# Maximising efficient water capacity through reservoir configuration with a case study for Malang City of Indonesia

G. Samudro[1], H. Samudro[2], S. Mangkoedihardjo[3*]

[1]Department of Environmental Engineering, Universitas Diponegoro, Semarang, Indonesia.
[2]Department of Architecture, State Islamic University of Malang, Malang, Indonesia.
[3]Department of Environmental Engineering, Institut Teknologi Sepuluh Nopember, Surabaya, Indonesia.

***ABSTRACT:*** All forms of water supply systems had unique characteristics of idle capacity. However, achieving a sustainable water supply over the long term could not eliminate idle capacity. This paper discussed methods for providing efficient capacity without compromising long-term water requirements. The objective of efficient capacity was to reduce idle water capacity and water-carrying infrastructure. This study method reviews previous research results with an in-depth case of a piped water supply system in an urban area. The assessment method referred to the pattern of water demand by consumers. Fluctuations in water demand determined the dimensions of all water supply system components. The results of this study showed that water distribution determines the minimum idle capacity, which directs the need for priority areas for efficient capacity and opens reservoir placement options. Under these priority areas, a decentralised reservoir position resulted in an efficient system dimension. The closer the reservoir was to the consumer, the smaller the idle capacity, which was the contribution of the onsite reservoir. The critical implementation was based on the flexibility of the phasing of water supply and infrastructure. The flexibility addressed the use of flow rates for a certain period, diversification of water sources, and system configuration that determines the dimensions of the infrastructure and maximising utilisation.

***KEYWORDS:*** Basic services, Consumption, Infrastructure, Resource efficiency, Rural, Urban, Water supply

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## I. INTRODUCTION

People everywhere need access to clean water due to the essence of water in human life. The access takes into account without and with a pipe system, both self-sufficient and institutionalised management. The self-management of clean water using shallow groundwater (Ketchemen-Tandia *et al.*, 2017) and rainwater (Abdulla and Al-Shareef, 2009), along with the water flow into the house within the boundary of the user's building land, is an example of an onsite system. The onsite system works in floating settlements and riverbanks (Üzümcüoğlu and Polay, 2022). Meanwhile, offsite self-management is a service system for people in mountainous areas, where people manually take water from springs and pipes (Samudro, 2020). Self-management also works in rural and rural settlements (Terzić *et al.*, 2022). Therefore, the coexistence of various services in one operational system, which is called a hybrid system for clean water services becomes the first and longest infrastructure since human life. The hybrid system for clean water services also continues to operate on institutionalised management through a piped system and non-piped water as bottled drinking water.

With attention to the importance of clean water quality, the offsite piping system requires long-term capacity (Annis and Razafinjato, 2012) as the main characteristic of a water supply system that maintains sustainable service to its users (Worden and Deaton, 2017). However, this principle leads to idle water capacity and excessive infrastructure dimensions in the short term. To minimise these two problems while still adhering to the principle of sustainable service, planning a piped water supply system provides an implementation stage.

The piped water supply system generally includes water sources, transmission, water treatment, reservoirs and distribution networks, and water flow equipment. The system component that is difficult to work in stages is the flow rate of the water source (Fotopoulou *et al*., 2022), which must be able to meet the consumer's maximum water demand. The rest, including the provision of several water sources, can carry out its functions gradually (Creaco *et al*., 2014).

Therefore, this paper focuses on an offsite piped water supply and discusses a phasing system to reduce idle capacity, which is a stepwise approach aiming for efficient capacity resources yet sustainable service. The term efficient capacity refers to infrastructure with maximum utilisation but minimum dimensions and water with maximum utilisation but minimal idle water. Furthermore, efficient capacity does not include leakage and water loss as part of the flow rate. This water supply system with efficient capacity characteristics is suitable for planning new systems for rural and urban areas and upgrading existing systems.

*Corresponding author: prosarwoko@gmail.com
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## II. METHODOLOGY

The methodological framework of this study follows the flow of the piped water supply system, as presented in Figure 1.

Pipelines along the water sources to the reservoir (W-R) represent equivalent lengths and diameters to account for the possibility of several pipes of different diameters. Likewise, from the reservoir to the service area (R-S) is for a pipeline network covering the service area, where there are more variations in length and diameter.

Figure 2B presents a method of determining reservoir volume by balancing water supply and demand. The reservoir volume requirement is the total graphic area above the average hourly supply, which is as follows: (4.99*1) + (10.00*3) + (7.50*2) + (8.33*3) – (4.17*9) = 37.45 % total 24 h demand. One may use the sum of the graphical areas below the average hourly supply, which results in the same volume as follows: (4.17*7) + {(4.17 - 3.75)*2} + {(4.17 - 1.67)*3} = 37.53 % total 24 h demand. A slight difference in results of 0.08 % is a matter of rounding off the numbers.

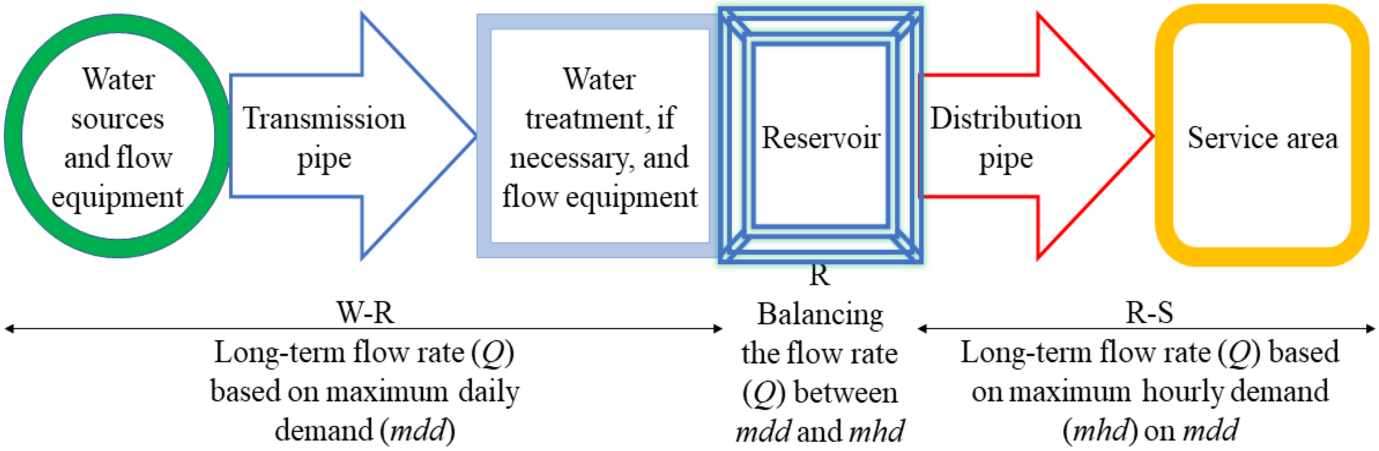


**Figure 1. Flow diagram of a water supply system**

The pipeline along the W-R transmits a constant long-term flow rate ($Q$) based on the maximum daily demand (*mdd*), as illustrated in Figure 2A. Constant flow rate applies to all required flow facilities, including water treatment, if any. Meanwhile, the R-S network distributes long-term fluctuating flow rates based on maximum hourly demand (*mhd*) (Beal and Stewart, 2014), as presented in Figure 2B.

Reservoir (R) is a flow rate balancer between constant transmission supply and fluctuating demand for consumer distribution covering the service area. As a flow balancer, a reservoir requires a volume, the calculation of which is in Figure 2B.

The two patterns of water demand fluctuation represent conditions in Indonesia (adapted from (Mangkoedihardjo, 2021)). In addition, water demand patterns vary between places according to local socio-cultural characteristics (Rondinel-Oviedo and Sarmiento-Pastor, 2020) and urban development (Heidari *et al*., 2021). Meanwhile, water demand in dense urban areas fluctuates less than in rural areas (van Duuren *et al.*, 2019).

Figure 2A explains the maximum water demand on a particular day throughout the year. The ratio of maximum daily demand and the average daily is the maximum daily factor (*mdf*), which is generally 1.3 – 1.5 (Mangkoedihardjo, 2021). At the same time, Figure 2B explains the maximum water demand at a particular hour during the maximum daily demand. The maximum hourly factor is the ratio of maximum hourly demand and average hours on a maximum day demand (*mhf*), generally between 1.7 and 2.5 (Mangkoedihardjo, 2021).

Both *mdf* and *mhf* have a significant relationship with the population. The more the population served, the smaller the factor (Samudro and Mangkoedihardjo, 2006). This fact is in line with the results of representative studies based on a literature review (Balacco *et al.*, 2017) and empirical research (Del Giudice *et al.*, 2020). The same relationship holds for reservoir volume (Patel and Katiyar, 2014). For Indonesian conditions, Figure 3 presents the population variable to *mhf* at *mdf* and reservoir volume (modified from (Samudro and Mangkoedihardjo, 2006) and (Mangkoedihardjo and Samudro, 2012)). Some countries record an *mhf* of more than 4.0 for a single building with fewer than ten occupants (Beal and Stewart, 2014; Buchberger *et al.*, 2017; Dahir, 2021; Mudashiru *et al.*, 2021; Rondinel-Oviedo and Sarmiento-Pastor, 2020; Zhou *et al.*, 2021).

This study simulates three options based on reservoir placement for various locations of water sources. Reservoir placement options include centralised, decentralised and onsite reservoirs.

In piped water, the flow rate uses the Hazen-William formula in Eqn. (1), which is a rearrangement of Abdulameer *et al.* (2022).

$$Q = fD^{2.63}S^{0.54} \quad (1)$$

Equation 1 explains where $Q$ represents flow rate (m/s), $f$ is a dimensionless constant related to unit conversion and pipe roughness, $D$ denotes pipe diameter (m), and $S$ describes hydraulic slope, i.e., head loss $hf$ (m) per unit length of pipe $L$ (m).

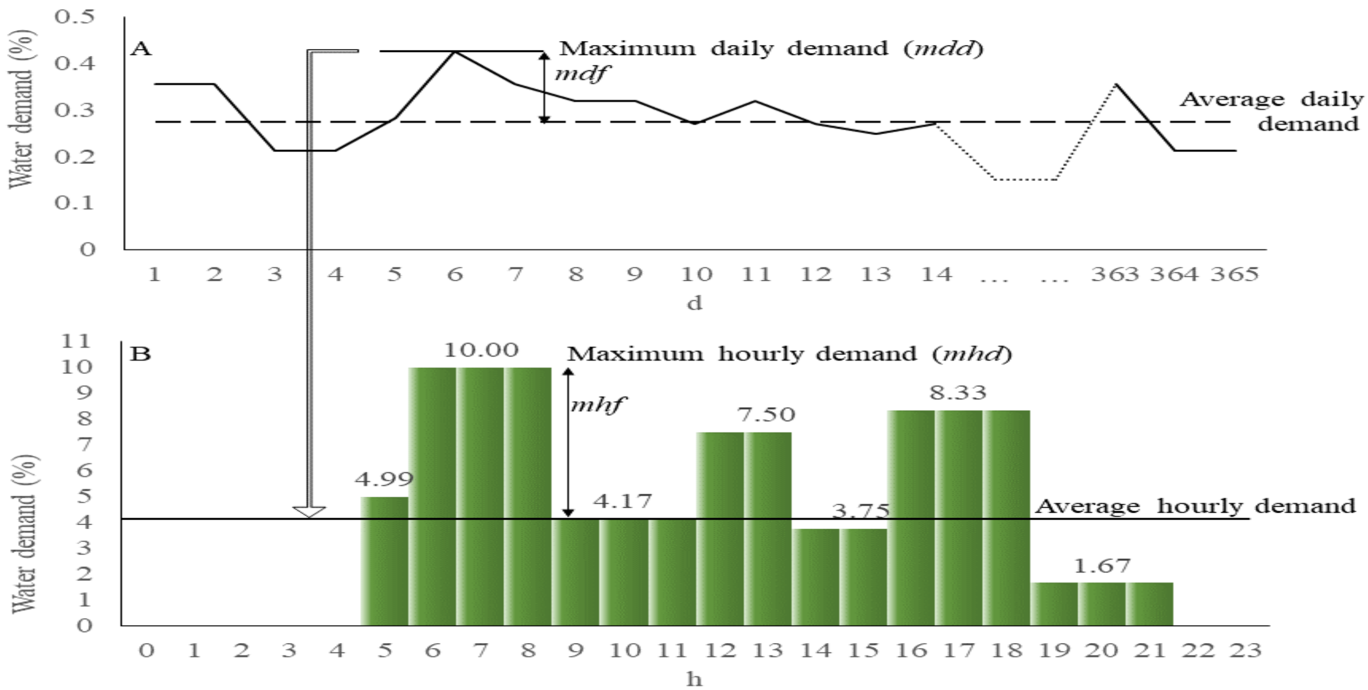


**Figure 2. Water demand fluctuation patterns (Mangkoedihardjo, 2021)**

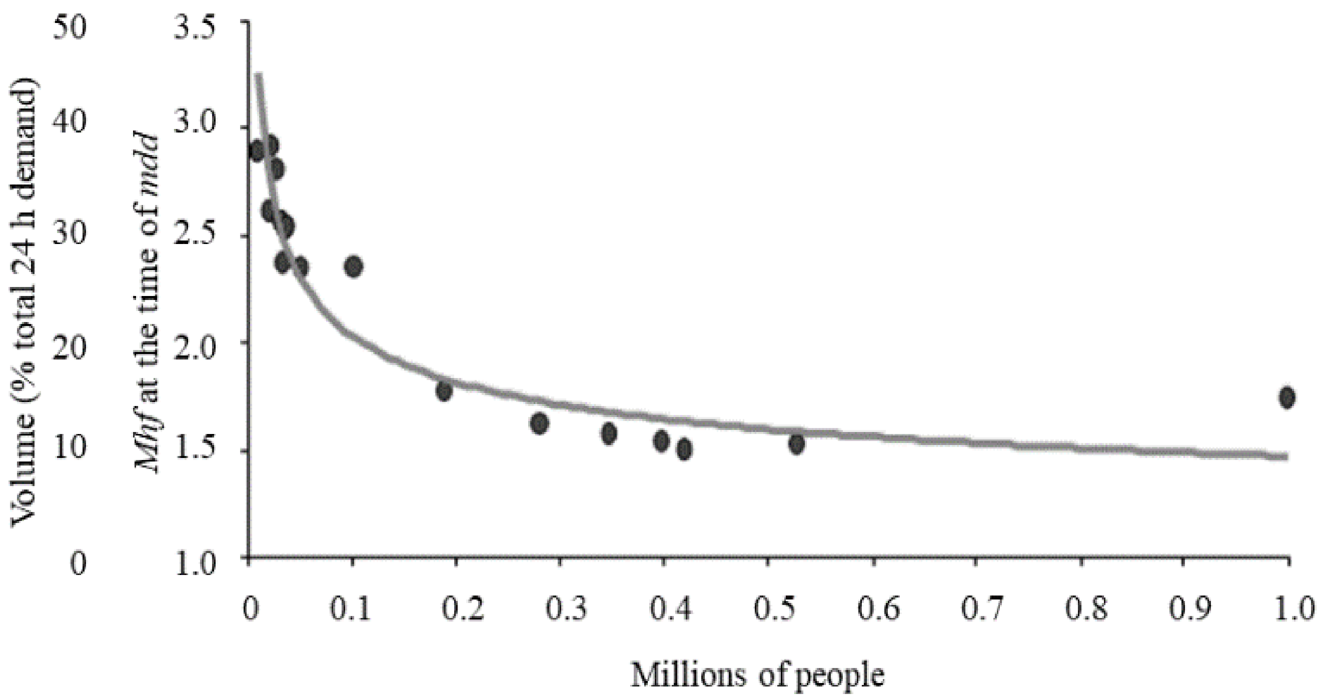


**Figure 3. Relation of maximum hourly factor and reservoir volume to the number of people (Samudro and Mangkoedihardjo, 2006; Mangkoedihardjo and Samudro, 2012)**

## III. RESULTS AND DISCUSSION

The first phasing system for the provision of piped water infrastructure works by prioritising service areas that can efficiently maximise water utilisation while minimising idle capacity. The second phase, as a continuation of the efficient priority area is a flexible reservoir configuration in the phasing of its provision. Besides these two phases, other system components require phasing according to short-term needs, which are easy to multiply to long-term needs.

### *A. Priority efficient service areas*

Population areas have different numbers, growth and densities. This difference affects the efficient capacity of both water and infrastructure. Therefore, the planning of water supply systems requires prioritisation of efficient areas.

In developing area conditions, the number of people or population growth can be a priority direction for efficient services. Figure 4 showed the service area stage prioritises areas with a large number of people first and then proceeds to areas with a small number. In dealing with areas that have reached the stationary phase, the service area stage prioritises high population density followed by low density. Thus, the priority service area direction is a form of phasing in the water distribution system to minimise idle capacity.

Apart from prioritising service areas based on population, the method for minimising idle capacity applies to maximising pipe length utilisation. This condition appears where non-priority areas are between the water supply sources and priority areas. There is no technical reason to include these non-priority areas as part of the service area except for the following two considerations. The first is to take advantage of the length of the embedded pipe while serving more people. The typical pipe length is throughout the service area. The second is the efficient use of long-term resources to minimise idle water-carrying materials as previously defined.

areas. As previously mentioned, including non-priority sub-districts into priority coverage areas is for the sake of the efficient capacity of the infrastructure that passes through.

As an example of a water source, Figure 4B shows that this city gets water flow from sources (S) outside the city boundary (Humas, 2021; Triningtias, 2015). The position of the water source and the priority area gives the scope of supply for the sub-districts of Klojen and Lowokwaru in the dotted circle.

*C. Reservoir placement*

Figure 5 illustrates three options for reservoir placement. The first is the onsite reservoir (OR), which serves every building, considering that many houses are used to having a water tank on the roof. This OR gets water supply outside the building area and becomes an offsite piped water supply system. The second is the decentralised reservoir (DR), which serves each sub-district. The third is the centralised reservoir (CR), which serves the district covering several sub-districts as its administrative area. In practice, the presence of at least two options constitutes a piped water supply hybrid system.
For the sake of clarity, in general, not all areas have a source of water that is sufficient for the population's needs.

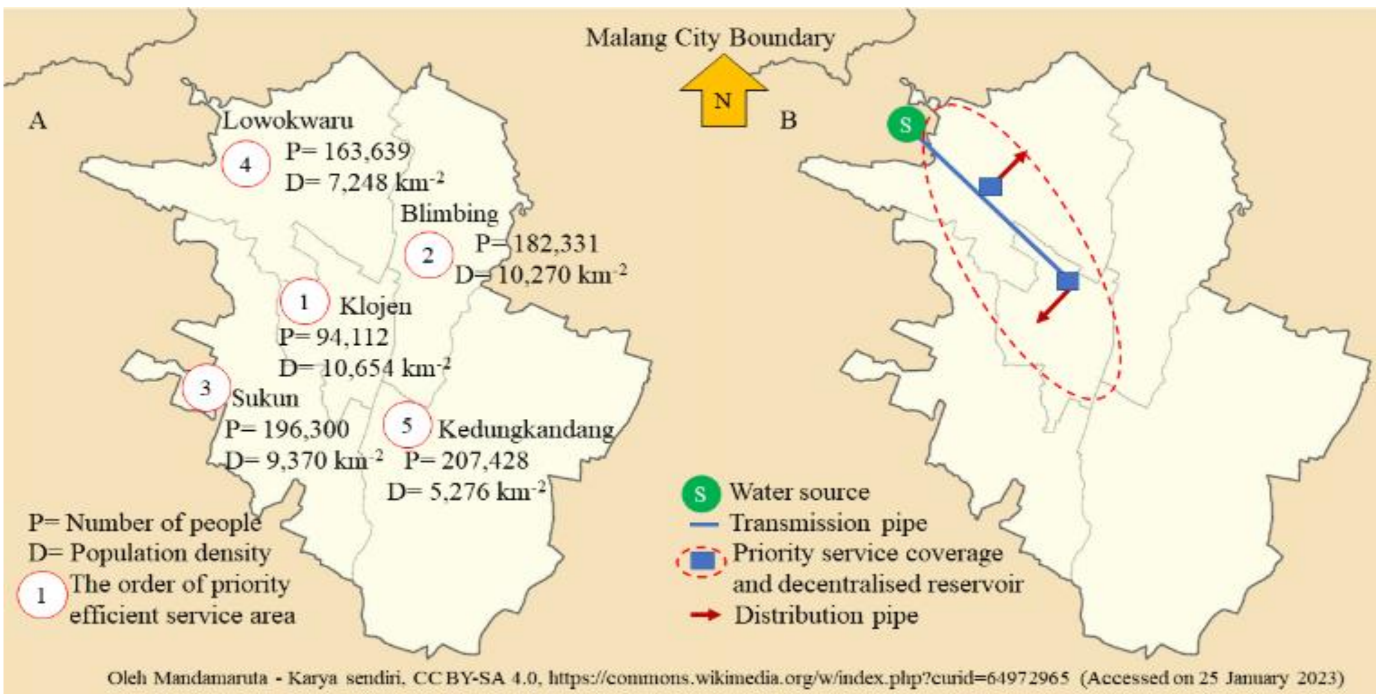


**Figure 4. Priority efficient service areas for Malang city**

*B. Study area*

The assessment of efficient capacity takes the example of Malang City, the second largest city in East Java, Indonesia. This city has five sub-districts, in which population data in units of population number and density for 2021 comes from the Central Bureau of Statistics for the City of Malang (BPS Kota Malang, 2022) (Figure 4A). Since Malang City has reached a stationary condition in the short term and has no significant long-term growth, the priority area is the city centre as the most densely populated. Wherever the water source is available outside the area, there are two sub-districts as priority service

Therefore, the location of water sources can be anywhere, both inside and outside the district, so there can be several sources, as shown in the dotted line marks in Figure 5. The same arrangement also applies to the provision of reservoirs depending on the local topography.

Table 1 presents the assessment of the three options for Malang City using the previously mentioned data. Deliberately, the determination of the population projection considers the population for the long-term perspective. The long-term maximum daily demand uses a typical Indonesian requirement (Mangkoedihardjo, 2010).

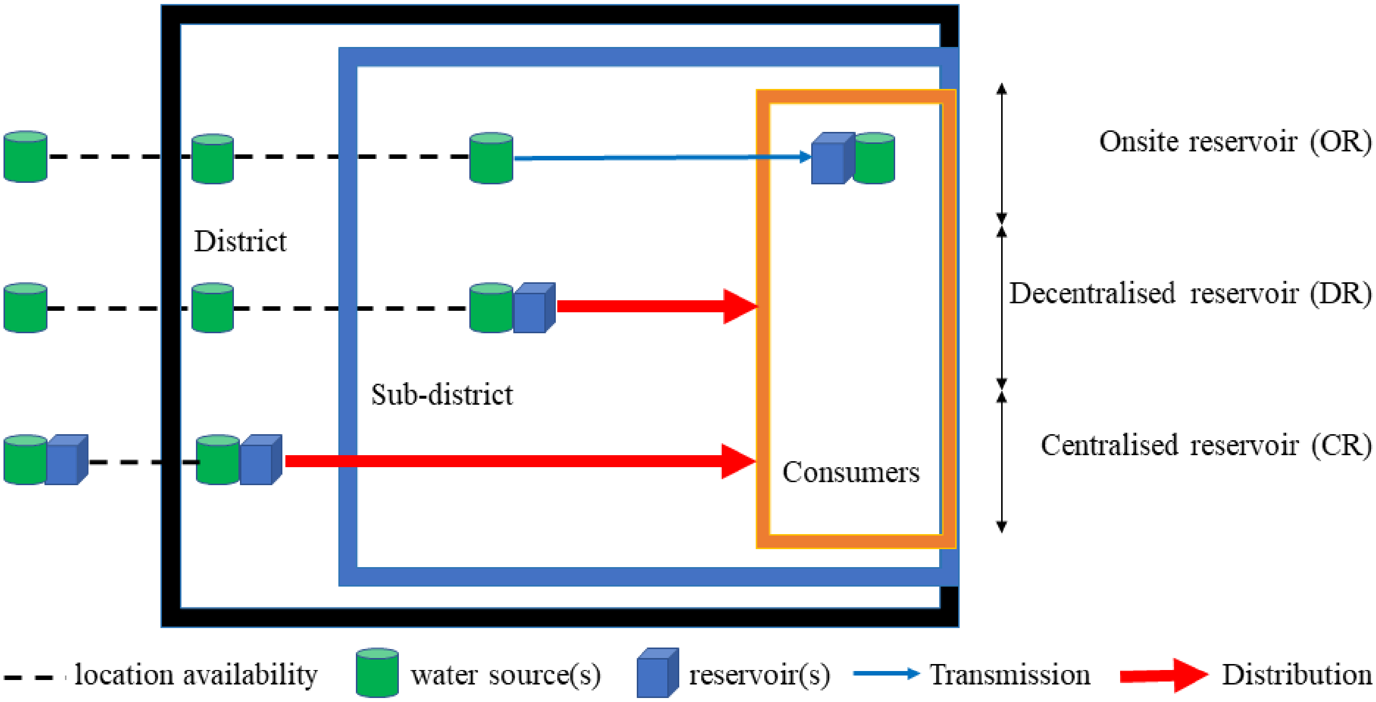


**Figure 5. Reservoir placement options**

**Table 1. Reservoir placement assessment for Malang City**

| **Service area** | **Long-term number of people** | **Maximum daily demand, *mdd*** | **Reservoir volume** | | **Distribution network** | | |
|---|---|---|---|---|---|---|---|
| | 910,000 | 0.18 $m^3$ /person /d | (%) (Figure 3) | ($m^3$) | *mhf* at the time of *mdd* (Figure 3) | Flow rate Q ($m^3$/s) | Equivalent diameter (m) (Equation 1) |
| Option 1: OR | | | | | | | |
| Each building | 5 | 0.9 | 50.0 | 0.45 | 3.5 | 0.007 | 0.025 |
| All buildings 182,000 | | | | 81,900 | 1.0 at *mdd* as transmission | | |
| Option 2: DR | | | | | | | |
| 1. Klojen | 100,000 | 18,000 | 20.0 | 3,600 | 2.00 | 0.42 | 0.7 |
| 2. Blimbing | 200,000 | 36,000 | 18.0 | 6,480 | 1.70 | 0.71 | 0.9 |
| 3. Sukun | 210,000 | 37,800 | 17.5 | 6,615 | 1.75 | 0.77 | 0.9 |
| 4. Lowokwaru | 180,000 | 32,400 | 18.5 | 5,994 | 1.90 | 0.71 | 0.9 |
| 5. Kedungkandang | 220,000 | 39,600 | 17.0 | 6,732 | 1.80 | 0.83 | 0.9 |
| | | | | 29,421 | 1.0 at *mdd* | | |
| Option 3: CR | | | | | | | |
| Malang city area | 910,000 | 163,800 | 10.0 | 16,380 | | | |
| | | | | | 1.60 | 3.02 | 1.5 |

Table 1 shows that the closer the reservoir is placed to the consumer, the greater the volume requirement accompanied by, the smaller equivalent diameter for the entire district area. Which outcome implementation is chosen opens various aspects of assessment, for example, from the point of view of financial (Creaco *et al.*, 2014; Nascimento *et al.*, 2019), social (Noubactep, 2021; Słyś and Stec, 2020; Zang *et al.*, 2021) and institutional feasibility (Annis and Razafinjato, 2012; Arora *et al.*, 2015; Piratla and Goverdhanam, 2015). However, in an efficient capacity perspective that maximises infrastructure utilisation and minimises idle water, the phasing of water supply is a way to determine system choices. Furthermore, this phasing method aligns with the service area priority approach mentioned above.

*D. Phasing on infrastructure*

Raw water sources are crucial in procurement within the sustainable clean water supply framework. However, in all seasons, the minimum capacity of water sources must serve the long-term maximum water demand (Avni *et al.*, 2015). Therefore, phasing the procurement of all flow rates is unrealistic to reduce idle capacity, except for phasing collection infrastructure for short-term needs.

The phasing of water collection infrastructure from a single raw water source determines the efficient water treatment capacity and all the necessary flow equipment, such as pumps. These infrastructures are flexible in implementing phases according to the practical operational lifetime (Septiariva *et al.*, 2021), so their management can reduce idle capacity.

Another effort to reduce idle capacity is to procure a similar source of raw water which can be in stages, in this case addressing deep groundwater. In addition, the procurement of various sources of raw water, for example, a combination of deep groundwater, lakes and rivers, in stages.

Concerning the boundaries of priority service areas in two sub-districts (Figure 4), the water supply system can use the DR option. This system covers the sub-districts of Lowokwaru and Klojen for a long-term projection of 280,000 population and requires a reservoir volume of about 6,000 and 3,600 $m^3$, respectively (Table 1). The pipe dimensions along source (S) to each DR are small as transmission pipes to deliver the maximum daily demand.

The next stage addresses DR. Reservoirs both below and above ground can be provided in stages regardless of their position in the sub-district because they do not affect the dimensions of the supply and demand pipeline network. Likewise, for the phasing of transmission pipelines whenever possible in field implementation. These results promise the benefits of implementing a decentralised reservoir by reducing the dimensions of the infrastructure, starting from short-term services to meeting long-term needs.

Finally, although the total volume of OR is larger than DR and CR, promoting OR for new water supply systems can be more flexible in its implementation phase than other infrastructure provisions. In addition to the small volume of around 1,000 L for a building with around five inhabitants (Table 1), OR is part of consumer management. A building can provide OR in short-term increments to minimise long-term idle capacity. Accordingly, consumers who are used to placing ORs at home can continue their operations.

In order to reduce the volume of OR from an offsite piping system, the presence of OR can also be coupled with a reservoir to accommodate other water sources, such as rainwater harvesting (Abdulla and Al-Shareef, 2009; Słyś and Stec, 2020) and groundwater. Under these conditions, a building can provide a hybrid system and strengthen water resilience to meet building health (Samudro *et al.*, 2022).

## IV. CONCLUSIONS

Idle capacity exists due to the need for a long-term water supply for sustainable use. The decrease in idle capacity leads to services according to the short-term needs of the stages. Short-term service directs the need for priority efficient capacity area directions following the pattern of population growth as consumers. The pattern of water demand by consumers determines the dimensions of the distribution system, which is larger than the transmission and source of water for the same flow rate. The placement of reservoirs as a balance between supply and demand also reduces idle capacity. Compared to a central reservoir, the closer the placement of a decentralised reservoir to the consumer, the longer the pipe with a small diameter. Decentralised reservoirs can meet the short-term needs of consumers and are flexible in phasing their supply. Additionally, it can open the phasing of source water collection, the diversity of sources, and the accompanying facilities. Therefore, the provision of sufficient water for each phase and the overall system infrastructure design significantly reduces idle capacity.

In addition to planning new water supply systems that can implement decentralised reservoirs, it is also flexible for expanding existing systems when achieving long-term needs. Under these conditions, all infrastructure dimensions use a flow rate based on the maximum daily demand, except for the reservoir flow rate to consumers, which uses the maximum hourly demand.

## AUTHOR CONTRIBUTIONS

**G. Samudro:** Conception, Methodology, Interpretation, Analysis, and Writing–original draft. **H. Samudro:** Conception, Design, Data Acquisition, and Writing–original draft. **S. Mangkoedihardjo:** Conception, Supervision, Interpretation, Analysis, Validation, Revision, and Correspondence. **G. Samudro, H. Samudro, and S. Mangkoedihardjo:** Conception, Methodology, Analysis, Design, Data Acquisition, Supervision, Validation, Writing–original draft, Revision, and Correspondence.

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