Non-Revenue Water (NRW) and its handling for a drinking water supply system in Kedewatan zone Gianyar Bali

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Abstract. Non-Revenue Water (NRW) is a common issue of drinking water supply system. NRW can be detrimental that should be addressed properly including NRW rates, NRW caused, and a guidance for preventing and reducing NRW. The water loss measured through water balance that calculated the percentage for differences the water distribution (m³) with the water recorded (m³) on the bill. Infrastructure Leakage Index (ILI) used to calculate the physical water loss based on the standard target matrix of IWA (International Water Association). The causes and handles of NRW were analysed based on a step test result, Ultrasonic Flow Meter (UFM) test result, and interviewing PDAM staffs. The result of NRW rates reach 986,884.92 m³/year (65.53 %). The ILI index was 69.98, and the water pressure was 17.2 m. As a result, this zone included D category, that has high of water loss rate > 200/s/connection/day. In this zone, the causes of water loss are categorized into the physical and non-physical water loss, and the mitigation must be carried out according to the type of water loss occurred. PDAM Gianyar should investigate the possibility of non-physical water loss so that can reduce the level of water loss and the ILI value. The further research can be conducted an evaluation of the whole network with the purpose of NRW can be calculated maximally.

1 Introduction

Regency of Gianyar has 47.9% of water loss, which is the highest in Bali and above of the standard Minister of Public Works regulation number 20/2006 that is equally 20%. NRW has occurred through physical and non-physical of water loss [1]. The physical of water loss can be caused by leakage of pipes transmission, distribution, and overflow of a reservoir. Although the non-physical of water loss can be caused by administrative errors, inaccuracy of water meters, and stealing water [2]. Moreover, NRW is not simply to be addressed, because of the repairing of the network must be identified by the location or the point where the water loss occurred [3, 4]. However, there are needed a high finance of investment [5] and a length of time to search the location nevertheless the water loss continued as time goes [6]. Moreover, the study needs to minimize the NRW value.

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Kedewatan Zone is a region of tourism and a part in District of Ubud, Regency of Gianyar. The number of customers has 1,787 SR (home connection) and an increase of NRW every month from July 2016 until December 2017, so that the earnings of PDAM (Local Water Supply Utility) was reduced, accordingly the maintenance of the network was increased. The NRW values are 17.08%, 50.7%, 58.47%, 61.55%, 65.26%, 67.13% from July until December 2016. The financial loss have been developed from the progressive of water loss, in other words, is a strong objective to do many efforts related to minimizing the water loss.

2 Methodology

The analyse data of accuracy meters can review the accuracy of water meters in customer’s connection (SR). The measurement of accuracy meters has conducted with a 20 litres of jerry can that was calibrated using a measuring glass. The calibration used to ensure the container precisely and accurately that can accommodate the volume of water [7].

The pipeline segments which have the greatest of potential loss dividing with the pipe segment V10 and V12 (the points location) based on the step test on 24 February and 11 August 2017. Therefore, 23 home connections (SR) of samples were taken with the highest of potential water loss, and the primary data was collected on 16 January 2018 by 2 surveyors. Formerly the research method described in Fig. 1.
3 Results and discussion

Kedewatan Zone is one of the service areas of PDAM Gianyar which has been established since 1980. The zone consists of six service areas, namely Br. Tanggayuda, Br. Bunutan, Br. Kedewatan Let, Br. Payogan, Br. Lungsiakan, and Br. Kedewatan Anyar. The number of customers is 1,787 SR with the majority consumption of water needs for the household and tourism. The water source of Kedewatan Zone was purchased from a private company, and was served by Air Jeruk Reservoir and a WTP (Water Treatment Plant). This zone has a gravity flow through the open branch of distribution of the network system.

The amount of water discharge for the Kedewatan Zone is 47.71 l/d, and for water needs is 16.15 l/d. Kedewatan Zone pipeline network consists of the transmission and distribution pipelines. The transmission pipeline network is the carrier of pipeline segments from the production unit to the reservoir, which has a pipeline segment from BBT (pipe 12”) to the Air Jeruk Reservoir and WTP Reservoir. Although the distribution pipeline network is the carrier of pipeline segments from the reservoirs to the service networks via diameter of pipes 2”, 3”, 4”, 6”, 8”, and 12”. The service networks were accomplished with the accessories of pipes such as valves, manometers, and water meters [8].

3.1 Calculate non-revenue water

The amount of water volume that was distributed and consumed for Kedewatan Zone based on data report from January to December 2017 of PDAM Gianyar is in Table 1.

\[
NRW = Volume\ of\ Input\ System - Billed\ Official\ Consumption
\]

NRW = 125,493.58 – 43,253 = 82,240.41 m³/month = 986,884.92 m³/year.

The value of NRW in percent can be calculated as:

\[
NRW\ (%) = \frac{Volume\ of\ Input\ System - Billed\ Official\ Consumption}{Volume\ of\ Input\ System} \times 100\%
\]
NRW (%) = \frac{125,493.58 - 43,253}{125,493.58} \times 100\% = 65.53\%

The percentage of NRW was exceeded from 20% of the water distributed. The result shows that NRW can be classified as high level [9] because the water loss are more than 50% of the distributed water, then it needs some strategies for reducing the water loss.

**Table 1.** Distribution and consumption in Kedewatan Zone.

| No | Month  | Distribution (m$^3$) | Consumption (m$^3$) | Maintenance (m$^3$) | SR |
|----|--------|----------------------|---------------------|---------------------|----|
| 1  | January| 129,980              | 38,752              | 21.85               | 1756|
| 2  | February| 148,288             | 44,537              | 451.00              | 1761|
| 3  | March  | 92,619               | 40,869              | 458.15              | 1767|
| 4  | April  | 85,304               | 36,302              | 47.80               | 1771|
| 5  | May    | 130,409              | 44,685              | 1870.65             | 1772|
| 6  | June   | 139,851              | 45,238              | 24.20               | 1777|
| 7  | July   | 129,116              | 47,641              | 252.17              | 1779|
| 8  | August | 120,319              | 36,945              | 2947.68             | 1779|
| 9  | September| 115,948             | 42,075              | 3292.06             | 1780|
| 10 | October| 121,590              | 47,094              | 362.16              | 1784|
| 11 | November| 144,584             | 46,391              | 3292.06             | 1785|
| 12 | December| 147,914             | 48,509              | 1211.01             | 1787|
|    | Average| 125,493.58          | 43,253              | 1185.90             | -  |

### 3.3 Customer’s water meter

The accuracy of the customer's water meter needed as primary data for this study. The result of the survey showed that in 23 samples there were 6 of inaccuracy water meter and 2 samples could be not read. There are 3 water meters had a difference of 0.1 litres, and 3 water meters had a difference of 0.2 litres. The total of water meter inaccuracy was 0.9 litres for 23 samples. The accuracy of the water meters has been decreased. The decreasing of accuracy water meters was produced by volume of water to be unreadable accurately, subsequently the non-physical of water loss occurred.

\[
\text{Customer’s inaccuracies} = \frac{\text{The difference water volume}}{\text{Number of samples}} \times 100\% \\
= \frac{0.9}{20 \times 21} \times 100\% = 0.214\%
\]
The calculation was conducted by multiplying the inaccuracy of water meter with the volume of the input system. The water meter inaccuracy was 2% that still below to 20% of allowable limit. The physical water loss was 268.91 m³/month = 3226.98 m³/year.

### 3.4 Water balance

The water balance can indication the level and amount of water loss both physically and non-physically in a water supply system [10]. The calculation of water balance below:

- **Step 1:** to determine the volume of input system
  
  \[
  \text{Volume of input system} = 125,493.58 \text{ m}^3/\text{month} = 1,505,922.92 \text{ m}^3/\text{year}
  \]

- **Step 2:** to determine the official consumption
  
  The official consumption is the amount of metered consumption, as well unbilled, and unmetered consumption:

  \[
  \begin{align*}
  &\text{Billed and metered} \quad = 43,253.17 \text{ m}^3/\text{month} = 519,038 \text{ m}^3/\text{year} \\
  &\text{Unbilled and unmetered} \quad = 1185.90 \text{ m}^3/\text{month} = 14,230.79 \text{ m}^3/\text{year} \\
  &\text{The official} \quad = 519,038 + 14,230.79 = 533,268.79 \text{ m}^3/\text{year}
  \end{align*}
  \]

- **Step 3:** to calculate the water loss
  
  \[
  \text{The water loss} \quad = (a) - (b)
  \]

  \[
  \text{The water loss} = 1,505,922.92 - 533,268.79 = 972,654.13 \text{ m}^3/\text{year}
  \]

- **Step 4:** to calculate non-physical loss
  
  The non-physical loss = water meter inaccuracies = 3226.98 m³/year

- **Step 5:** to calculate physical loss
  
  \[
  \text{The physical loss} \quad = (c) - (d)
  \]

  \[
  \text{The physical loss} = 972,654.13 - 3226.98 = 969,427.15 \text{ m}^3/\text{year}
  \]

- **Step 6:** to calculate the water balance
  
  In Table 2 present the amount of NRW was 986,884.92 m³/year (65.53%) with a very high level of water loss that was 972,654.13 m³/year (64.59%). The water loss were divided 969,427.15 m³/year (64.37%) for the physical water loss, and 3226.98 m³/year (0.21%) for non-physical water loss.

### Table 2. Water balance of Kedewatan zone in 2017

| Volume of input system = 1,505,922.92 m³/year (100%) | Official consumption = 533,268.79 m³/year (35.42%) | Billed official consumption = 519,038.0 m³/year (34.47%) | Billed metered consumption = 519,038.0 m³/year (34.47%) | Billed unmetered consumption |
|---|---|---|---|---|
| Unbilled official consumption = 14,230.79 m³/year (0.95 %) | Unbilled metered consumption | Unbilled unmetered consumption | Unbilled unmetered consumption |
| Water loss = 972,654.13 m³/year (64.58 %) | Physical loss = 969,427.15 m³/year (64.37%) | Non-official consumption | No-official consumption |
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3.5 Infrastructure Leakage Index (ILI)

The calculation of Infrastructure Leakage Index (ILI) can identify the physical loss [11] based on the standard target matrix of IWA (International Water Association) [12] below:

a) Step 1: to calculate CAPL (Current Annual of Physical Loss)

CAPL is the annual volume in litres/year (from the water balance)

\[
\text{CAPL in (litres/day)} = \frac{969,427.15 \text{ m}^3/\text{year}}{365} = 969,427,150 \text{ litres/year} \\
\text{CAPL} = 2,692,853.19 \text{ litres/day}
\]

b) Step 2: to calculate MAAPL

MAAPL is a minimum annual physical loss estimation that can be achieved when the infrastructure is in good condition and there is a control leakage

\[
\text{MAAPL (litres/day)} = (18 \times L_m + 0.8 \times N_c + 25 \times L_p) \times P
\]

where MAAPL = Minimum Achievable Annual Physical Loss (litres/day), \( L_m \) = primary pipe length (km), \( N_c \) = number of home connection (SR), \( L_p \) = average length of distribution pipeline (km), \( P \) = average pressure (m).

The recognized values:
\[
L_m = 25,020 \text{ m} = 25.02 \text{ km} \\
N_c = 1787 \text{ SR} \\
L_p = 0.008 \times 1787 = 14.296 \text{ km} \\
P = 1.72 \text{ atm} = 17.2 \text{ m}
\]

So that MAAPL can be calculated:
\[
\text{MAAPL} = [18 \times L_m + 0.8 \times N_c + 25 \times L_p] \times P \\
\text{MAAPL} = 38,482.59 \text{ litres/day} = 13,853,733.12 \text{ litres/year}
\]

c) Step 3: calculate ILI

\[
\text{ILI} = \frac{\text{CAPL}}{\text{MAAPL}}
\]

\[
\text{ILI} = \frac{969,427,150}{38,482.59} = 69.98
\]

Additionally, the ILI values and the pressure averages are compared with the target matrix of physical water loss that the matrix expressions the expected level of ILI values [11] and physical loss for drinking water companies in various countries [13] [14]. As a result, the ILI adjustment with the matrix of physical water loss target that founded this zone was included in the category D performance. The category D included the level of physical water loss that was extraordinary. Therefore, the company must conduct a program to reduce the water loss in Kedewatan Zone.

3.6 Causes and mitigation non-revenue water

The causes of NRW were analyzed with the results of step tests (secondary data), the accuracy of water meters, and interviews of PDAM employees in the transmission and distribution sections. In Kedewatan Zone, the three times of step tests were considering because this zone was a wide enough so that the time is needed was more than one night.
The implementation of the *step test* did not run perfectly, so only the pipelines that had the potential leakage were identified. Moreover, the Ultrasonic Flow Meter (UFM) was as a follow-up to the *step test*.

In Kedewatan Zone based on the results of the step test, the UFM test and the interview founded there are several causes of water loss that divided in two aspects: 1) physical water loss such as the pipe accessories were not functioning properly, the roots of trees wrapped the pipes, the leakage of distribution network, the disconnection of distribution pipes, the old of the networks, and the decreasing of pipe strength, and 2) non-physical water loss such as the accuracy of the water meter, the administration errors, the commitment to human management, the human resources, and the availability of equipment.

NRW prevention that occurs must be in accordance with the causes that based on the NRW causes mentioned above, the efforts can be taken to minimize NRW are as follows: 1) physical water loss such as: the replacement of the pipe accessories, the rejuvenation of the network, the pressure control, the upgrading time of repairing, the controlling time of water loss, and the installation of DMA (District Meter Area) [15], and 2) non-physical water loss such as: the calibration and replacement of water meter, the training for employees, the survey house to house, and the implementation of sanction to illegal activities.

4 Conclusions

In Kedewatan Zone, Non-Revenue Water occurred 65.53% (986,884.92 m$^3$/year) with a water loss 972,654.13 m$^3$/year (64.59%) dividing the physical water loss 969,427.15 m$^3$/year (64.37%) and the non-physical water loss of 3226.98 m$^3$/year (0.21%). The value of Infrastructure Leakage Index (ILI) was 69.98 with a pressure of the system 17.2 m. This zone classified in category D with a physical leakage rate > 200 litres/SR/day. In Kedewatan zone, the cause of water loss is categorized into two categories, the physical and non-physical water loss. The mitigation can be done to suppress the NRW value that must be carried out according to the type of water loss occurred. The company should increase the speed of localizing pipelines that have the potential for water loss so that the water loss points are more briefly to be found. Accordingly, the NRW and the water loss experiences can be minimized. The company should review the components of the old network and infrastructures, then repairing the damaged pipes. PDAM Gianyar should investigate the possibility of non-physical water loss that can reduce the level of water loss and the ILI value. For further research that can be conducted an evaluation of the whole network with the purpose of NRW can be calculated maximally.

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