional, environmental, technological, and social aspects that influence sustained service delivery (Valcourt *et al.* 2020), a system approach is proposed to facilitate better service delivery for Jakarta.

System strengthening can be used to understand the complex and interrelated social, political, environmental, institutional, and technical factors like Jakarta. System strengthening is increasingly being adopted by water and sanitation practitioners (Neely 2019). This study aims to focus on some elements as part of a robust water service delivery system by answering two research questions: (1) what the current status/pattern of water supply and demand in Jakarta is, and (2) what and how different aspects/elements influence Jakarta's current supply and demand status/pattern. We use an equation developed based on previous studies to estimate the demand and supply. The estimation covers local and imported water. To analyze interconnected aspects influencing the water supply and demand status/pattern, we utilized the DPSIR framework. The results were applied to develop suggestions for water planning in Jakarta.

METHODS

The data were collected from the desktop study (statistics and archives), interviews with 10 key resource persons, and two focus group discussions in 2019 and early 2020; all respondents and participants of the discussion are working with Jakarta water-related agencies. Prior to the interview, a set of general questions relating to sources of water for Jakarta and its volume, how water comes to the city, institutional arrangement, master plan for the city water provision, and the problem with the city water system provision were prepared. The interviews were recorded, and a step-by-step thematic analysis was then performed based on DPSIR classifications. Thematic analysis is a method for identifying, analyzing, organizing, describing, and reporting themes found within a data set (Braun & Clarke 2008).

To estimate the demand and supply in Jakarta, approaches by Ahmadi (2019), Sharvelle *et al.* (2017), and Li *et al.* (2019) were used to develop an equation that fits with the availability of data in Jakarta. Ahmadi (2019) calculated cities' utility net water demand by quantifying the urban population and average water per capita demand and gross water demand by dividing the net water by 100 and subtracting with the physical water loss percentage. The supply is quantified by identifying the nature of water supply sources (i.e., groundwater and surface water), and the percentage of water from these resources for each city was calculated. Sharvelle *et al.* (2017) estimated detailed household water use both indoor and outdoor. The indoor residential water use is estimated using demand profiles that relate the household size to average daily indoor water use and household units. Li *et al.* (2019) define domestic water demand as the total population multiplied with domestic water consumption per capita and surface water supply as the sum of groundwater supply, wastewater reuse, and rainwater utilization. Due to the limited data available, we explained the equation for Jakarta as follows:

$$\begin{aligned} &\text{Domestic demand} + \text{Commercial demand} + \text{Agriculture demand} \\ &\quad = \text{Local groundwater} + \text{Local surface water} + \text{Import surface water} \end{aligned} \tag{1}$$

In this equation, demand consists of domestic demand, equivalent to the total amount of water consumption based on per capita average water use: commercial demand or the total amount of non-domestic water use; and agricultural use. Supply is obtained from local groundwater (the total amount of underground water, the shallow and deep groundwater use), local surface water indicating the total amount of water used from rivers in Jakarta, Import surface water shows the total amount of water diverted from outside Jakarta and the desalination water through a Sea Water Reverse Osmosis (SWRO) process.

We estimated demand and supply for five consecutive years from 2016 to 2020; each represents the primary input and output of water volume relative to one-year data. Total input from piped water is billed meter or water consumed by the customer and does not count the non-revenue water (NRW). The calculation is equivalent to the estimate for groundwater use. Domestic water demand is calculated by multiplying the number of populations with 175 liters/person/day for residents and 120 liters/person/day for commuters. The estimation for commercial demand is based on PAM Jaya's 21 years of historical data on average domestic and commercial

Downloaded from http://iwaponline.com/h2open/article-pdf/5/2/221/1046139/h2oj0050221.pdf
by guest

consumption. Water for agriculture is calculated based on wetland use data from the Ministry of Agriculture (Kementrian Pertanian 2020) and multiple with average water need for cultivating land (Juliardi & Ruskandar 2006). The bulk water supply for piped water is taken from PAM Jaya's data. The groundwater supply is the total water needs deducted from the total supply for piped water consumption.

The DPSIR framework is used to understand the cause and effect relations contributing to the current supply and demand pattern. DPSIR is a simple qualitative causal framework for understanding and describing people's interactions with the environment, the impact of human activities on the environment and vice versa (Pahl-Wostl 2015; Kapetas *et al.* 2019). The DPSIR framework helps describe the relationship between environmental problems' origins and consequences and understand their dynamics (Kristensen 2004). The framework has been used frequently in water issues and demonstrated to better understand the interaction between water and people. DPSIR provides a practical analytical framework to support problem scoping and structuring. DPSIR also provides the starting point for hypothesizing the relationship among the system components, bridges the gaps between ecological, social science, and economic disciplines, and represents relationships between humans and the environment (Zare *et al.* 2019; Zhao *et al.* 2021). However, DPSIR also has some criticisms, including how the indicators are static and cannot consider the dynamics of the system under discussion and cannot offer a clear cause–effect association of a complex system (Song & Frostell 2012).

Drivers are societal, economic, and population forces that cause pressure on the system; *Pressures* are direct stresses that affect the system states; *States* denote the system's condition; *Impact* reflects observable changes in system conditions; and *Responses* are the institutional responses to change the system (Sun *et al.* 2016; Zare *et al.* 2019). It must be applied to a system with boundaries, inputs, and outputs (Akmalah 2010).

Studies have employed DPSIR to analyze Jakarta's water, but none use it to analyze the supply and demand. Lubis (2018) examines the issues and problems of urban hydrogeology in Jakarta and makes suggestions on improving the groundwater management strategy. Jensen & Khalis (2020) used PSIR (Pressures, State, Impact, and Responses) to develop indicators for urban water security, Akmalah (2010) evaluated the flood issues in Jakarta and described the causes and relationships related to the flood, and Soentoro (2011) evaluated the cause–effect for the raw water problem.

We use the DPSIR framework to understand the contextual understanding of cause and effect association, identifying the key pressure that 'if address' would offer the highest benefit and recognize the gaps in control management or responses. Elements of DPSIR were acquired from interviews and focus group discussions and put under categorization based on category definition (Sun *et al.* 2016; Zare *et al.* 2019) and the ways in which they are interlinked. We identified an initial set of 42 DPSIR, and later focused on 18 statements. We put aspects related to the social, demographic, and economic developments in societies under the *Drivers* categorization; activities affecting the socio-ecological system are classified as *Pressures*; state of water service provision and state of water resources as *States*; cascading social, environmental, or economic changes as *Impact*; and institutional policies and programs to reduce and control the problem as *Responses*, all are validated by literature reviews and our demand and supply analysis.

RESULTS AND DISCUSSION

Supply and demand analysis

Jakarta relied on multiple sources (supply): groundwater, surface water (local and imported), and seawater (Pradafitri *et al.* 2018; Pratiwi & Herdiansyah 2018; Jensen & Khalis 2020). We used the data from Jakarta water utility as a baseline to calculate the supply for five consecutive years (BPS-Statistic of DKI Jakarta Province 2017, 2018, 2019, 2020, 2021). This study categorizes supply into three groups: surface water consisting of both local and imported water, groundwater, and seawater. Water use (demand) consists of domestic, commercial, and agricultural water. To estimate the domestic water use, we multiplied the population by the standard of daily water use of 175 liters per day and 120 liters per day for commuters. We used water utility historical data to calculate the commercial demand.

Yearly total water demand from 2016 to 2020 did not change significantly; the demand is around 1.2 billion cubic meters per year (Table 1). The increase in demand from year to year occurred with a relatively small volume. Average domestic demand leads the number with 61.5%, followed by commercial demand of 35.5%. Domestic demand is between 61 and 62% of total demand, with a volume of 748 million cubic meters in 2016 and 769 million cubic meters in 2020. Commercial water need is around 440 billion cubic meters or 35–36%

Downloaded from http://iwaponline.com/h2open/article-pdf/5/2/221/1046139/h2oj0050221.pdf
by guest

Table 1 | Jakarta water supply and demand 2016–2020 (m^3)

	2016	2017	2018	2019	2020
Demand (m^3)					
Residents	656.226.548	668.356.260	668.358.112	674.116.169	674.389.319
Commuters	92.498.652	94.208.400	94.208.661	95.020.290	95.058.792
Domestic – D	748.725.200	762.564.660	762.566.773	769.136.459	769.448.111
Commercial – C	434.260.616	442.287.503	442.288.728	446.099.146	446.279.904
Agriculture – A	37.918.686	29.782.441	26.111.670	23.576.189	35.345.362
Total Demand D+C+A	**1.220.904.502**	**1.234.634.604**	**1.230.967.171**	**1.238.811.793**	**1.251.073.377**
Supply (m^3)					
Piped/surface water – P	341.601.198	352.007.000	362.371.000	372.189.000	342.401.394
Groundwater – G	879.303.304	882.548.764	868.517.331	866.086.680	908.135.870
SWRS – S	–	78.840	78.840	536.113	536.113
Total Supply P+G+S	**1.220.904.502**	**1.234.634.604**	**1.230.967.171**	**1.238.811.793**	**1.251.073.377**

of total yearly demand. Most of the supply is provided by groundwater, as much as 70–72.6%, while piped water using surface water sources contributed 28% in 2016, 28.51% in 2017, 29.43% in 2018, 30.04% in 2019, and 27.37% in 2020. SWRO, although small (less than 1%), started to contribute to supply in 2017 (Figure 2). The percentage of piped water supply is comparable with data from The Water Supply Development Supporting Agency which said that the piped water service coverage in Jakarta was 28.05% in 2018 (BPPSPAM 2019).

We also examined further the origin of the water to explain the composition between local water and water obtained from other areas. Data from PAM Jaya, the public water company, showed that they bought bulk water from Jatiluhur Dam in Purwakarta, West Java, and treated water from PDAM Tangerang in West Java daily. The bought surface water, i.e., imported water, accounted for around 96% of the whole piped water system. Dependence on other regions for most of the piped water supply showed that Jakarta's water security is weak and gradually reduced. Every day around 17.300 litres/second of bulk water is directly transferred daily from Jatiluhur Dam, transported using a 72 km open channel, and treated water from PDAM Kerta

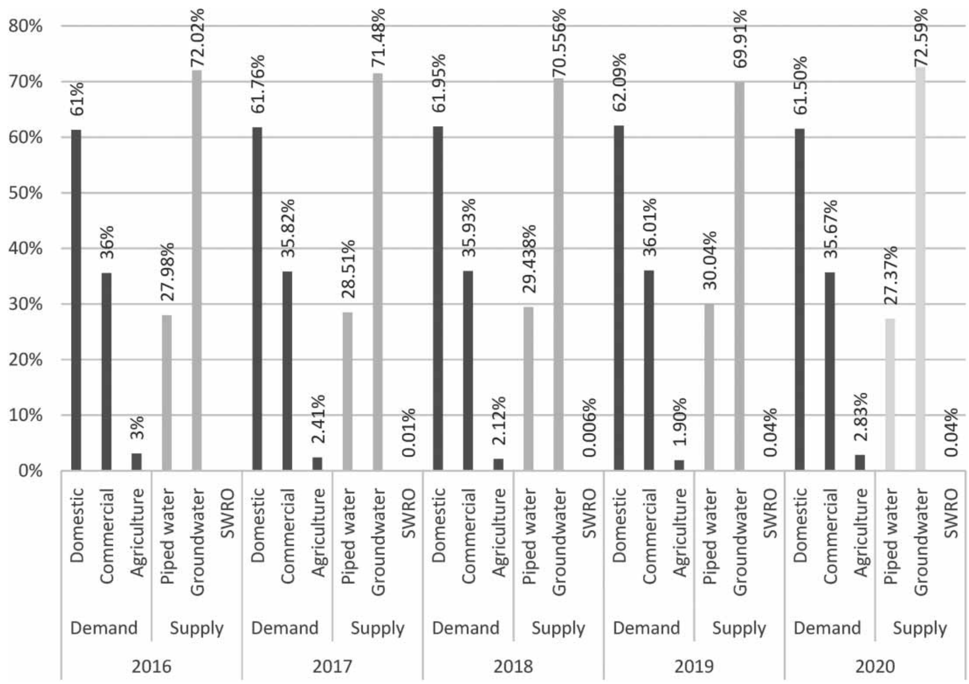

Figure 2 | Jakarta water supply and demand 2016–2020 (%).

Downloaded from http://iwaponline.com/h2open/article-pdf/5/2/221/1046139/h2oj0050221.pdf
by guest

Rajasa in Tangerang Regency using a 30-km pipeline. Only 4% of the water from Jakarta's rivers is utilized for piped water (PAMJAYA 2020). Compared with the total water supply for the whole city, the imported water is approximately 28%. However, this imported water is responsible for 96% supply for all piped water systems (Figure 3).

All imported water is treated through a complex infrastructure system consisting of seven water installation plants with varied capacities from 150 litres/second in Taman Kota to 4.000 litres/second in Pulo Gadung, some Distribution Central Reservoir (DCR), and many other smaller processing facilities. The entire system is divided into two subsystems: the east and west system; each is managed by different private operators under public water company supervision (PAMJAYA 2020). The imported water is essential to the piped water system in Jakarta, while groundwater is essential for self-supply practice by households and commercials. The high percentage dependency on groundwater is aligned with other countries, whereas nearly 85% of the Indian population uses groundwater, as well as sub-Saharian countries where groundwater is the primary drinking water source for between 70 and 90% of domestic water users (Grönwall & Danert 2020).

Groundwater comes from the Jakarta groundwater basin, an area of 1,439 km^2 that covers the entire DKI Jakarta Province, as well as some parts of the Banten and West Java province (Pemprov DKI 2021). People can use groundwater for daily needs without restriction, while its use for commercial purposes or large amounts is requires a permit and is subjected to a groundwater tax. While regulation has set gradually stricter requirements for permits and higher tariffs, a study reported that there are figures of 4,000 illegal deep wells in Jakarta, in addition to the registered users who are also under-reporting their actual consumption (Agustinus 2016).

Following (Samsuhadi 2009) calculation of groundwater potential capacity of 1,170–4,600 m^3/year for shallow groundwater, 62–230 m^3/year for deep groundwater, and the suggestion that when the utilization rate of water resources exceed 60%, the ecological environment will deteriorate (An *et al.* 2021), we understand that groundwater utilization in Jakarta is already at an alarming rate which is 76% of its potential capacity.

DPSIR analysis

This study identifies that increased demand for domestic and commercial activities, and population growth are the main *Drivers* that give escalation to *Pressure* (water pollution, inadequate/low investment in infrastructure, and privatization). The *Pressures* then resulted in a *State*, i.e., limited access to piped water and groundwater over abstraction. *The Impact* is water insecurity, falling groundwater table, land subsidence, water-related disease, and low productivity. *Responses* are demand management measures, desalination, supply from other places (trans-basin water transfer), wastewater treatment, law enforcement, and capacity building of institutions working on the water-related issue (Figure 4).

Regarding the *Drivers*, we argue that the increased demand for commercial needs is more significant than the population growth. The population in 2000 was 8.3 and 11 million in 2019, which increased approximately less than twice the population size in 2000. While the regional income tax received by the province rose 19 times. In 2000, the regional income of DKI Jakarta Province was IDR 2.1 trillion and rose to IDR 40.2 trillion in 2019 (BPS-Statistic of DKI Jakarta Province 2001, 2020). Regional income is a tax obtained from various economic activities, including motor vehicles, hotels, restaurants, billboards, parking, entertainment, and buildings.

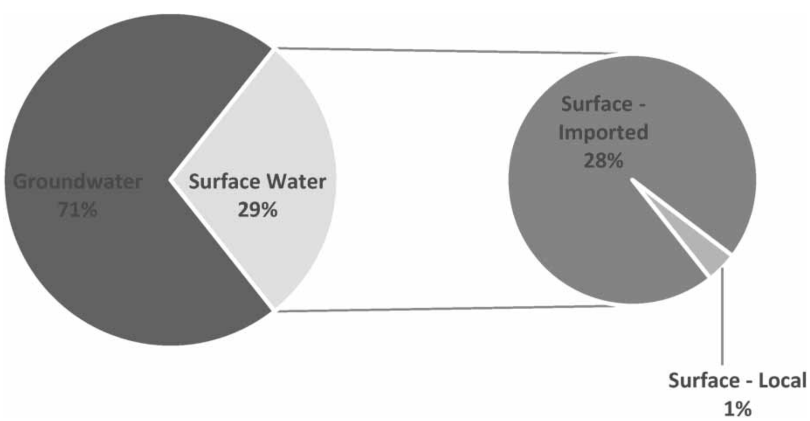

Figure 3 | Jakarta water sources (Local and Imported).

Downloaded from http://iwaponline.com/h2open/article-pdf/5/2/221/1046139/h2oj0050221.pdf
by guest

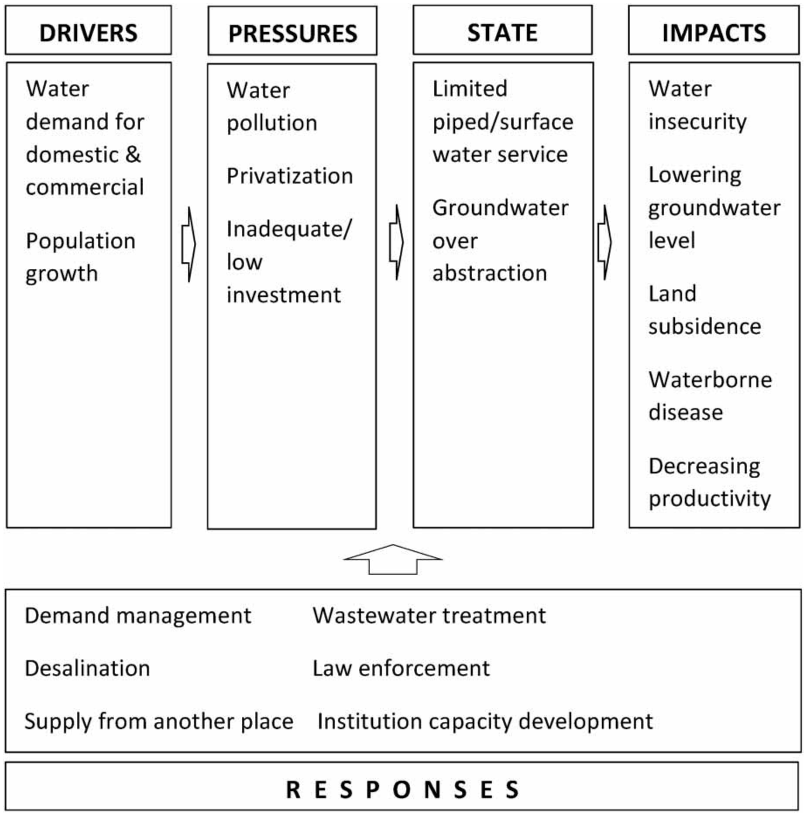

Figure 4 | DPSIR for Jakarta water supply and demand.

Data from the consecutive 10 years showed the same phenomenon. The three years with the most considerable rise were 2010, 2012, and 2019. The total regional tax increase in 2010 was 41.6%, 2012 was 31.9%, and 2019 with an increase of 24.5%, while the increases of population in those years were 1.16%, 1.09%, and 0.04% (Figure 5). The average rise of regional tax for 10 years is 17%, and the average population growth is 1%. The fact that the growth of the commercial demand is big showed two opportunities: (1) cross-subsidy tariff from commercial consumer to low-income families is available and (2) if the commercial consumers use water-saving technologies, the amount of water that can be saved is significant.

Unfortunately, the increasing water demand that goes hand in hand with the increasing economic activities is not supported with the piped water supply capacity. The Jakarta water treatment production capacity, volume

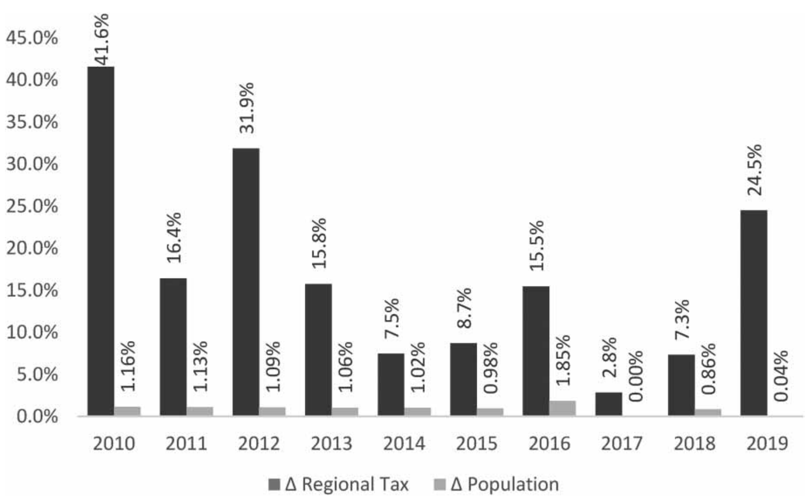

Figure 5 | Comparison between population growth and regional tax 2010–2019.

Downloaded from http://iwaponline.com/h2open/article-pdf/5/2/221/1046139/h2oj0050221.pdf
by guest

sold, and the number of piped water customers in Jakarta only increased by less than double its quantity from 2000 to 2019, whereas the business activities rose 19 times. The production capacity in 2000 was 465 million m^3 and increased 34% by 2019 into 622 million m^3. The volume sold in 2000 is 228 million m^3 and increased 59% to 362 million m^3 in 2019 (BPS-Statistic of DKI Jakarta Province 2020). Nasution (2016) showed that investment in the system decreased from USD 160 million in 1997 to around USD 30 million in 1998 when privatization started. Since then, the investment has continued to be in the same range and has even fallen in recent years.

This situation produced the *Status* of limited pipe water services and gave no alternative except to resort to groundwater as the business sector typically requires a significant amount of water (Neise 2019). This aligns with the supply and demand calculation above that showed groundwater supplied around 70% of Jakarta's total water needs. Since access to groundwater is quite easy with relatively low installation cost, especially for illegal wells, it has caused severe problems for Jakarta (Irawan *et al.* 2015); the excessive groundwater abstraction and imbalance in replenishment have led to a decrease in the groundwater level and indirectly led to land subsidence at an alarming rate, i.e., up to 20 cm per year in some locations in Jakarta (Delinom *et al.* 2015). Massive land conversion also adds more pressure as recharging water into the ground becomes more difficult.

All these *Pressures* have turned Jakarta into experiencing *Impacts* such as water insecurity (Danielaini *et al.* 2019), lower groundwater levels (Soentoro 2011), land subsidence (Deltares 2016), waterborne disease (Mungkasa 2017), and low productivity (Argo 1999). Different *Responses* to the corresponding *Drivers*, *Pressures*, and *Impact* are in place, but some of the *Responses* given by the government have not been adequate to solve the urgent water problem in Jakarta. Some *Responses*, such as fragmented management and frequent change of responsibilities within water-related agencies to some extent obfuscate Jakarta's efforts to solve its water problems.

A previous study indicated that the institutional aspects is one of the most critical aspects to sustain water services in Indonesia (Octavianti & Charles 2018; Daniel *et al.* 2021). Jensen & Khalis (2020) stated that, currently, governance of the water sector in Jakarta is complex and highly fragmented: water supply, water resources management, groundwater, wastewater, and flood management are all under the responsibility of different government agencies. Moreover, the institutional responsibility changes frequently as articulated by a focus group discussion's participant: 'Last year the management of groundwater was under the agency where I worked, recently it transferred to another agency. I was starting to understand how it works; now I have to learn new things again'.

Indonesia has decentralized the water supply provision to the local government. The fragmentation can also be seen from the weak law enforcement which leads to high rates of groundwater and piped water theft, the frequent changes of name, structure, and scope of work of these institutions. Another thing that reflects the suboptimal performance of water management institutions is the low number of piped water and wastewater coverage. An improvement has been identified though, as starting from 2020, the management of groundwater, surface, desalination, and flooding are under one agency i.e., Dinas Sumber Daya Air (Water Resource Agency).

A significant measure for the future of Jakarta is strategic planning or a master plan. The government aims to have the master plan as soon as possible, 'Other cities have developed the master plan and the government has made guidelines on the thing that must be included in the master plan. We will include the budget to develop a master plan in the next year's budget', as said by a senior government official in an interview.

Strategic planning is important to make fundamental changes. Planning includes analyzing the future as a different reality from the *status quo* by acknowledging that human beings and changes are inevitable; thus, fundamental changes are likely to happen. Planning aims to make a difference by preparing for, contributing to, and facilitating change (Hagen & Higdem 2020). Strategic planning can also be understood as a valuable tool to direct the city's overall development to address challenges and benefit from opportunities (Thi Bich Ngoc 2011). Urban water strategic planning should comprise a wastewater strategy, clean water planning, recycling strategies, and prioritizing local water supply (Najar & Persson 2019).

Key points for water planning in Jakarta

Traditionally, strategic planning has gained insignificant attention in the infrastructure sectors as competition in infrastructure is low or non-existent and captive customers or the public can accept the investment risks. On the other hand, there has been insufficient concern in the literature on how to improve the performance of public organizations. However, the urgency and interest in the need for adequate strategic planning have been growing

Downloaded from http://iwaponline.com/h2open/article-pdf/5/2/221/1046139/h2oj0050221.pdf
by guest

in the field of infrastructure-based services, and several planning methods to inform strategy making have recently earned attention (Dominguez *et al.* 2009).

Sanitation and Water for All identified five building blocks needed for the well-functioning water and sanitation sector, i.e., (1) sector policy strategy, (2) institutional arrangement, (3) financing, (4) planning, monitoring, and review, and (5) capacity development (Sanitation & Water for All 2021). Strategic planning is associated with two building blocks: the sector policy strategy and planning, monitoring, and review. For planning, it is important to understand the resource situation, and demand and supply analysis is one solid foundation for it as the evaluation can provide information about who, when, from where and for what purposes the water in a specific area is utilized.

The above demand and supply calculations and the DPSIR analysis showed that due to limited piped water access, Jakarta's groundwater basin supplies most of the total water needs at the level that puts Jakarta at risk of experiencing critical land subsidence. Therefore, a program to reduce reliance on untreated groundwater use and control groundwater over-abstraction by developing new infrastructure and increasing raw water supply to increase household access to piped water is important.

For groundwater management in Jakarta, this study has three recommendations. First, Jakarta must prioritize the management of the groundwater basin by improving its quality, especially because many residents use the contaminated groundwater and are potentially exposed to contaminants, such as harmful chemicals and microorganisms daily (Luo *et al.* 2019) and programs to improve access to wastewater services need to be seriously developed and executed (PALJAYA 2017). Communities need to understand the benefits of processing wastewater and not dumping it directly into the water bodies. Jakarta already has Governor Decree No. 45/1992, which stipulates that every building in an area with a sewage pipe installed must dispose of its wastewater into the pipe through a parcel connection pipe. The provision of a piping system/wastewater management facility can reduce contamination of groundwater and surface water. Wastewater from grey and blackwater will flow through a piping system and be treated to meet the quality standards for disposal to the receiving water body, i.e., river. Some water can go further through a process to improve its quality in order to meet the standard for bulk piped water supply.

Second, increasing supply from surface water by decentralizing the supply system and utilizing water from the river that meets the health and environmental standard. Mini-plants can be built near the selected river to process and supply water to a specific area (Mungkasa 2017). Developing a smaller structure under the management of the current system does not need huge investment, so it is an urgent priority to help the residents that indeed need clean water. The benefits are more significant than the costs (Tsegaye *et al.* 2020).

Also, rainwater reservoirs made from light material complete with small water treatment can be built to provide services in certain areas. Light materials are needed to reduce soil loads and do not increase the pressure on land subsidence. Increasing the capacity of water treatment facilities should be developed through both decentralized and centralized systems while reducing the high NRW of the piped water system. It should be applied as it will help increase the supply significantly. The Jakarta non-revenue for water in 2020 is 45.7% or around 280 million m^3 (PAMJAYA 2021). This is above the average of NRW in Indonesia, i.e., 37% (El-Ahmady & Sembiring 2014). If the leakage can be reduced to half of the current figure, there will be approximately 140 million m^3 of water for daily consumption. However, it is important to calculate the economic level of water losses to make sure that the strategies to reduce the NRW are cost-efficient (Heryanto *et al.* 2021).

Third, measures to control the groundwater use by big industries especially those located in industrial parks are important as a large amount of deep groundwater withdrawal can lead to shallow groundwater decrease due to the lowering water table. This situation has implications for the equity of access as shallow groundwater is used for people's daily consumption. Incentives in the form of tax reduction can be given to the companies willing to report their illegal wells and change to water-saving equipment or technology (Amundsen *et al.* 2014; Montginoul *et al.* 2016). At the same time, disincentive, i.e., additional charges can be applied to the companies using groundwater in areas with piped water connections.

Other management measures targeted to surface water are needed through encouraging consumer demand for water-saving technologies at commercial, government buildings, and at household levels as well as system maintenance and renovation. A study in four European cities found that investments in renovation and maintenance of networks are the most important measures to conserve water, followed by regulations, individual meters, and public campaigns promoting the use of water-saving technologies and water conservation practices (Biswas & Tortajada 2019). All measures need to be combined with an affordable tariff scheme for every stratum of society

Downloaded from http://iwaponline.com/h2open/article-pdf/5/2/221/1046139/h2oj0050221.pdf
by guest

which also should be strengthened by implementing a policy that provides basic free water for daily needs (minimum standard of water supply) targeted to the unprivileged. This subsidy policy means that even if a customer is not capable of paying the tariff due to lack of means, they should not be disconnected from a minimum amount of basic water service, which is to ensure the right to water of all people is protected. Disconnections due to non-payment are only acceptable if it can be shown that the beneficiaries do not pay the water fee when they are able to pay.

In early 2023, the clean water supply and service improvement for the western and eastern part of Jakarta between PAM Jaya and PT Palyja and PT Aetra covering all Jakarta areas except Seribu Island will end; strategic planning following the new setting should be developed soon. The new institutional setting, capacity building, and new governance framework are required to manage a system that can provide safe and affordable water for all residents. The water resource understanding provided by this study can be used as a foundation for planning the strengthening of the Jakarta water system to achieve equitable access for all.

Study limitation

We used a simple approach to estimate the water balance. Further research is needed including research that covers climatological data and water needs for the environment to better estimate the water balance. Furthermore, the results concluded from this study are in the early stages yet are important to assist the planning process for clean water supply in the capital city.

CONCLUSION

Jakarta is experiencing rapid economic and social growth with limited water resources and infrastructure. Moreover, there is no comprehensive data on the water demand and supply in Jakarta which is challenging for proper water planning. This study estimated that the yearly total water demand for Jakarta in 2016–2020 was around 1.2 billion m^3. Furthermore, Jakarta's local water resources account for about 73% of the final water demand, and neighboring provinces support the remaining 27%. However, this imported water is responsible for more than 90% of raw water for the piped water system, indicating that the sustainability of water services in Jakarta depends on the areas tens of kilometers away from the city. The dependence on groundwater is already at 76% of its potential capacity, causing land subsidence at a hazardous level, decreasing the groundwater table and risking Jakarta's water supply. The DPSIR framework reveals that the water scarcity problem results in other problems, such as uneven water access and waterborne disease. There are some responses from the government of Jakarta, but the implementations are still not sufficient to eliminate water problems. This study also underlines some factors related to institutional aspects that should be improved in Jakarta. Finally, we also provided some recommendations to improve water management in Jakarta.

DATA AVAILABILITY STATEMENT

Data cannot be made publicly available; readers should contact the corresponding author for details.

REFERENCES

Abidin, H. Z., Andreas, H., Gumilar, I., Fukuda, Y., Pohan, Y. E. & Deguchi, T. 2011 Land subsidence of Jakarta (Indonesia) and its relation with urban development. *Natural Hazards* **59** (3), 1753–1771. https://doi.org/10.1007/s11069-011-9866-9.

Agustinus, R. B. 2016 *Understanding the Implementation of Groundwater Regulations and Policies for the Commercial Deep Well Users in Jakarta, Indonesia*. UNESCO-IHE Institute for Water Education, Delft.

Ahmadi, M. S. 2019 *Assessment of Water Demand Changes in Several Rapidly Growing Global Cities*. IHE Delft Institute for Water Education, Delft, the Netherlands.

Akmalah, E. 2010 Integrated flood management model: a socio-technical systems approach to overcome institutional problems in Jakarta. In *Itinerario*, Vol. 5. Colorado State University. https://doi.org/10.1017/S0165115300023299.

Amundsen, E. S., Jensen, F. & Hansen, L. G. 2014 Regulating groundwater use in developing countries: a feasible instrument for public intervention. *Journal of Institutional and Theoretical Economics* **170** (2), 317. https://doi.org/10.1628/093245614X13867465880983.

An, M., Fan, L., Huang, J., Yang, W., Wu, H., Wang, X. & Khanal, R. 2021 The gap of water supply-demand and its driving factors: from water footprint view in Huaihe River Basin. *PLoS ONE* **16**, 1–16. https://doi.org/10.1371/journal.pone.0247604.

Apip, Sagala, S. A. & Pingping, L. 2015 Overview of Jakarta water-related environmental challenges. Water and Urban Initiative Working Paper Series 4, pp. 1–5.

Argo, T. A. 1999 Thirsty Downstream: *The* Provision of Clean Water in Jakarta, Indonesia. University of British Columbia.

Downloaded from http://iwaponline.com/h2open/article-pdf/5/2/221/1046139/h2oj0050221.pdf
by guest

BBC 2019 Jakarta, the fastest-sinking city in the world. *BBC News*. Available from: https://www.bbc.com/news/world-asia-44636934

Biswas, A. K. & Tortajada, C. 2019 Water crisis and water wars: myths and realities. *International Journal of Water Resources Development* **35** (5), 727–731. https://doi.org/10.1080/07900627.2019.1636502.

BPPSPAM 2019 *Buku Kinerja PDAM 2019 Wilayah II*, Vol. 1. BPPSPAM, Jakarta.

BPS-Statistic of DKI Jakarta Province 2001 *Jakarta Dalam Angka 2001*.

BPS-Statistic of DKI Jakarta Province 2017 *Jakarta Dalam Angka 2017*.

BPS-Statistic of DKI Jakarta Province 2018 *Jakarta Dalam Angka 2018*.

BPS-Statistic of DKI Jakarta Province 2019 *Provinsi DKI Jakarta Dalam Angka 2019*.

BPS-Statistic of DKI Jakarta Province 2020 *Provinsi DKI Jakarta Dalam Angka 2020*.

BPS-Statistic of DKI Jakarta Province 2021 *Provinsi DKI Jakarta Dalam Angka 2021*.

Braun, V. & Clarke, V. 2008 Using thematic analysis in psychology, qualitative research in psychology. *Journal of Chemical Information and Modeling* **3** (2), 77–101. http://dx.doi.org/10.1191/1478088706qp063oa.

Daniel, D., Djohan, D. & Nastiti, A. 2021 Interaction of factors influencing the sustainability of water, sanitation, and hygiene (WASH) services in rural Indonesia: evidence from small surveys of wash-related stakeholders in Indonesia. *Water (Switzerland)* **13** (3), 1–11. https://doi.org/10.3390/w13030314.

Danielaini, T. T., Maheshwari, B. & Hagare, D. 2019 An assessment of household water insecurity in a rapidly developing coastal metropolitan region of Indonesia. *Sustainable Cities and Society* **46**, 101382. https://doi.org/10.1016/j.scs.2018.12.010.

De Albuquerque, C. & Roaf, V. 2012 *On the Right Track. Good Practices in Realising the Rights to Water and Sanitation*. Available from: http://www.ohchr.org/Documents/Issues/Water/BookonGoodPractices_en.pdf

Delinom, R. M., Lubis, R. F., Bakti, H. & Imron, M. 2015 In: *Ancaman Bawah Permukaan Jakarta* (Delinom, R. M. ed.). LIPI Press, Jakarta.

Deltares. 2016 *Sinking Jakarta Causes & Remedies (2016)*.

Dinas Lingkungan Hidup Jakarta. 2018 *Air Tanah di Jakarta Sudah Tercemar Detergen Dan E. coli*. Available from: http://www.pdamtirtabenteng.co.id/berita/air-tanah-di-jakarta-sudah-tercemar-detergen-dan-ecoli

Dinas Lingkungan Hidup Jakarta. 2021 Laporan Akhir Pemantauan Kualitas Lingkungan Air Tanah Dki Jakarta Tahun Anggaran 2020. In *Dinas Lingkungan Hidup* (Issue 6).

Dominguez, D., Worch, H., Markard, J. & Guier, W. 2009 Closing the capability gap: strategic planning for the infrastructure sector. *California Management Review University of California Berkeley* **51** (2).

Dsikowitzky, L., Hagemann, L., Dwiyitno, Ariyani, F., Irianto, H. E. & Schwarzbauer, J. 2017 Complex organic pollutant mixtures originating from industrial and municipal emissions in surface waters of the megacity Jakarta – an example of a water pollution problem in emerging economies. *Environmental Science and Pollution Research* **24** (35), 27539–27552. https://doi.org/10.1007/s11356-017-0164-2.

El-Ahmady, I. I. & Sembiring, E. 2014 Pemilihan program pengendalian kehilangan air peningkatan pendapatan PDAM. *Jurnal Teknik Lingkungan* **20**, 142–151.

Grönwall, J. & Danert, K. 2020 Regarding groundwater and drinking water access through a human rights lens: self-supply as a norm. *Water* **12** (2), 419. https://doi.org/10.3390/w12020419.

Hagen, A. & Higdem, U. 2020 *Innovation in Public Planning Calculate Communicate and Innovate*. Palgrave Macmillan, London.

Heryanto, T., Sharma, S. K., Daniel, D. & Kennedy, M. 2021 Estimating the economic level of water losses (ELWL) in the water distribution system of the city of Malang, Indonesia. *Sustainability (Switzerland)* **13** (12). https://doi.org/10.3390/su13126604.

INSEKDA NO 1/2021 2021

Irawan, D. E., Silaen, H., Sumintadireja, P., Lubis, R. F., Brahmantyo, B. & Puradimaja, D. J. 2015 Groundwater–surface water interactions of Ciliwung River streams, segment Bogor–Jakarta, Indonesia. *Environmental Earth Sciences* **73** (3), 1295–1302. https://doi.org/10.1007/s12665-014-3482-4.

Jensen, O. & Khalis, A. 2020 Urban water systems: development of microlevel indicators to support integrated policy. *PLoS ONE* **15** (2). https://doi.org/10.1371/journal.pone.0228295.

Juliardi, I. & Ruskandar, A. 2006 *Teknik Mengairi Padi: Kalau Macak-Macak Cukup, Mengapa Harus Digenang*, p. 3213024. Available from: http://www.Pustaka-Deptan.Go.Id/Publikasi/.Pdf [18 Juni 2015].

Kapetas, L., Kazakis, N., Voudouris, K. & McNicholl, D. 2019 Water allocation and governance in multi-stakeholder environments: insight from Axios Delta, Greece. *Science of The Total Environment* **695**, 133831. https://doi.org/10.1016/j.scitotenv.2019.133831.

Kementrian Pertanian 2020 Pusat Data dan Sistem Informasi Pertanian. Sekretariat Jenderal-Kementerian Pertanian. Center for Agriculture Data and Information System. Secretariat General-Ministry of Agriculture, pp. 1–203.

Kooy, M. 2014 Developing informality: the production of Jakarta's urban waterscape. *Water Alternatives* **7** (1), 35–53.

Kooy, M. & Walter, C. T. 2019 Towards a situated urban political ecology analysis of packaged drinking water supply. *Water (Switzerland)* **11** (2). https://doi.org/10.3390/w11020225.

KPPIP. 2019 *Pengolahan Air Limbah Jakarta*. KPPIP. Available from: https://kppip.go.id/proyek-prioritas/air-dan-sanitasi/pengolahan-air-limbah-jakarta/

Downloaded from http://iwaponline.com/h2open/article-pdf/5/2/221/1046139/h2oj0050221.pdf
by guest

Kristensen, P. 2004 *The DPSIR Framework. A Comprehensive/Detailed Assessment of the Vulnerability of Water Resources to Environmental Change in Africa Using River Basin Approach*, pp. 1–10. Available from: http://enviro.lclark.edu:8002/rid=1145949501662_742777852_522/DPSIROverview.pdf

Li, T., Yang, S. & Tan, M. 2019 Simulation and optimization of water supply and demand balance in Shenzhen: a system dynamics approach. *Journal of Cleaner Production*. https://doi.org/10.1016/j.jclepro.2018.10.052.

Loucks, D. P. & Van Beek, E. 2017 *Water Resource Systems Planning and Management: An Introduction to Methods, Models, and Applications*. Springer International Publishing. https://doi.org/10.1007/978-3-319-44234-1.

Lubis, R. F. 2018 Urban hydrogeology in Indonesia: a highlight from Jakarta. *IOP Conference Series: Earth and Environmental Science* **118** (1). https://doi.org/10.1088/1755-1315/118/1/012022.

Luo, P., Kang, S., Apip, Zhou, M., Lyu, J., Aisyah, S., Binaya, M., Regmi, R. K. & Nover, D. 2019 Water quality trend assessment in Jakarta: a rapidly growing Asian megacity. *PLoS ONE* **14** (7). https://doi.org/10.1371/journal.pone.0219009.

Montginoul, M., Rinaudo, J. D., Brozović, N. & Donoso, G. 2016 Controlling groundwater exploitation through economic instruments: current practices, challenges and innovative approaches. In: *Integrated Groundwater Management: Concepts, Approaches and Challenges*. Springer International Publishing, pp. 551–581. https://doi.org/10.1007/978-3-319-23576-9_22.

Mungkasa, O. M. 2017 *Desain Besar Air Minum dan Limbah DKI Jakarta*. Available from: http://tarulh.com/wp-content/uploads/2018/01/3.-Desain-Besar-Air-Minum-dan-Limbah-Domestik.pdf

Najar, N. & Persson, K. M. 2019 Strategies, processes, and results for the future water supply of the Växjö municipality: evaluation of an evidence-based case study of long-term strategies within the water and wastewater sector in Sweden. *Water (Switzerland)* **11** (10). https://doi.org/10.3390/w11102150.

Nasution, N. 2016 *The Dynamics of Piped Water and Sewer Development in Jakarta, Indonesia (1945–2015): A Case Study Using Multilevel Perspective*. The University of North Carolina, Chapel Hill, NC.

Neely, K. 2019 *Systems Thinking and WASH*. https://doi.org/10.3362/9781780447483.

Neise, T. 2019 *Firms' Adaptation Strategies to Floods and Their Potential Implication on Regional Economic Development-Insights From Jakarta and Semarang, Indonesia. The Effect of Natural Disasters on FDI Attraction – A Sector-Based Analysis Over Time and Space View Project*. University of Cologne. Available from: https://www.researchgate.net/publication/333146677

Octavianti, T. & Charles, K. 2018 The evolution of Jakarta's flood policy over the past 400 years. *Environment and Planning C: Politics and Space* **37** (6), 1–30.

Padawangi, R. & Douglass, M. 2015 Water, water everywhere: toward participatory solutions to chronic urban flooding in Jakarta. *Pacific Affairs* **88** (3), 517–550. https://doi.org/10.5509/2015883517.

Pahl-Wostl, C. 2015 *Water Governance – Concepts, Methods, and Practice*. Available from: http://www.springer.com/series/13400

PALJAYA 2017 *Menuju Layanan Pengolahan Air Limbah Handal dan Terintegrasi di DKI Jakarta [Towards Reliable and Integrated Waste Water Treatment Service in DKI Jakarta].*

PAMJAYA 2020 *Laporan Tahunan PAM JAYA 2019*.

PAMJAYA 2021 *Surat Penyampaian Kajian Subsidi Pelayanan Air Minum DKI Jakarta ke DSDA*. PAM Jaya.

Pemprov, D. K. I. 2021 *Rencana Kerja Pemerintah Daerah 2021*.

Pradafitri, W. S., Moersidik, S. S. & Abdini, C. 2018 East Canal Flood as PDAM water resource DKI Jakarta. In: *E3S Web of Conferences*, p. 74. https://doi.org/10.1051/e3sconf/20187409001.

Pratiwi, D. M. & Herdiansyah, H. 2018 Development of desalination technology using reverse osmosis membrane for the provision of clean water in DKI Jakarta. *AIP Conference Proceedings* **2026**. https://doi.org/10.1063/1.5064987.

Samsuhadi 2009 Pemanfaatan air tanah Jakarta. *JAI* **5** (1), 9–22.

Sanitation and Water for All 2021 *Five Building Blocks*. Available from: https://ebookcentral-proquest-com.aib.idm.oclc.org

Sharvelle, S., Dozier, A., Arabi, M. & Reichel, B. 2017 A geospatially-enabled web tool for urban water demand forecasting and assessment of alternative urban water management strategies. *Environmental Modelling and Software* **97**, 213–228. https://doi.org/10.1016/j.envsoft.2017.08.009.

Soentoro, E. A. 2011 *Integrated Decision-Making for Urban Raw Water Supply in Developing Countries*. Colorado State University, Fort Collins, CO.

Song, X. & Frostell, B. 2012 The DPSIR framework and a pressure-oriented water quality monitoring approach to ecological river restoration. *Water (Switzerland)* **4** (3), 670–682. https://doi.org/10.3390/w4030670.

Sun, S., Wang, Y., Liu, J., Cai, H., Wu, P., Geng, Q. & Xu, L. 2016 Sustainability assessment of regional water resources under the DPSIR framework. *Journal of Hydrology* **532**, 140–148. https://doi.org/10.1016/j.jhydrol.2015.11.028.

The Human Rights to Water and Sanitation 2010 *UN Resolution 64/292*. https://doi.org/10.4324/9781315471532-2.

Thi Bich Ngoc, D. 2011 *Application of City Water Balance Model to Develop Strategies for Urban Water Management in Hanoi, Water Balance, Contaminant Fluxes*. UNESCO-IHE Institute for Water Education.

Tsegaye, S., Missimer, T. M., Kim, J. Y. & Hock, J. 2020 A clustered, decentralized approach to urban water management. *Water (Switzerland)* **12** (1). https://doi.org/10.3390/w12010185.

United Nations 2002 General comment No. 15: The right to water (arts. 11 and 12 of the Covenant) - Twenty-ninth session (2002). *Human Rights Instruments, Vol. I. Compilation of General Comments and General Recommendations Adopted by Human Rights Treaty Bodies – HRI/GEN/1/Rev.9*, 2003(15), 97–113.

Downloaded from http://iwaponline.com/h2open/article-pdf/5/2/221/1046139/h2oj0050221.pdf
by guest

Valcourt, N., Javernick-will, A., Walters, J. & Linden, K. 2020 System approaches to water, sanitation, and hygiene: a systematic literature review. *International Journal of Environmental Research and Public Health* **17** (3). https://doi.org/10.3390/ijerph17030702.

Vörösmarty, C. J., Green, P., Salisbury, J. & Lammers, R. B. 2000 Global water resources: vulnerability from climate change and population growth. *Science* **289** (5477), 284–288. https://doi.org/10.1126/science.289.5477.284.

WaterAid 2020 *System Strengthening for Inclusive, Lasting WASH That Transforms People's Lives*, pp. 1–92. Available from: https://washmatters.wateraid.org/sites/g/files/jkxoof256/files/suswash-global-learning-report.pdf

Zare, F., Elsawah, S., Bagheri, A., Nabavi, E. & Jakeman, A. J. 2019 Improved integrated water resource modelling by combining DPSIR and system dynamics conceptual modelling techniques. *Journal of Environmental Management* **246**, 27–41. https://doi.org/10.1016/j.jenvman.2019.05.033.

Zhao, R., Fang, C., Liu, H. & Liu, X. 2021 Evaluating urban ecosystem resilience using the DPSIR framework and the ENA model: a case study of 35 cities in China. *Sustainable Cities and Society* **72**, 102997. https://doi.org/10.1016/j.scs.2021.102997.

First received 4 February 2021; accepted in revised form 31 March 2022. Available online 12 April 2022

Downloaded from http://iwaponline.com/h2open/article-pdf/5/2/221/1046139/h2oj0050221.pdf
by guest