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Strategies for Accelerating Sustainable Drinking Water Pipeline Utilization

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ABSTRACT

Uncontrolled and excessive use of groundwater leads to economic, social, and environmental impacts. This study investigated factors influencing the low willingness to utilize piped water. The research was conducted in Duren Sawit Village, East Jakarta. The study focused on the sources of household clean water and the factors affecting the low utilization of piped water. A qualitative research approach was employed through in-depth interviews with key informants selected using purposive sampling, and the problem was analyzed using a fishbone diagram. The study found 81% of households use groundwater, only 9% use piped water, and 10% use both sources. The findings reveal that 25% of the households using piped water still rely entirely on groundwater. The low utilization of piped water was influenced by several factors, including socio-economic conditions, environmental behavior, groundwater quality, performance of PAM Jaya, and groundwater regulations for household usage. Based on the analysis, strategies for accelerating piped water utilization were proposed, including socialization and education on groundwater conservation, quality of groundwater, improvement of PAM Jaya performance, and changes in regulations regarding groundwater use for household. Environmental behavior is identified as the primary factor influencing the high use of groundwater. Several strategies involving stakeholders are necessary to promote the use of piped water among households.

1. INTRODUCTION

More than two billion people worldwide rely on groundwater as their primary source of water, contributing 33% of the total global water extraction (Famiglietti, 2014). This usage continues to increase, particularly in urban areas, due to population growth, accelerated urbanization, higher environmental temperatures, increased per capita water use, and reduced security of access to river water due to increased pollution (Howard, 2007; Taniguchi *et al*., 2009; Foster & Hirata, 2011; Foster *et al*., 2018). This increasing trend is also driven by the lower costs of drilling deep wells and pump equipment (Foster, 2020), and the inability of government policies to address groundwater utilization effectively (Hasibuan *et al*., 2023).

Uncontrolled groundwater extraction leads to a decline in groundwater levels (Miller & Spoolman, 2016), reduces groundwater availability, affects vegetation root absorption, and damages ecosystems (Wada & Heinrich, 2013; Zeng *et al*., 2017). Groundwater extraction also impacts ecological processes and hydrological cycles (Konikow & Kendy, 2005; Leng *et al*., 2015) and causes land subsidence (Furuno *et al*., 2015; Kearns *et al*., 2015; Minderhoud *et al*., 2015), as observed in Jakarta and other major cities worldwide. Jakarta has experienced a subsidence rate of 8 cm per year from 1982 to 1991, which increased to 26 cm per year from 1991 to 1997 (Abidin *et al*., 2001) and from 1999 to 2005, subsidence rates ranged from 1 to 31.9 cm per year (Djaja *et al*., 2004; Abidin *et al*., 2008). Another factor contributing to groundwater level decline is the reduction in groundwater recharge areas, which decreased from 33,467 ha (29%) in 2007 to approximately 10,008 ha (9%) in 2013 (Sagala *et al*., 2015).

Groundwater is the subsurface water that moves through soil due to friction and gravity (Hölting & Coldewey, 2019). It results from hydrological processes and infiltrates through the soil into the groundwater zone. In Jakarta, groundwater is sourced from the Jakarta groundwater basin. Although the use of groundwater for personal needs is a right guaranteed by the state, health risks must be prioritized to ensure social welfare. Several studies have found that many groundwater sources are unsafe and unsuitable for consumption due to contamination from wastewater seepage (Shaad & Burlando, 2019). In 2022, globally, at least 1.7 billion people used drinking water sources contaminated with feces, which contain microbes posing risks to water safety. Microbiologically contaminated drinking water can transmit diseases such as diarrhea, cholera, dysentery, typhoid, and polio, and is estimated to cause approximately 505,000 deaths from diarrhea each year (WHO, 2023).

The Regional Government, addresses this issue by establishing the Regional Drinking Water Company of Capital Region of Jakarta (PAM Jaya). PAM Jaya was established to meet drinking water for the community needs through the infrastructure of the drinking water supply system (SPAM) (Gubernur DKI Jakarta, 2021). Although PAM Jaya has been constructed the distribution pipe network coverage includes nearly all sub-districts in East Jakarta, the number of piped water connections remains low. Duren Sawit Village has particularly low piped water connection rates, with only 20% of the 24,455 households having piped water connections (PAM Jaya, 2024). This ratio is below the average for DKI Jakarta, where the customer connection rate has reached 40.17%, despite the distribution network covering 66% of the total area. This indicates that households still rely on groundwater and exhibit a low willingness to use piped water. Households' dependence on groundwater is driven by their confidence in the quality of the groundwater they use and the perception that piped water is expensive, whereas groundwater is perceived as free.

The aims of study is to address the questions regarding the quantity, quality, and continuity of groundwater sources utilized by households and to formulate strategies for transitioning from groundwater use to piped water. The study analyzes the factors influencing the low level of piped water utilization by households compared to groundwater use. This presents a challenge in achieving the goals set by water resource regulations, which state that groundwater use should be a last resort if surface water that meets the necessary standards and is accessible is available in the area.

2. MATERIALS AND METHODS

2.1. Time and Location of the Study

This study was conducted over a period of four months, from February 2024 to April 2024. The study was carried out in Duren Sawit Village, East Jakarta, located at a geographic position of 106° 49’ 35” East Longitude and 6° 10’ 37” South Latitude. The location of the study area is shown in Figure 1. The selection of location was based on the consideration that groundwater use remains high despite the long-standing availability of piped water in the area, which is capable of meeting community needs with good water pressure quality due to its proximity to the Water Treatment Plant (WTP) located on Jalan Raya Kalimalang.

2.2. Methods

The approach used in this study is a mixed method. Quantitative data collection was conducted through a literature review of groundwater quality standard reports published by the DKI Jakarta Environmental Agency and performance reports from PAM Jaya. Qualitative data were collected through semi-structured interviews. The choice of semi-structured interviews was made due to their more flexible execution compared to structured interviews, allowing for more open and comprehensive findings on the issues.

2.3. Observation and Measurement

Research variables consist of the dependent variable, which is the households' willingness to use piped water, and independent variables, including groundwater, socio-economic factors, PAM Jaya’s performance, and environmental behavior. Secondary data include the quantity, quality, and continuity of piped water, obtained from PAM Jaya's reports and groundwater quality data from monitoring reports published by the DKI Jakarta Environmental Agency. Primary data encompass groundwater quantity, groundwater quality, groundwater continuity, socioeconomic factors, and environmental behavior. Primary data were collected through semi-structured interviews with 15 informants selected

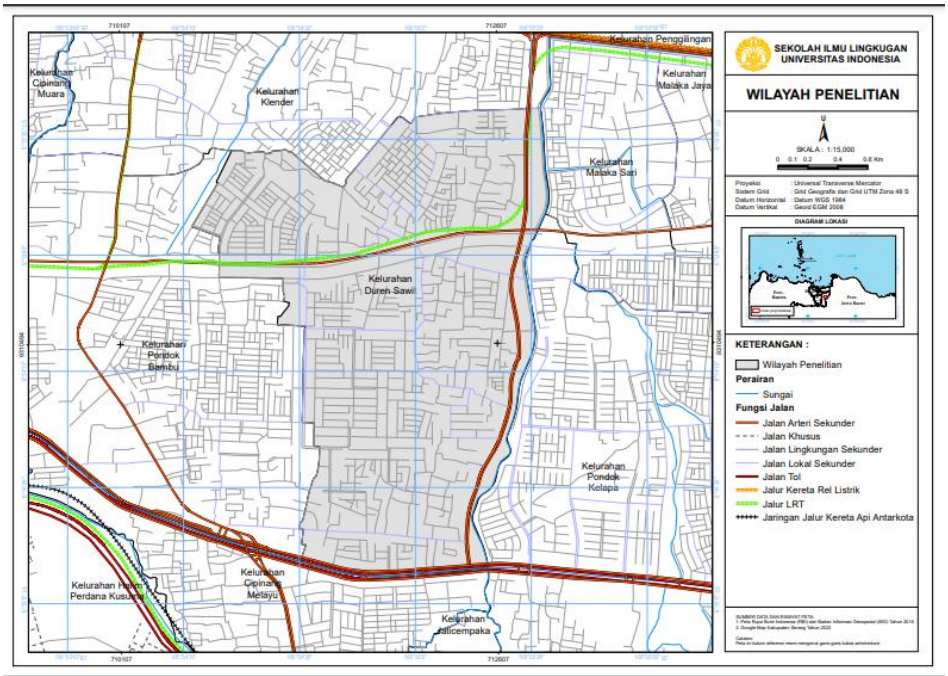

Figure 1. Research area location (Source: Geospatial Information Agency of Indonesia, 2024)

purposively. Semi-structured interviews, classified as in-depth interviews, offer greater flexibility compared to structured interviews. The advantage of semi-structured interviews is that they provide more open and comprehensive insights into the issues (Sugiyono, 2011).

The research informants are categorized into two (2) groups. Category 1: Informants using groundwater, piped water, or both sources of groundwater and piped water. The inclusion criteria for selecting informants in this group are that they have used the relevant water sources and have resided at the same property for at least 10 years. This criterion is set to explore households' perspectives on the condition of the water sources used to meet their needs and their views on groundwater conservation efforts. This group of informants includes: 4 (four) midle-high income informants using groundwater, 2 (two) low-income informants using groundwater, 1 (one) midle-high income informant using both sources, 2 (two) midle-high income informants using piped water.

Category 2: Informants from governmental institutions and community groups related to groundwater, based on their functions, duties, and authorities, including: (1) RW Chairperson, who acts as a liaison between the government and the community directly; (2) Village Head (Lurah), who has knowledge of the area, the socio-economic conditions of the community, and roles in community empowerment and development; (3) PAM Jaya, the agency responsible for providing and managing piped water; (4) Environmental Agency (Dinas Lingkungan Hidup Provinsi) DKI Jakarta, which monitors groundwater quality in Jakarta; (5) Water Resources Agency (Dinas Sumber Daya Air), DKI Jakarta, responsible for formulating the Master Plan for Drinking Water Supply Systems (RISPAM); (6) Balai Konservasi Air Tanah (Groundwater Conservation Office), responsible for monitoring groundwater and addressing the impacts of groundwater extraction, specifically in the Jakarta groundwater basin.

2.4. Data Analysis

The approach in this research employs grounded theory, a qualitative method for developing theory. There are three reasons for using this theory: (1) it is suitable for studying human behavior to generate knowledge about how individuals interpret reality (Suddaby, 2006); (2) the primary aim of grounded theory is to build theory rather than to test it, making it appropriate when an existing theory does not fully explain a process (Thornberg & Dunne, 2019; Creswell & Creswell, 2017). Grounded theory facilitates the documentation and interpretation of individuals subjective experiences. Through

the methodological processes of theoretical sampling and constant comparison, it allows for the abstraction of individuals subjective experiences into theoretical statements (Fendt & Sachs, 2008); (3) guidelines for using grounded theory are available, including data interpretation, particularly systematic approaches (Intissar & Rabeb, 2015).

The formulation of strategies to accelerate the transition to piped water uses a fishbone diagram, which illustrates major issues within a process. The fishbone diagram is employed as a method to identify the primary causes leading to the unsustainability of a process and to assist in visualizing and communicating the critical relationships between elements that may appear unrelated (Jayswal *et al*., 2011). This method is a form of analysis that systematically visualizes the relationship between effects and the causes contributing to those effects. The diagram is used to investigate all potential or actual causes (inputs) that result in a single effect (output); thus, it is often referred to as a cause-and-effect diagram. Causes are organized based on their importance or level of detail, creating a depiction of relationships and a hierarchy of events. Root cause analysis is conducted using various questioning tools, commonly known as the "five whys" (Ammerman, 1999; Robitaille, 2010; Surhone *et al*., 2010).

3. RESULTS AND DISCUSSION

3.1. Description of the Research Area and Findings

The research locus is Duren Sawit Village, East Jakarta. It is one of seven villages in Duren Sawit District and is geographically located in the Eastern part of DKI Jakarta. It comprises 17 RW (neighborhood units) and 180 RT (neighborhood associations), with a population of 77,284 people spread across 24,288 households. On average, each household consists of 3 to 4 members. The population in Duren Sawit is heterogeneous in terms of gender, age, and educational levels. The educational profile of the community ranges from no formal education to doctoral degrees (S3), including the heads of households, as presented in Table 1. The majority of households head have completed high school or its equivalent (38.84%) and hold a Diploma IV or Bachelor Degree (25.6%). In total, 76.2% of households head have either high school or higher education. This reflects a relatively high level of educational attainment among households head in Duren Sawit.

Table 1. Educational profile of households in Duren Sawit Village

No	Education Level	Male	Female	Total	%
1	Strata III	64	15	79	0.3%
2	Strata II	1,064	121	1,185	4.9%
3	Diploma IV/ Strata I	5,373	834	6,207	25.6%
4	Diploma III/Bachelor Degree	1,112	470	1,582	6.5%
5	Diploma I/II	74	38	112	0.5%
6	Senior High School or equivalent	7,569	1,757	9,326	38.4%
7	Junior High School or equivalent	1,999	609	2,608	10.7%
8	Elementry School or equivalent	1,979	943	2,922	12.0%
9	Incomplete Elementry School or equivalent	67	81	148	0.6%
10	No formal education	53	66	119	0.5%
	Total	19,354	4,934	24,288	100.00

Source: Dukcapil DKI Jakarta (2024)

Based on professional backgrounds of household head, private sector employees and entrepreneurs each represent 44% and 20%, respectively. Other professions, which make up 13%, include a mix of various professions such as doctors, accountants, pilots, and others. It is assumed that these other professions have good income levels, given their educational qualifications. The total percentage of households in these three professions accounts for 73% of all households in Duren Sawit, suggesting that these families are likely to be capable and earn above the minimum wage in DKI Jakarta for 2024, which is IDR 5,067,381 (Pemerintah Provinsi DKI Jakarta, 2023).

3.2. Water Sources for Household

Households in Duren Sawit obtain clean water from the following sources: (1) groundwater sourced from unconfined aquifers; (2) piped water supplied and managed by PAM Jaya; and (3) bottled and refillable drinking water for drinking

purposes, with some households also using it for cooking. Groundwater is extracted from wells with varying depths, ranging from 20 meters to 60 meters. The groundwater from these wells is pumped into storage tanks positioned at a certain height using jet pumps. The water is then stored in the tanks and distributed by gravity through the piping system to outlets such as faucets in bathrooms, kitchens, and toilets. The use of water storage tanks helps reduce electricity costs by utilizing gravity for distribution, eliminating the need for electric power.

As the population has increased, the demand for and competition for groundwater access has also intensified. Shallow wells (using standard pumps) have become unusable for many households over the past 10 years, with some households experiencing this issue for up to 20 years, as reported by several informants. This is due to a decline in groundwater levels. The imbalance between the natural recharge of groundwater and its extraction results in a situation where the amount of incoming water (recharge) is less than the amount being extracted (discharge). During prolonged dry seasons, even though pumping continues, the continuity of flow is disrupted. It takes several hours to fill a tank to capacity, as the groundwater level is below the pump's suction point. This situation increases electricity costs due to the pump automation system, which only operates when the groundwater level reaches the pump's suction point.This phenomenon indicates a decline in groundwater levels and an imbalance between the rate of extraction and the recharge from surrounding aquifers (Samsuhadi, 2009). The rate of groundwater extraction is significantly higher than the rate of recharge, and this imbalance has been occurring for several years, leading to a decline in groundwater levels. This phenomenon is also exacerbated by climate change, which impacts not only the quantity and continuity of groundwater but also its quality (Salvati *et al*., 2015; Zhi-Jie *et al*., 2015; Zirulia *et al*., 2021).

What about the quality of groundwater in Kelurahan Duren Sawit? Households believe that the groundwater they consume is still good because it is colorless and odorless. Physically, the groundwater in Kelurahan Duren Sawit still meets the requirements set by Ministerial of Health Regulation No. 2 of 2023. However, chemical and biological parameters show that some elements do not meet health standards, such as lead, manganese, total coliform, and Escherichia coli (E. coli), particularly during the dry season, as monitored by the Environmental Agency (DLH) of DKI Jakarta. DLH conducts groundwater quality monitoring twice a year to assess the quality of groundwater across different seasons. This monitoring is carried out in all Kelurahan areas in DKI Jakarta. Tables 2 and 3 show that the chemical parameters for lead and manganese are elevated above the required quality standards.

The groundwater quality monitoring results conducted by the Environmental Agency (Dinas LH) are subsequently coordinated with relevant government agencies (SKPD) for follow-up actions or as a reference in program planning. However, these results have not been fully disseminated to households or the community, either directly or through

Table 2. Groundwater quality test results in Duren Sawit Village (Period-1, 2022)

No	Parameter Types	Unit	Maximum Allowable Concentration	Test Results and Measurements
1	Lead		0.01	0.03
2	Total Coliform	CFU/100 ml	0	4,500
3	Escherichia Coli	CFU/100 ml	0	100
4	Temperature	°C	Air temperature +/- 3	
5	pH		6.5-8.5	7.5
6	Total Dissolved	mg/L	<300	321
7	Turbidity	NTU	<3	0.08
8	Color	TCU	10	15
9	Iron	mg/L	0.2	0.32
10	Fluoride	mg/L	1.5	0.08
11	Manganese	mg/L	0.1	0.41
12	Nitrate	mg/L	20	0.05
13	Nitrite	mg/L	3	0.01
14	Mercury	mg/L	0.001	0.0001
15	Cadmium	mg/L	0.003	0.003
16	Chromium	mg/L	0.01	0.003
17	Zinc	mg/L	3	0.006

Source: Jakarta Environmental Agency (2022)

Table 3. Groundwater quality test results Duren Sawit Village (Period-2, 2022)

No	Parameter Types	Unit	Maximum Allowable Concentration	Test Results and Measurements
1	Lead		0.01	0.04
2	Total Coliform	CFU/100 ml	0	0
3	Escherichia Coli	CFU/100 ml	0	0
4	Temperature	°C	Suhu udara +/- 3	
5	pH		6.5-8.5	7.53
6	Total Dissolved Solid	mg/L	<300	283
7	Turbidity	NTU	<3	1.80
8	Color	TCU	10	15
9	Iron	mg/L	0.2	0.25
10	Fluoride	mg/L	1.5	0.11
11	Manganese	mg/L	0.1	0.44
12	Nitrate	mg/L	20	2.7
13	Nitrite	mg/L	3	0.01
14	Mercury	mg/L	0.001	0.0005
15	Cadmium	mg/L	0.003	0.03
16	Cromium	mg/L	0.01	0.003
17	Zinc	mg/L	3	0.006

Source: Jakarta Environmental Agency (2022)

hierarchical socialization via the Kelurahan, RW (neighborhood units), and RT (neighborhood committees). This lack of communication has led to continued reliance on groundwater by households, due to the belief that the water quality remains good and the absence of information clarifying the actual condition.

The next water source is piped water supplied by PAM Jaya. Currently, the utilization of piped water by households is driven by the poor quality of groundwater. Figure 2 illustrates the piped water network installed in Duren Sawit, along with the properties of PAM Jaya customers. Areas with high numbers of PAM connections include RW 08, 09, 11, and parts of RW 14. The low-quality condition of groundwater has led the community to rely on piped water as the primary source to meet their needs. Conversely, areas with lower PAM connections are where the groundwater quality is still deemed suitable for consumption.

Despite having 4,635 piped water connections, only 3,334 households utilize this service. There are 1,301 (28%) PAM Jaya customers who do not use piped water at all. These customers are categorized as "zero consumption," utilizing piped water only as a backup in case of issues with groundwater pumping. Figure 3 shows the average usage of PAM Jaya customers from November 2023 to March 2024, with 1,043 (22.5%) customers still using both sources of water, and the remaining 49% relying entirely on piped water.

Several Informants who use piped water expressed satisfaction with PAM Jaya's service performance, both in technical aspects (quantity, quality, and continuity) and non-technical aspects such as response speed to customer complaints. Technically, issues such as water outages, cloudiness, or odor are rare, and water pressure can reach up to 4 meters (second-floor level). They also mentioned that the costs incurred are proportional to the service received, with no complaints about the monthly billing amount.

However, despite some customers being satisfied with PAM Jaya's performance, there are areas for improvement, particularly in technical aspects. This is evident from the number of customer complaints over the past year, as shown in Figure 4. The most frequent issue reported is the continuity of water flow, accounting for 64% of the total complaints. Although the complaint often refers to water pressure rather than a complete lack of water flow, it primarily affects customers with two-story or larger homes.

According to PAM Jaya's report, there were 252 customer complaints in Duren Sawit Village over the past fifteen (15) months, averaging 17 complaints per month. These complaints reflect technical issues with PAM Jaya, a Key Stakeholder in providing sustainable drinking water services (Wardhana, 2018). Efforts should be made to enhance performance in several key areas : providing a sufficient quantity of drinking water, ensuring that water quality meets

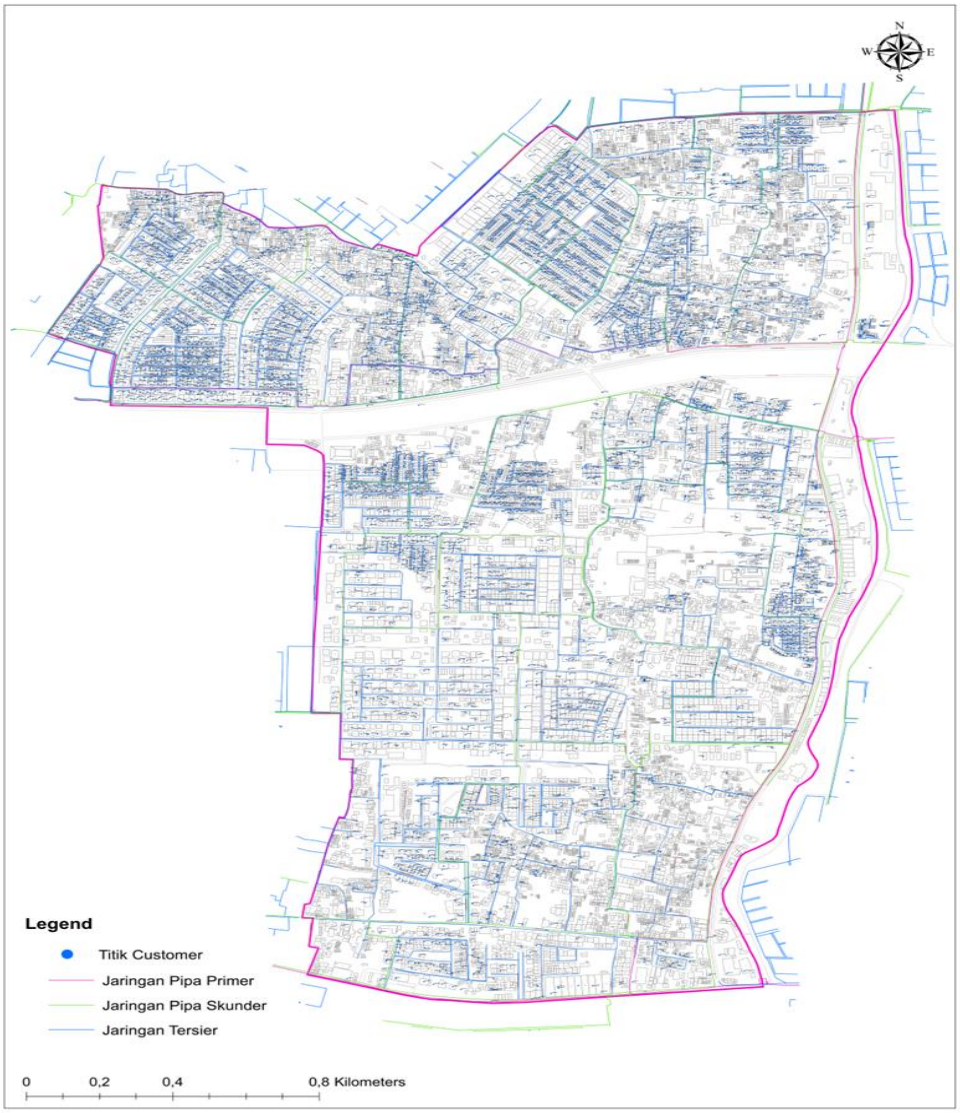

Figure 2. Pipe networks on Duren Sawit (Sources: PAM Jaya, 2024)

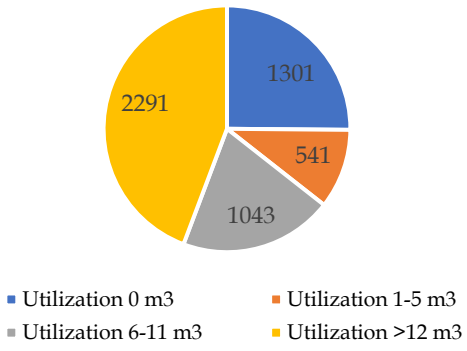

Figure 3. Number household based on water utilization on November 2023-March 2024 in Duren Sawit (Source: PAM Jaya, 2024)

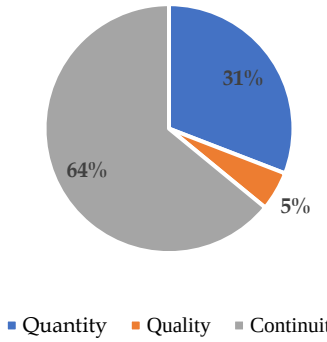

Figure 4. Type of complaints of water service in Duren Sawit during January 2023 – March 2024 (Source: PAM Jaya, 2024)

standards, maintaining 24-hour continuity of supply, reducing water loss, and improving the operation and maintenance of the clean water supply system (SPAM). These actions are necessary to ensure that water delivered to consumers meets the required standards of quantity, quality, and continuity.

Based on the findings, it can be concluded that there are three categories of households based on their access to clean water: 19,653 households (81%) continue to rely on groundwater; 2,234 households (10%) use both sources: groundwater and piped water; and 2,291 households (9%) exclusively use piped water.

3.3. Fishbone Diagram (Cause-and-Effect Diagram)

Analysis of the acceleration of the transition from groundwater to piped water using a fishbone diagram. The fishbone diagram, also known as the cause-and-effect diagram, is used to describe the causes and effects of a problem within a framework shaped like a fishbone. The primary issue identified is the low usage of piped water by households and the high dependency on groundwater. The process of creating this diagram begins with identifying and categorizing the causes of the problem. Data sources include interviews with informants and secondary data from reports by the DKI Jakarta Environmental Agency and PAM Jaya. The cause-and-effect analysis results in five main categories or factors that contribute to the low utilization of piped water, as presented in Figure 5.

1. Household income

Head of households in Duren Sawit have diverse professional backgrounds, as shown in Table 1. It is assumed that 77% Head of households have incomes above the minimum wage, while 23% of households have incomes below the minimum wage. Head of Households with incomes below the minimum wage use groundwater due to their inability to pay for piped water. Interviews with informants reveal that low-income households often lack stable employment and some are semi-unemployed. When it comes to essential expenses, they prioritize electricity bills over piped water. To reduce costs, they often pool resources with 4-5 households to share the expenses of drilling, purchasing, and installing a jet pump.

2. Environmental Behavior

Another factor affecting the low level of piped water usage is environmental awareness, particularly among households with higher incomes. Interviews with several informants reveal that they are unaware of the long-term impacts of uncontrolled groundwater use. This lack of awareness can be attributed to limited knowledge and understanding of environmental issues. Environmental awareness is closely linked to knowledge and understanding of environmental matters (Ostman & Parker, 1987; Dillon & Gayford, 1997). There have been no socialization and educational activities, campaigns, or advisories from government institutions regarding the use and conservation of groundwater. One barrier to these activities is the absence of legal frameworks regulating such measures, as noted by informants from relevant agencies.

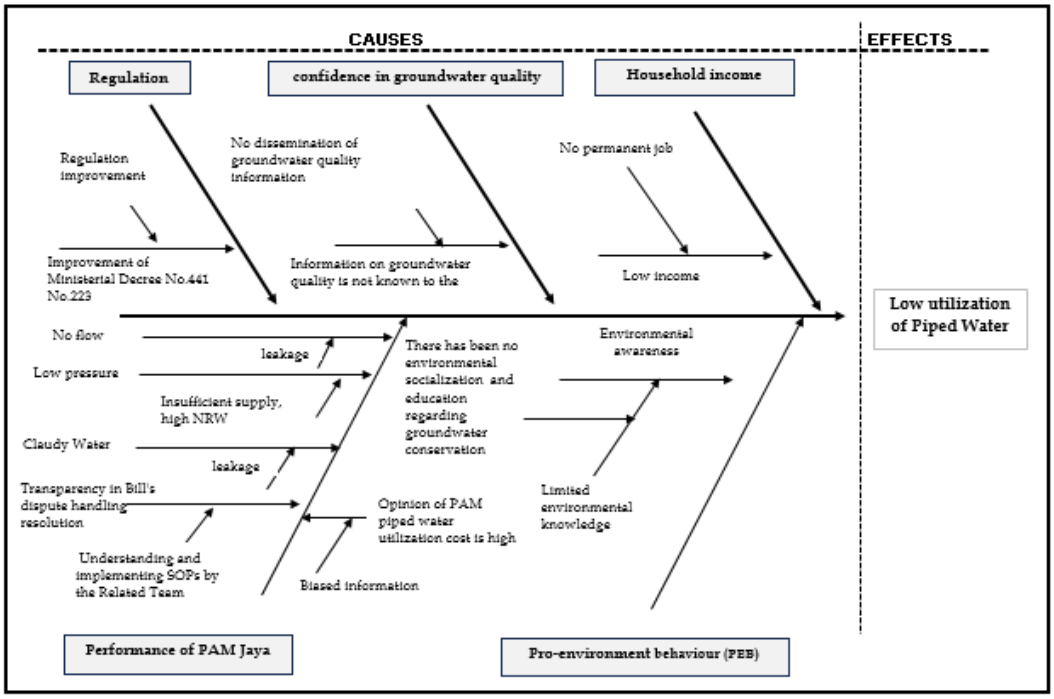

Figure 5. Fishbone diagram of utilization of piped water in Duren Sawit Village

The lack of awareness regarding the use of groundwater as a last resort, coupled with uncontrolled groundwater exploitation by financially capable households, is likely to continue. This behavior is considered a basis for environmental crises and has become a concern for social scientists (Coertjens *et al*., 2010). The government needs to encourage participation from all stakeholders in water management, including the use of groundwater, and promote a strong sense of environmental responsibility among the community (Pradipta *et al*., 2023).

3. Belief in Groundwater Quality

Households continue to use groundwater because they still believe in its quality, which appears clear, colorless, and odorless. Interviews with several informants revealed that they have been residing in Duren Sawit for 20 years and have used groundwater throughout this period, with no perceived change in its quality. This physical appearance of groundwater aligns with the monitoring results conducted by Environmental Agency of Jakarta. Data from 2022 indicates that groundwater in Duren Sawit still meets the standard drinking water quality parameters for temperature, pH, color, odor, and taste. Most chemical parameters also comply with drinking water quality standards. However, issues arise with biological quality parameters, as total coliform and Escherichia coli levels exceed the established standards. The trend of increasing coliform and E. coli levels is not limited to Duren Sawit Village but is observed throughout Jakarta. As stated by one informant: "Groundwater is becoming increasingly contaminated, especially with *E. coli*. The growing population density is a factor contributing to higher *E. coli* levels. The most contaminated areas are in the North. However, this does not mean the South is free of *E. coli*; there are also heavily contaminated areas there. This problem has been escalating every year. Additionally, with the latest Minister of Health regulations imposing stricter parameters, this also impacts the condition of groundwater, as the quality standards become higher."

Among the groundwater users interviewed, only one had ever tested their groundwater at their own initiative and expense. This was done once, at the beginning of their residence with a new well. The test results at that time showed that the groundwater quality met all parameters. Environmental changes due to population growth and property development have triggered changes in groundwater quality, especially in areas with poor sanitation communities, making the decline in groundwater quality, particularly in biological parameters, an unavoidable issue.

4. Performance of PAM Jaya

The performance of PAM Jaya is a key factor driving households' desire to switch to piped water. Households are likely to use piped water if PAM Jaya can meet the required volume, quality, and continuity of supply, as noted by one informant. The issue of adequate supply is a major concern for customers. This is reflected in the customer complaint data over the past year, as illustrated in Figure 4. Another issue is the high level of water loss, which has shown no improvement over the past four years, remaining in the range of 45%-46%, and reaching 47% in 2021.

Based on brainstorming sessions with informant sources, PAM Jaya has developed a strategic plan to enhance customer service. This strategic plan includes increasing supply volume through agreements for bulk water purchases with SPAM Regional Jati Luhur 1 and Karian. Other strategic programs involve maximizing PAM Jaya's assets, which were previously not operated by private partners during the concession period. Additionally, the plan includes constructing communal reservoirs in areas with critical pressure to provide more equitable service to all PAM Jaya customers. The informant also mentioned that PAM Jaya currently offers a corporate social responsibility program, which includes providing water storage tanks and booster pumps to less affluent customers with low water pressure at their properties. This demonstrates PAM Jaya's commitment to maximizing customer service.

5. Regulation and Institutional Framework for Groundwater

Monitoring, investigation, and management of groundwater are carried out by the Center for Groundwater and Geological Mineral Planning, an Agency under the Ministry of Energy and Mineral Resources. In Jakarta, this role is performed by the Groundwater Conservation Office (BKAT), which is a Technical Implementation Unit under the Geological Agency. The primary responsibilities of BKAT include monitoring the quantity and quality of groundwater in the Jakarta aquifer basin. Other tasks include evaluating groundwater permits and usage.

According to the regulations, groundwater used for commercial purposes must have a permit, with a preference for using piped water first, and groundwater being used as a last resort (Pemerintah Indonesia, 2019). Therefore, for commercial use of groundwater, such as for hotels, industries, and businesses, when high-quality piped water or surface water is available and meets the required standards of quality, quantity, continuity, and affordability, groundwater use is not permitted (Kementerian ESDM, 2023). Issues arise when groundwater is not intended for commercial use but for public needs, daily household consumption, small-scale agriculture, and social purposes. As noted by an informant, households with insufficient resources cannot access adequate clean water due to the presence of neighboring households with better access using deeper pumps. This competition for groundwater access can lead to social issues if there is unfairness in obtaining groundwater.

3.4. Strategic Formulation for Switching Groundwater to Piped Water

The strategy for increasing the use of piped water is formulated based on the issues identified in each category of the fishbone diagram presented in Figure 5. The formulation of problem-solving is summarized based on problem analysis and brainstorming with source informants, as summarized in Table 4. It explains the strategy for the economic category, which involves providing subsidies to low-income households by waiving piped water connection fees. This subsidy strategy is being implemented in several selected locations in Jakarta. However, it needs to be expanded along with an explanation of the simulation that shows the cost of piped water usage is not expensive, as attached in Table 5.

The category of environmentally friendly behavior emphasizes programs aimed at increasing knowledge and encouraging public awareness of environmental preservation. Next is the category of PAM Jaya performance, which focuses on improving services based on quantity, quality, and continuity. Likewise, the socialization of water usage cost calculations and the campaign for water conservation need to be implemented more intensively. Interviews with groundwater users revealed a common perception that piped water is expensive. This perception is based on information they receive from external sources, such as colleagues or relatives who use piped water and have monthly bills reaching Rp300,000. In fact, the cost of using piped water is still affordable, as shown in Table 5.

Referring to Table 5, the monthly expenditure for subscribing to piped water for a very simple household (II) is Rp 20,544, and for a simple household (IIIA), it is Rp 67,038. When compared to the minimum of regional wage in DKI

Table 4. Matrix of solutions for the enhance of piped water usage in Duren Sawit

Category	Root Cause	Recommended Solution
Economic	Head of house hold has no permanent job.	(1) Providing free connections through PMD funds (Regional Equity Participation)
Environmental Behavior	Inadequate environmental knowledge	(1) Environmental education and groundwater conservation programs by relevant agencies through the sub-district, neighborhood units, and community units (2) Promoting education programs in the form of posters and stickers (3) Promoting education programs through social media and WhatsApp group
Ground water	No socialization of groundwater quality information	(1) Socialization of groundwater quality through the sub-district, neighborhood units, and community unit. (2) Increasing the number of monitoring sample points for groundwater conditions in the area, so that the representativeness of groundwater quality in the Duren Sawit is high.
PAM Jaya	Piped water not flow	(1) No flow water is caused by burst or leaks in the distribution network pipes. This issue is caused by the aging condition of the pipes. Therefore, it is necessary to accelerate the implementation of the rehabilitation (replacement) program for the old pipes.
	Low pressure piped water	(1) Increasing the volume of bulk water supply from the Jatiluhur 1 and Karian Regional Water Supply Systems. (2) Reducing water loss by accelerating the capital expenditure (CAPEX) implementation, such as the rehabilitation program for aging pipeline networks (supported by timely permitting processes for pipe replacement by the DKI Jakarta Public Works Department). (3) Increasing water pressure by constructing communal reservoirs and pumping stations in low-pressure areas. (4) Reactivating booster pumps that were previously deactivated by private partners (Aetra and Palija). (5) Providing CSR programs in the form of water storage tanks and booster pumps to customers with low water pressure.
	Contaminated and Smelling	(1) Regularly flushing pipe network (2) Leak repair
	Opinion of high-water cost	(1) Socialization of water usage cost along with a campaign for water conservation.
Regulation	Amendment to Ministerial Decree No. 443 of 2023	(1) Currently, the Ministry of Energy and Mineral Resources is reviewing Ministerial Decree No. 441 of 2023. One of the points of concern is Article B.2.a.1, which states that groundwater usage for essential household needs above 100 m³ per month must obtain approval. The minimum threshold of 100 m³ per month needs to be re-evaluated to determine if it is effective for current conditions, where many economically capable households still use below 100 m³ per month. (2) The refinement of the changes to the aforementioned Ministerial Decree needs to include more specific sanctions for violations.

Table 5. Simulation of monthly piped water usage cost calculation in Duren Sawit

Household category	Consumption (m^3/month)	Cost calculation					
		(0-10 m3)	(11-20 m3)	Fixed Cost	Rent Cost	VAT	Total
II	14.4	10,500	4,620	1,660	3,400	374	20,544
IIIA	14.4	35,500	20,680	6,640	3,800	418	67,038
IIIB	14.4	49,000	26,400	7,550	4,400	484	87,834
IVA	14.4	68,250	35,860	14,190	5,200	572	124,072

Jakarta of Rp 5,067,381, the expenditure ratio for piped water usage is 0.41% (for simple households) and 1.05% (for very simple households). This ratio is below the household expenditure standard for drinking water needs, which should not exceed 4% of income (Minister of Home Affairs, 2006).

Lastly, in the regulatory category governing groundwater usage activities, a review of the minimum threshold of 100 m^3 per month for daily needs is necessary. The establishment of this minimum threshold has led to a limited number of applications for groundwater usage permits from economically capable households, resulting in restricted monitoring and oversight, which relies solely on reports from the surrounding community. Without the issuance of groundwater usage permits, controlling the use of groundwater by economically capable households becomes challenging.

There is a potential for misuse of groundwater for commercial activities, which is explicitly regulated by Ministerial Decree No. 259 of 2022, stating that groundwater for business or commercial purposes must have a permit, with very strict regulations. When a piped water supply network or surface water that meets quality, quantity, continuity, and affordability standards is achieved, the use of groundwater should not be permitted.

4. CONCLUSION

This research shows that 81% of households in Duren Sawit Village still utilize groundwater; 9% use piped water; and 10% use both sources of groundwater and piped water. In general, households never experience a shortage of water, even during the dry season. Disruptions occur only in terms of continuity, where pumps operate longer due to a decrease in the groundwater level. On the other hand, the quality of groundwater does not meet the established quality standards, with elevated levels of lead (0.03 > 0.01 mg/L), manganese (0.41 > 0.1 mg/L), and iron (0.32 > 0.20 mg/L), which exceed the quality standards, as well as coliform (4500 > 0 CFU/100 ml) and E. coli (100 > 0 CFU/100 ml) levels during the dry season.

Based on the fishbone diagram, a cause-and-effect relationship was established regarding several factors influencing the low utilization of piped water in Duren Sawit Village, despite the availability of piped water. There are five factors contributing to the low utilization of piped water (categories): (1) socio-economic; (2) environmentally friendly behavior; (3) belief in the adequacy of groundwater; (4) performance of PAM Jaya; and (5) groundwater regulations.

Based on the categories in the fishbone diagram, strategies were formulated to reduce groundwater usage by households and encourage a switch to piped water. The proposed strategies include: education and socialization on groundwater conservation by optimizing the role of community organizations at the sub-district, neighborhood, and community levels; improving PAM Jaya's performance; providing subsidies to households that cannot afford connection fees; and revisiting Ministerial Regulation No. 443 of 2023 regarding the minimum usage threshold of 100 m^3 per month for midle-high income households.

REFERENCES

Abidin, H.Z., Djaja, R., Darmawan, D., Hadi, H., Akbar, A., Rajiyowiryono, H., Sudibyo,Y., Meilano, I., Kasuma, M.A., Kahar, J., & Subarya, C. (2001). Land subsidence of Jakarta (Indonesia) and its geodetic monitoring system. *Natural Hazards*, ***23***, 365–387. https://doi.org/10.1023/A:1011144602064

Abidin, H.Z., Andreas, H., Djaja, R., Darmawan, D.,& Gamal, M. (2008). Land subsidence characteristics of Jakarta between 1997 and 2005, as estimated using GPS surveys. *GPS Solutions*, ***12***, 23–32. https://doi.org/10.1007/s10291-007-0061-0

Ammerman, M. (1998). *The Root Cause Analysis Handbook - A Simplified Approach to Identifying, Correcting, and Reporting Workplace Errors*. Productivity Press, 444 Park Avenue South, Suite 604 New York, 135 pp.

Badan Informasi Geospasial. (2024). *Peta Wilayah DKI Jakarta*.

Coertjens, L., Boeve-de Pauw, J., De Maeyer, S., & Van Petegem, P. (2010). Do schools make a difference in their students' environmental attitudes and awareness? Evidence from Pisa 2006. *International Journal of Science and Mathematics Education*, ***8***, 497–522. https://doi.org/10.1007/s10763-010-9200-0

Creswell, J.W., & Creswell, J.D. (2017). *Research Design: Qualitative, Quantitative, and Mixed Methods Approaches*. Sage Publications, Inc. 2455 Teller Road, Thousand Oaks, California, 320 pp.

Dillon, P.J., & Gayford, C.G. (1997). A psychometric approach to investigating the environmental beliefs, intentions and behaviours of pre-service teachers. *Environmental Education Research*, ***3***(3), 283–297.

Dinas Lingkungan Hidup DKI Jakarta. (2022). *Pemantauan Kualitas Lingkungan Air Tanah di Provinsi DKI Jakarta Tahun 2022*.

Djaja, R., Rais, J., Abidin, H.Z., & Wedyanto, K. (2004). Land subsidence of Jakarta metropolitan area. *Proceedings of the 3rd FIG Regional Conference for Asia and the Pacific*, 3–7 October, 2004.

Famiglietti, J.S. (2014). The global groundwater crisis. *Nature Climate Change*, ***4***(11), 945–948. https://doi.org/10.1038/nclimate2425

Fendt, J., & Sachs, W. (2008). Grounded theory method in management research: Users' perspectives. *Organizational Research Methods*, ***11***(3), 430–455. https://doi.org/10.1177/1094428106297812

Foster, S. (2020). Global policy overview of groundwater in urban development—A tale of 10 cities! *Water*, ***12***(2), 456. https://doi.org/10.3390/w12020456

Foster, S., Bousquet, A., & Furey, S. (2018). Urban groundwater use in Tropical Africa–a key factor in enhancing water security? *Water Policy*, 20(5), 982–994. https://doi.org/10.2166/wp.2018.056

Foster, S., & Hirata, R. (2011). Groundwater use for urban development: enhancing benefits and reducing risks. In *SIWI On-the-Water-Front 2011* (Technical Report): 21-29.

Furuno, K., Kagawa, A., Kazaoka, O., Kusuda, T., & Nirei, H. (2015). Groundwater management based on monitoring of land subsidence and groundwater levels in the Kanto Groundwater Basin, Central Japan. *Proceedings of the International Association of Hydrological Sciences* (*PIAHS*), ***372***, 53–57. https://doi.org/10.5194/piahs-372-53-2015

Gubernur DKI Jakarta. (2021). *Peraturan Daerah Provinsi Daerah Khusus Ibukota Jakarta Nomor 4 Tahun 2021 Tentang Perubahan Bentuk Hukum Perusahaan Daerah Air Minum Daerah Khusus Ibukota Jakarta (PAM JAYA) Menjadi Perusahaan Umum Daerah Air Minum Jaya*.

Hasibuan, H.S., Tambunan, R.P., Rukmana, D., Permana, C.T., Elizandri, B.N., Putra, G.A.Y., Wahidah, A.N., & Ristya, Y. (2023). Policymaking and the spatial characteristics of land subsidence in North Jakarta. *City and Environment Interactions*, ***18***, 100103. https://doi.org/10.1016/j.cacint.2023.100103

Hölting, B., & Coldewey, W.G. (2019). *Hydrogeologie: Einführung in die Allgemeine und Angewandte Hydrogeologie*. Spektrum Akademischer Verlag, Heidelberg: 438 pp.

Howard, K.W.F. (2007). *Urban Groundwater, Meeting the Challenge: Selected papers from the 32nd International Geological Congress (IGC), Florence, Italy, August 2004*. Taylor & Francis, London, UK: 324 pp.

Intissar, S., & Rabeb, C. (2015). Étapes à suivre dans une analyse qualitative de données selon trois méthodes d'analyse: la théorisation ancrée de Strauss et Corbin, la méthode d'analyse qualitative de Miles et Huberman et l'analyse thématique de Paillé et Mucchielli, une revue de la lit. *Revue Francophone Internationale de Recherche Infirmière*, ***1***(3), 161–168.

Jayswal, A., Li, X., Zanwar, A., Lou, H.H., & Huang, Y. (2011). A sustainability root cause analysis methodology and its application. *Computers & Chemical Engineering*, ***35***(12), 2786–2798. https://doi.org/10.1016/j.compchemeng.2011.05.004

Kearns, T.J., Wang, G., Bao, Y., Jiang, J., & Lee, D. (2015). Current land subsidence and groundwater level changes in the Houston metropolitan area (2005–2012). *Journal of Surveying Engineering*, ***141***(4), 5015002. https://doi.org/10.1061/(ASCE)SU.1943-5428.0000147

Kementerian Dalam Negeri. (2024). *Data Kependudukan tahun 2022*.

Kementrian ESDM. (2023). *Keputusan Menteri Energi dan Sumber Daya Mineral Nomor 443.K/GL.01/MEM.G/2023 tentang Perubahan atas Keputusan Menteri Energi dan Sumber Daya Mineral Nomor 291.K/GL.01/MEM.G/2023 tentang Standar Penyelenggaraan Persetjuan Penggunan Air Tanah*.

Konikow, L.F., & Kendy, E. (2005). Groundwater depletion: A global problem. *Hydrogeology Journal*, ***13***, 317–320. https://doi.org/10.1007/s10040-004-0411-8

Leng, G., Huang, M., Tang, Q., & Leung, L.R. (2015). A modeling study of irrigation effects on global surface water and groundwater resources under a changing climate. *Journal of Advances in Modeling Earth Systems*, ***7***(3), 1285–1304. https://doi.org/10.1002/2015MS000437

Mendagri (Menteri Dalam Negeri) (2006). *Peraturan Menteri Dalam Negeri Nomor 23 Tahun 2006 Tentang Pedoman Teknis dan Tata Cara Pengaturan Tarif Air Minum Pada Perusahaan Daerah Air Minum*.

Miller, G.E., & Spoolman, S.E. (2016). *Environmental Science*. 15th ed. Cengage Learning, Australia: 551 pp.

Minderhoud, P.S.J., Erkens, G., Pham, V.H., Vuong, B.T., & Stouthamer, E. (2015). Assessing the potential of the multi-aquifer subsurface of the Mekong Delta (Vietnam) for land subsidence due to groundwater extraction. *Proceedings of the International Association of Hydrological Sciences* (*PIAHS*), ***372***, 73–76. https://doi.org/10.5194/piahs-372-73-2015

Ostman, R.E., & Parker, J.L. (1987). Impact of education, age, newspapers, and television on environmental knowledge, concerns, and behaviors. *The Journal of Environmental Education*, 19(1), 3–9. https://doi.org/10.1080/00958964.1987.10801954

PAM Jaya. (2024). *Laporan Bulanan*. Perusahaan Daerah Air Minum Daerah Khusus Ibukota Jakarta.

Pemerintah Indonesia (2019). *Undang-undang Nomor 17 Tahun 2019 tentang Sumber Daya Air*.

Pemerintah Provinsi DKI Jakarta (2023). *Upah Minimum Provinsi Tahun 2024*.

Pradipta, I., Herdiansyah, H., & Putri, L.S. (2023). Balinese way of governing water: A social survey on water governance. *Jurnal Penelitian Pendidikan IPA*, ***9***(7), 4983–4990. https://doi.org/10.29303/jppipa.v9i7.3679

Robitaille, D. (2010). *Root Cause Analysis – Basic Tools and Techniques*. Paton Professional, Chico, California: 122 pp.

Sagala, S.A.H., Luo, P. and others (2015). Overview of Jakarta water-related environmental challenges. *Water and Urban Initiative Working Paper Series*, Number 04 – April 2015: 5 pp.

Salvati, L., Moretti, V., Zitti, M., & Ferrara, C. (2015). Towards soil water scarcity? An exploratory time-series analysis of the aridity index in Castelporziano forest, Rome. *Rendiconti Lincei. Scienze Fisiche e Naturali*, ***26***, 289–295. https://doi.org/10.1007/s12210-015-0409-2

Samsuhadi, S. (2009). Pemanfaatan air tanah Jakarta. *Jurnal Air Indonesia*, 5(1), 9-22.

Shaad, K., & Burlando, P. (2019). Monitoring and modeling off shallow groundwater dynamic in urban contexd: The case study of Jakarta. *Journal of Hydrology*, ***572***, 1046-1056. https://doi.org/10.1016/j.jhydrol.2018.01.005

Suddaby, R. (2006). From the editors: What grounded theory is not. *Academy of Management Journal*, ***49***(4), 633–642. https://doi.org/10.5465/amj.2006.22083020

Sugiyono, S. (2011). *Metode Penelitian Kuantitatif, Kualitatif dan Kombinasi* (*Mixed Methods*). Alfabeta, Bandung: 630 pp.

Surhone, L., Timpledon, M., & Marseken, S. (2010). *Pareto Analysis: Statistics, Decision Making, Pareto Principle, Fault Tree Analysis, Failure Mode and Effects Analysis. Pareto Distribution*. Wikipedia Betascript Publishing Saarbrücken, Germany.

Taniguchi, M. et al. (2009). *Trends and Sustainability of Groundwater in Highly Stressed Aquifers*. Proceedings of Symposium HS. 2 at the Joint Convention of the International Association of Hydrological Sciences (IAHS) and the International Association of Hydrogeologists (IAH), Hyderabad, India, 6–12 September 2009.

Thornberg, R., & Dunne, C. (2019). Literature review in grounded theory. In *The SAGE Handbook of Current Developments in Grounded Theory*, 206–221. https://doi.org/10.4135/9781526485656.n12

Wada, Y., & Heinrich, L. (2013). Assessment of transboundary aquifers of the world—vulnerability arising from human water use. *Environmental Research Letters*, ***8***(2), 024003. https://doi.org/10.1088/1748-9326/8/2/024003

Wardhana, Y.M.A. (2018). Policy model for sustainable drinking water supply system. *Journal of Infrastructure Policy and Management*, ***1***(01), 17–27. https://doi.org/10.35166/jipm.101.0002

WHO. (2023). Drinking-water, WHO. Available at: https://www.who.int/news-room/fact-sheets/detail/drinking-water (Accessed: 9 November 2023).

Zeng, Y., Xie, Z. and Liu, S. (2017). Seasonal effects of irrigation on land–atmosphere latent heat, sensible heat, and carbon fluxes in semiarid basin. *Earth System Dynamics*, ***8***(1), 113–127. https://doi.org/10.5194/esd-8-113-2017

Zhi-Jie, L., Tian-Feng, W.A.N., & Zhen-Guo, Z. (2015). The enhanced geothermal system (EGS): Huge capacity and difficult exploitation. *Earth Science Frontiers*, ***22***(1), 335-344. https://doi.org/10.13745/j.esf.2015.01.029

Zirulia, A., Brancale, M., Barbagli, A., Guastaldi, E., & Colonn, T. (2021). Hydrological changes: are they present at local scales? *Rendiconti Lincei. Scienze Fisiche e Naturali*, ***32***, 295–309. https://doi.org/10.1007/s12210-021-00983-5