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New Approach on Planning for Water Provision using Water Balance (Case Study: Sewakaderma Municipal Waterworks, Denpasar)

Pendekatan Baru pada Perencanaan Penyediaan Air Menggunakan Neraca Air (Studi Kasus: PDAM Sewakaderma, Denpasar)

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Abstract

The rapid growth of urban populations has led to an increase in water demand. Moreover, Public Water Supply Companies need to deal with water loss. This issue is primarily caused by aging water networks and poor infrastructure due to a lack of maintenance, which makes the piping system susceptible to damage and leakage. In Denpasar City, the pipeline network, which spans over 94,753 meters, is more than 40 years old. Given the current circumstances, in 2023 the amount of unaccounted water loss due to leakage reach 38%. This high percentage of Non-Revenue Water (NRW) has several negative consequences, including a decrease in the quality of distributed water, a reduction in PDAM profits, and limitations on the city government's ability to expand and achieve 100% coverage. The objective of this study is to estimate the potential demand and supply of PDAM Denpasar City. Using Quantitative and qualitative approach, with minimum water demand of 129.46 liters per person per day (lpd). The Water Supply Simulation of Denpasar City reveals that to achieve optimal conditions, PDAM Denpasar City must reduce NRW from 38% to 19.5% by 2044. This can be accomplished through various measures, including the replacement of the Primary Distribution Network along 116.95 kilometers, replacement of 51.03 kilometers Secondary Distribution Network, the installation of 78 District Metered Areas (DMAs), and an increase in the number of customers by at least 20,750 households (representing a 22% increase from 2023).

Keywords: water provision, simulation, non-revenue water.

***SDGs*:**

9 INDUSTRY, INNOVATION AND INFRASTRUCTURE

Abstrak

Jumlah penduduk di perkotaan pada umumnya terus bertambah, pertumbuhan ini juga berdampak pada pesatnya pertumbuhan kebutuhan air. Di sisi lain, PDAM juga menghadapi masalah kehilangan air, hal ini dikarenakan kurangnya pemeliharaan dan jaringan air yang sudah tua membuat sistem perpipaan rentan terhadap kerusakan dan kebocoran. Di Kota Denpasar, jaringan perpipaan Denpasar sepanjang 94.753 m telah berusia lebih dari 40 tahun. Dengan kondisi saat ini tidak dapat dipungkiri bahwa pada tahun 2023 air tidak berekening akibat kebocoran mencapai 38%. Dampak dari persentase NRW yang tinggi juga berdampak negatif pada berbagai kegiatan seperti menurunnya kualitas air yang didistribusikan, berkurangnya keuntungan PDAM, serta menghambat pemerintah kota untuk memperluas dan mencapai cakupan layanan 100%. Penelitian ini bertujuan untuk memperkirakan potensi kebutuhan dan penyediaan PDAM Kota Denpasar dengan menggunakan pendekatan kuatitatif dan kualitatif, kebutuhan air minimum/orang/hari sebesar 129,46 lpd. Dari hasil Simulasi Penyediaan Air Minum Kota Denpasar dapat disimpulkan bahwa untuk menurunkan NRW dari 38% menjadi 19,5% pada tahun 2044, perlu dilakukan penggantian Jaringan Distribusi Primer sepanjang 116,95 Km, dan 51, 03 km Jaringan Distribusi Sekunder,memasang 78 DMA, serta meningkatkan jumlah pelanggan sekurang-kurangnya 20.750 KK (meningkat 22% dari tahun 2023).

Kata Kunci: penyediaan air, simulasi, air non pendapatan.

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1. INTRODUCTION

Water is an essential resource that is critical for human survival and advancement. It is vital for meeting primary needs, upholding public health standards, facilitating agricultural and industrial processes, and ensuring the proper functioning of ecosystems (Revollo-Fernández, Rodríguez-Tapia and Morales-Novelo, 2020). During recent years the development of urban areas causes some huge impacts. One of them is increasing the amounts of populations. Subsequently, this growth negatively impacts the surrounding areas such as environmental pollution, increased water demand, diminishing water supply, and other natural resources.

In addition to addressing the rising demand, water management encounters another obstacle known as non-revenue water or the loss of water in distribution networks (Farouk, Rahman and Romali, 2023). This phenomenon also happened in PDAM Sewakaderma (Denpasar). According to Hunaido and Wang, physical losses can result in the diversion of precious water resources from customers and escalate operational expenditures (Hunaidi and Wang, 2006). These losses might require larger investments than are necessary to enhance network capacity. Conversely, Commercial losses, which are caused by inaccuracies in customer metering, poor data management, and illegal connections, lead to a decrease in revenue.

Farley, et al., argued that water utilities may have additional supply to expand their services if they can manage to reduce water losses/non-revenue water (Farley *et al.*, 2008). Apparently, Meeting consumer demands becomes significantly more challenging when a substantial amount of supplied water is lost. Furthermore, the inability to generate revenue from this lost water contributes to the difficulty of maintaining water tariffs at a reasonable and affordable level. This scenario is prevalent in numerous Asian cities (Frauendorfer, 2010).

Thus, its evident that through the reduction of Non-Revenue Water (NRW), new sources of both water and finances can be unlocked. According to Singh and Mahanta, reducing the occurrence of excessive physical losses leads to a higher quantity of surplus water, which can be utilized to enhance water coverage and customer satisfaction (Singh and Mahanta, 2021). Additionally, by doing so it can delays the necessity of allocating funds towards acquiring new water resources and reduces operational expenses (Makara, 2009; Kanakoudis and Tsitsifli, 2014). thus, reducing commercial losses generates more revenue.

Non-Revenue Water (NRW) can be defined as the variance between System Input Volume and Billed Authorized Consumption, as stated by the International Water Association (IWA) Task Force on Water Loss in 2003. The control of water losses in NRW requires significant resources in terms of logistics, staffing, and finance, with the real losses and the apparent losses being the two key components that demand utmost attention. These components play a crucial role in determining the allocation of resources for effectively managing and reducing water losses. The third component, Efficient management of unbilled authorized consumption can be achieved with minimal resources. The initial step in addressing non-revenue water (NRW) is to perform a water balance (Butler and Memon, 2006). Water balance calculations are employed to determine the amount of water lost in a distribution system. To accomplish this, the water supply and different components of water consumption within a specific period are examined and evaluated.

2. METHODOLOGY

The methodology is essential in research as it encompasses the researcher's theoretical standpoint and approach (Ryan, 2006). Quantitative research methods, such as those outlined by Bouquet and Wu & Little, are widely used due to their ability to provide measurable and countable data, which enhances scientific credibility (Bouquet, 2005; Wu and Little, 2024). These methods involve a systematic process of sample selection, data collection, and operationalization of research variables.

However, Lakshman, et al., argues that while quantitative methods are valuable (Lakshman *et al.*, 2000), they may not fully capture the complexities of human behavior and the impact of certain phenomena. Therefore, a balanced mix of both qualitative and quantitative methods is recommended to ensure the validity and reliability of research results. Thus, the for the purpose of this study the author use both quantitative and qualitative approach.

For the quantitative approach, the author collecting data from Denpasar Sewakaderma Municipalities, this data including NRW, Denpasar's city population, customer, number of pumps stationed, number of pipes, reservoar, etc. after gathering all the information that needed the author continue to process this data into water balance table. The process can be seen as follows.

First, it is essential to have a thorough understanding of the entire water system, which involves creating a water balance, to minimize water losses. A deep knowledge of the production and distribution systems used in Sewakaderma Municipalities is necessary for accurately calculating the water balance. Currently the Water Balance calculated as follow (DFSA, 2021):

$$y = (a - (a \times n)) - b \qquad (1)$$

where:

y = Water Balance
a = Production Capacity/Volume Input
n = % non-revenue water
b = Water Consumption

The results of the equilibrium are then used to create performance metrics, which allow for the comparison of water losses, analysis of their impacts, identification of key factors, and development of strategies to address them (Farley and Liemberger, 2005).

After the author creates water balance for Denpasar Sewakadherma Municipalities, the next step is using qualitative approaches. The author then finds anomalies or complexities that can affect the water balance calculation. Based on Minister of Health, water consumption/day/person (lpd) is around 120 lpd, while based on Ministry of Public Works and Housing (MPWH) its 170 lpd (Adhyatma, 1992). Yet, when calculating water consumption for Denpasar Municipalities, the author uses 129,46 l/p/day or equal to 19,42 m^3 per household/month. This number is based on the average consumption of the past 6 months. The municipalities acknowledge that people tend to reduce their water consumption when water tariffs increase. This finding also aligned with Tsur and Suárez-Fernández, et al. (Tsur, 2005; Suárez-Fernández, García-Valiñas and Martínez-Espiñeira, 2022). Smith and Al-Maskati, found that in Bahrain, households in a city experienced a 15% decrease in water consumption after the implementation of higher water tariffs (Smith and Al-Maskati, 2007).

In Traditional approach, when water consumption isn't locked to certain number, the municipality often failed to reach their targeted revenue. This due to the phenomenon where people tend to use less water during increase tariff. By locking 19.42 m^3 per household/month, the author then can find the number of additional households needed by PDAM Sewakaderma to reach their targeted revenue.

2.1. Study Area

2.1.1. Identifiying PDAM Sewakaderma Service Area & Water Production Capacity

The water supply system in Denpasar City has been operational since the era of Dutch colonization, precisely in 1932 when it was established as the Drinking Water Company. In 1971, the Australian Government extended financial assistance amounting to $1,194,000 under the Colombo Plan. This funding was effectively utilized for the development of multiple drinking water facilities as follows:

- 10 bore/deep wells with a total capacity of 425 l/d
- Build Transmission pipe 375 mm to 650 mm with total length 8,500 meters
- Build Distribution pipe 25 mm – 350 mm with total length 125,000 m
- Balance tank Darmasaba with 1.250 m^3 Capacity
- Build Belusung Reservoir with 10,000 m^3 Capacity
- Build Tonja Reservoir with 3,000 m^3 Capacity

In 2023, the water supply facilities that have been build since 1971, still used and opperated. In 2023, Denpasar Municipalities devide its networks into 7 different zone which can be seen from the following schematic diagram on Figure 1 and Figure 2.

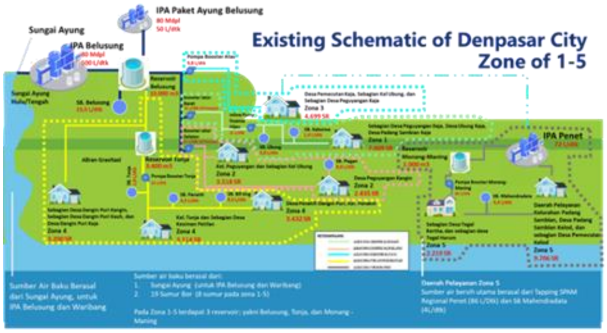

Figure 1. Existing schematic diagram of PDAM Sewakadherma (Zone 1 to 5) and development schematic diagram (PDAM, 2022).

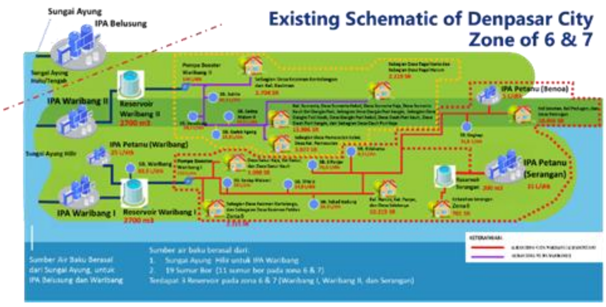

Figure 2. Existing schematic diagram of PDAM Sewakadherma (Zone 6 to 7) and development schematic diagram (PDAM, 2022).

In 2023, total water production Capacity of Denpasar Municipalities is around 1240 l/s. this is sourced from various WTP, Deep Wells, and tapping from other municipalities around Denpasar as can be seen from Table 1.

Table 1. Composition of Denpasar municipalities water production capacity (BPKP, 2021).

Composition (l/s)			
WTP Belusung	WTP Waribang	Deep wells	Off-Take
495	234	398	113

2.1.2. Identifying PDAM Sewakaderma NRW

As mentioned before, some of the drinking water facilities that are being used by Denpasar Municipalities were built around 1971. Some pipes made from Asbestos Cement Pipe (ACP) which are used for more than 40 years, have a high risk of leakage and therefore need to be replaced as soon as possible, this pipe shown in Table 2.

Table 2. Data of old ACP pipe in Sewakaderma municipalities.

No.	Ø	Length (m')	Year Built
1	4"	44,707	1976-1983
2	6"	15,352	1976-1980
3	8"	7,656	1976-1977
4	9"	1,990	1976
5	10"	1,054	1976
6	12"	6,965	1976
7	14"	2,209	1976-1990
8	15"	887	1975-1976
9	21"	730	1976
10	24"	7,501	1976
	Total	**89,051**	

The Old ACP pipes are spread in 7 zones with the percentage of spread in each zone as shown in the following Figure 3.

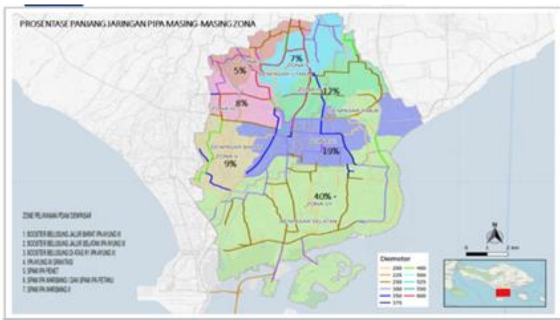

Figure 3. Map of the percentage pipeline length on each zone of Denpasar Sewakaderma municipalities (PDAM, 2022).

Table 3. Input volume, consumption, and water loss of Denpasar Sewakaderma municipalities in 2022 (PDAM, 2022).

No	Description	M³	%
1.	Input Volume	33.360.670	113
2	Unbilled metered consumption	3.255.612	9,8%
3	Non-Physical water loss	3.381.158	10,1%
4	**Physical water loss**	**6.047.448**	**18,1%**

With aged and deteriorated water networks. It's inevitable that physical water losses due to leakage contribute the highest percentage on municipal Total NRW. Based on Development and Finance Supervisory Agency report in 2022 (DFSA, 2021), it's recorded that Denasar municipal Input Volume /produce 33,360,670 m^3 water, unbilled metered water consumption 3,255,612 m^3 (9.8%), Non-physical water loss 3,381,158 m^3 (10.1%), and Physical losses 6,047,448 m^3 (18.1%) (see Table 3). Thus, in 2022 total NRW is 38%. Where the largest component is physical water losses.

3. RESULTS AND DISCUSSION

3.1. Effort to Reduce NRW

3.1.1. Pipe Replacement

As mentioned before, in general the largest component that contributes to 38% NRW is physical water losses which are mostly caused by aged and deteriorated pipes. Yekti, et al., argued that regular maintenance and repair of pipes and infrastructure play a crucial role in mitigating physical water loss (Yekti, Norken and Wentiari, 2019). This encompasses activities such as detecting and rectifying leaks, substituting worn-out or impaired pipes, and guaranteeing appropriate connections. In align with Yekti's et al findings, to reduce physical water losses in PDAM Sewakaderma, pipe replacement is needed. This measure is needed so that PDAM Sewakaderma can improve the network system into a drinkable water standard which is according to WHO standard (WHO, 2022). In PDAM Sewakaderma's pipe network, at least the total length of pipe that needs to be rehabilitated/replaced reach 1,460,651 m (consist of: 116,949 m main distribution pipe, 51,309 secondary distribution pipe, and 1,292,389 Tertiary distribution pipe).

3.1.2. Improve Monitoring on Each Zone

The first step to identify NRW is to measure the amount of water discharge in each zone, then the subsequent phase entails the quantification of authorized usage. Authorized usage is classified into four categories: billed metered consumption, billed unmetered consumption, unbilled metered consumption, and unbilled unmetered consumption. Access to billed metered consumption and billed unmetered consumption can be obtained either through the billing department or the subscription department. However, the existing data is based on district area, it's not devided based on Zone. Thus, to calculate each zone's NRW is difficult. Since there is no matched result between input volume (water discharge which is based on Zone) and authorized consumption (see Table 4).

Table 4. List of pipelines that need replacement.

Ø PIPA	Length (m)	Material	ZONE
1"	94,612	GI, PVC	1,2,3,4,5,6,7
1½"	308,140	GI, PVC	1,2,3,4,5,6,7
2"	401,170	GI, PVC	1,2,3,4,5,6,7
3"	211,670	GI, PVC	1,2,3,4,5,6,7
4"	164,220	AC, PVC, GI, GWI	1,2,3,4,5,6,7
6"	111,581	AC, PVC, DCI, GI, GWI	1,2,3,4,5,6,7
8"	48,924	AC, PVC, DCI, GI	1,2,3,4,5,6,7
9"	2,385	AC, PVC	3,6
10"	42,843	AC, PVC, JIS	2,4,5,6,7
12"	28,060	AC, PVC, STEEL	2,3,4,6,7
14"	13,629	AC, STEEL	3,4,5,6
15"	3,648	AC, DCI,	6,7
16"	11,755	PVC, PE, STEEL	3,4,5,7
21"	730	AC	6
24"	16,284	AC, STEEL	3,4,6

Table 5. Detailed input - consumpption of each zone.

ZONE	(a) Input Volume (M^3/Y)	(b) Consumption (M^3/Y)	NRW (M3)	NRW (%)
Zone 1	2,230,363	1.485.319	745.044	33%
Zone 2	1,408,994	1.410.845	-1.851	0
Zone 3	4.718.140	1.084.605	3.633.535	77%
Zone 4	6.349.569	2.254.101	4.095.468	64%
Zone 5	2.053.822	2.629.369	-575.547	-28%
Zone 6	9.547.823	6.858.497	2.689.326	28%
Zone 7	7.783.896	5.408.898	2.374.998	31%

According to Al-Bulushi, et al. it is emphasized that the accuracy and effective operation of water meters play a vital role in minimizing non-physical water loss (Al-Bulushi, Sulti and Abushammala, 2018). However, in the case of PDAM Sewakaderma, the current state of water meters is inadequate and fails to provide precise data on NRW in each Zone. Without accurate data of consumption in each zone, it will be difficult to measure % NRW. Thus, another thing that is important for Denpasar Sewakaderma Municipality to reduce NRW is to improve their monitoring and leakage detector on each zone. This can be done by:

1). Improving monitoring and controlled system using SCADA (Supervisory Control dan Data Acquisition)
2). Build District Meter Area (DMA) that spread on each zone.

Utilizing advanced technologies such as SCADA systems and software like WaterCAD can enhance water loss control by providing real-time monitoring and data analysis. Romdloni, argued that implementation of this approach by the municipalities may enhanced efficiency in the management and optimization of water distribution systems (Romdloni, 2022).

Meanwhile, implementing DMA is aligned with Renggani findings (Rengganis, 2022). They argued that Implementing District Metered Areas (DMAs) can enhance water loss control efficiency by segmenting a large distribution system into smaller, independent sections. This strategy enables focused monitoring and upkeep, ultimately decreasing Non-Revenue Water (NRW). By replacing pipe and improving monitoring system. Through water balance simulation, NRW predicted to reach 19,5% in 2044 this can be seen in Figure 4.

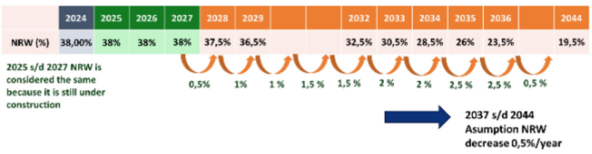

Figure 4. Assumption of NRW reduction.

3.2. Utilization of Water Surplus

The amount of water that can be saved due to NRW reduction can be utilized by Denpasar Sewakaderma Municipality, to increase coverage and customers. The increase of water thiat can be sold can be seen in Figure 5.

By using 129.46 l/p/day or equal to 19.42 m^3 per household/month, the number of customers that are predicted to be added as a new customer of Denpasar Sewakaderma Municipality will be around 20,750 households. Or it will reach 118,210 customer in 2044.

Figure 5. Increase of water sold.

4. CONCLUSION

Leaks not only lead to monetary losses and the wastage of a precious natural asset, but they also present a hazard to the health of the public. This peril to the welfare of the community can emerge when contaminants infiltrate the pipeline through leakages caused by a decrease in water pressure within the distribution network.

Denpasar city had a water supply management crisis; thus, the current system uses an extra 150 l/s from other regional networks to meet water demand. Water utilities face a major challenge in the form of a significant volume of water lost in the distribution network. This loss of water does not contribute to any financial gains, and the considerable losses add to the complexity of maintaining water tariffs at a fair and affordable level. In 2021, Water supply company suffered losses. In situations where there is intermittent water supply, often due to excessive leakage, it is the urban poor who bear the brunt of the consequences. This is primarily because they lack the financial means to invest in adequate storage facilities and pumps. Consequently, they are compelled to purchase water from vendors during periods when the supply is unavailable. Total NRW of Municipal Sewakaderma Denpasar in 2022 is 38%. The highest are physical losses up to 18%. The next step for reducing NRW is network review. Replacing 116.95 km of Main Distribution Pipe and 51.3 km Secondary Distribution Pipe. By minimizing physical losses, a greater quantity of water will be accessible, thereby empowering water utilities to expand their reach and enhance coverage and add new customers including the poor communities.

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