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Pipe Characteristics Influence on Burst Incidence and Non-Revenue Water

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Abstract

NRW are due to unbilled water consumption, unauthorized use, meter inaccuracies, data handling errors, and leakage in pipe or storage tank. NRW is undesirable as it is seen as one of the stumbling block towards achieving sustainable water management. NRW is a world-wide issue. The government of Malaysia has set the target of reducing NRW down to 25% by year 2030. In order to address this issue, the goal of this study is to establish relationship between pipe burst cases and NRW. Characteristics of pipe that influence pipe burst were also investigated. Records of pipe burst cases, and NRW of districts of Tangkak and Muar within the period of 5-year, i.e. from 2018 to 2022 were used to obtain regression relationship. Analyses have shown that 45.2% to 52.9% of pipe burst cases involved pipe with size 150 mm. Pipe with diameter 100 mm contributed to 32.4% to 37.6% of the burst cases. These pipes are located after the service tanks, i.e. within the reticulation system. Materials of 150 mm pipe and 100 mm pipe are mostly of MS and GI. The rate of NRW can be estimated based on number of pipe burst cases BC, where NRW = 7.08BC + 108.7. Rate of NRW is seven-fold of the number of pipe burst case. The R-squared shows that the relationship represented 64.93% of the 5-year data. These results highlighted that pipe burst/leakage is one of the main cause of NRW generation. Further studies can be made to determine whether location of pipe (e.g. subject to traffic loading, or effect of soil characteristics) also plays an important role in burst cases.

1. Introduction

In late 1990s, the International Water Association (IWA) has established a Water Loss Task Force (WLTF) with the role to examine international best practices and develop performance indicators related to water loss. WLTF defines non-revenue water (NRW) as "difference between volume of water put into a water distribution system and water that is billed to customers” [1]. Fig. 1 shows components of water supplied which account for NRW [2]. NRW comprises of (a) unbilled authorized consumption; (b) apparent commercial losses (unauthorized consumption, and errors in meter and data); and (c) real physical losses (leakages). Improving NRW is one strategy in sustainable water supply management, gearing towards achieving UN Sustainable Development Goal (SDG) 6 on Clean Water and Sanitation [3].

<table>
<tr><th colspan="7">IWA & AWWA Water Balance</th></tr>
<tr><td rowspan="9">Volume From Own Sources (corrected for known errors)</td><td rowspan="11">System Input Volume</td><td>Water Exported (corrected for known errors)</td><td colspan="3">Billed Water Exported</td><td>Revenue Water</td></tr>
<tr><td rowspan="10">Water Supplied</td><td rowspan="4">Authorized Consumption</td><td rowspan="2">Billed Authorized Consumption</td><td>Billed Metered Consumption</td><td rowspan="2">Revenue Water</td></tr>
<tr><td>Billed Unmetered Consumption</td></tr>
<tr><td rowspan="2">Unbilled Authorized Consumption</td><td>Unbilled Metered Consumption</td><td rowspan="8">Non-revenue Water</td></tr>
<tr><td>Unbilled Unmetered Consumption</td></tr>
<tr><td rowspan="6">Water Losses</td><td rowspan="3">Apparent (Commercial) Losses</td><td>Customer Metering Inaccuracies</td></tr>
<tr><td>Unauthorized Consumption</td></tr>
<tr><td>Systematic Data Handling Errors</td></tr>
<tr><td rowspan="3">Real (Physical) Losses</td><td>Leakage on Transmission and Distribution Mains</td></tr>
<tr><td rowspan="2">Water Imported (corrected for known errors)</td><td>Leakage and Overflows at Utility’s Storage Tanks</td></tr>
<tr><td>Leakage on Service Connections up to the Point of Customer Metering</td></tr>
<tr><td colspan="7">NOTE: All data in volume for the period of reference, typically one year.</td></tr>
</table>

Fig. 1 *Water balance model which shows components of NRW (in green-colored cells) [2]*

In Asia’s urban areas, it is estimated that 29 billion m^3 of treated water is lost annually [4]. According to National Water Services Commission (SPAN) of Malaysia, national average NRW in 2022 was 37.2%, which is equivalent to 7.084 million litres/day of water or RM2 billion/year. In December 2020, Ministry of Environment and Water has announced that the government aims to reduce NRW in Malaysia from 36.8% (in 2020) to 30% in 2025 and 25% by 2030 [5].

Annual Report 2022 of Ranhill Utilities Berhad reported that Johor annual average NRW is 26.3%, which is marginally higher than SPAN’s key performance indicator of 26.0% [6]. The report attributed the NRW in Johor to leakages in water supply network, ageing reticulation and distribution assets, and unplanned water supply disruption due to low quality of raw water and disruption of electricity power supply. It has been reported that the age of underground water supply pipes in Johor are between 30 and 40 years old [7]. A utility map system has traced about 26,000 km of underground pipelines in the state of Johor. Approximately 20,000 km of pipelines have been upgraded or replaced [7].

Objectives of this paper are to assess effect of pipe characteristics on burst incidence, and establish relationship between burst cases and physical water losses of NRW. The study investigated pipe burst cases of two Johor districts, i.e. Muar and Tangkak within five-year period, i.e. between 2018 and 2022. Characteristics of pipe, i.e. material and diameter of pipe were correlated against pipe burst incidence.

1.1 Water Supply Network in Johor

Each state or territory in Malaysia is responsible for overseeing water supply operations within its territory, including water abstraction, treatment, and distribution. Ranhill SAJ Sdn. Bhd., a subsidiary of Ranhill Utilities Berhad, is an integrated water supply firm that handles everything from water treatment and distribution of treated water to invoicing and collection in the state of Johor, Malaysia. Meanwhile, water supply tariff is regulated by SPAN. Fig. 2 shows typical components of water supply distribution system.

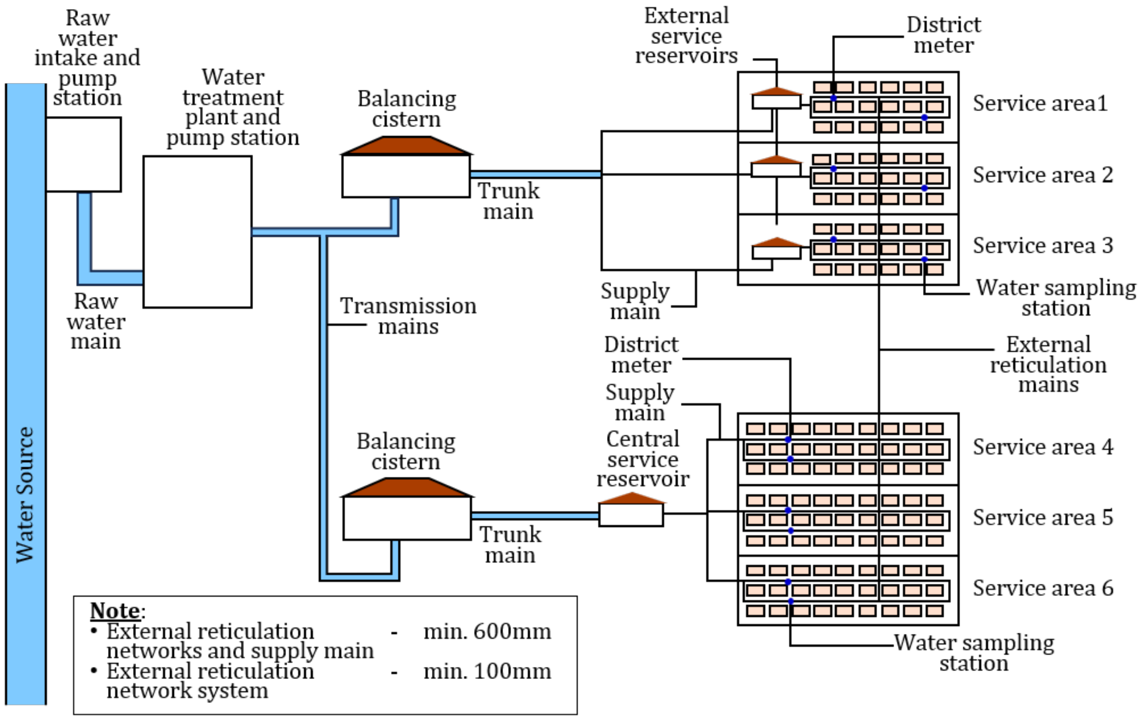

Fig. 2 *Water supply distribution system components [SPAN, 2018]*

Table 1 lists materials of water supply pipe within state of Johor. Trunk main typically consisted of mild steel (MS) and has a minimum diameter of 350 mm. Pipes after service tank are generally MS pipes, ductile iron (DI) pipes, and unplasticized polyvinyl chloride (uPVC) pipes. Size of MS and DI pipes ranges between 150 mm and 300 mm, while uPVC has size ranging from 75 mm to 150 mm. DI pipes are soon to be completely replaced by MS [7].

Table 1 *Distribution of types of water supply pipe in the state of Johor* [8]

Type of pipe	Length of pipe (km)
Unplasticized polyvinyl chloride (uPVC)	8,516.51
Asbestos cement (AC)	6,426.13
Mild steel (MS)	5,312.33
Ductile iron (DI)	1,942.50
High-density polyethylene pipe (HDPE)	876.09
Modified polyvinyl chloride (mPVC)	637.73
Cast iron (CI)	134.19
Others [9]	4.04
Total	23,849.52

1.2 Causes of Pipe Burst

Among the factors identified that lead to pipe burst [10],[11],[12],[13],[14] include:

i. High operating pressure/ internal pressure build-up in pipe;
ii. Background leakage e.g. continuous leak due to material gradual deterioration;
iii. Burst leakage, where initial pipe rupture can cause additional stress on adjacent sections of pipe, cause further rupture or burst;

iv. Transient pressure or water hammer produced by operational variations, pump starts or pauses, or network draw-off;
v. Corrosion in pipes;
vi. Poor quality of pipes, fittings and construction work;
vii. Soil or ground movement;
viii. Soil properties i.e. acidic or highly alkaline soils, pressure from soil settlement or compaction, expansion and contraction of soil due to varying moisture content, and abrasive soils;
ix. High or heavy traffic loading; and
x. Variations in temperature, e.g. due to freezing temperature, or extreme heat causing expansion of water.

Leakages in pipes can either be detectable or undetectable (Fig.3). Background leakage such as due gradual deterioration of pipe is not detectable at times. Reported leakages are typically leakages that appear above soil and detected through pressure management. This study is based on data on reported leakages due to pipe burst.

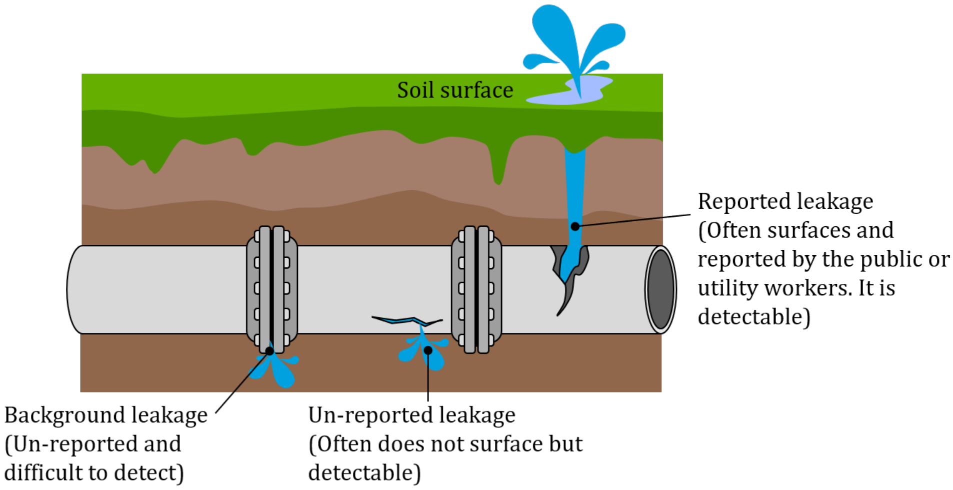

Fig. 3 *Types of leakage* [15]

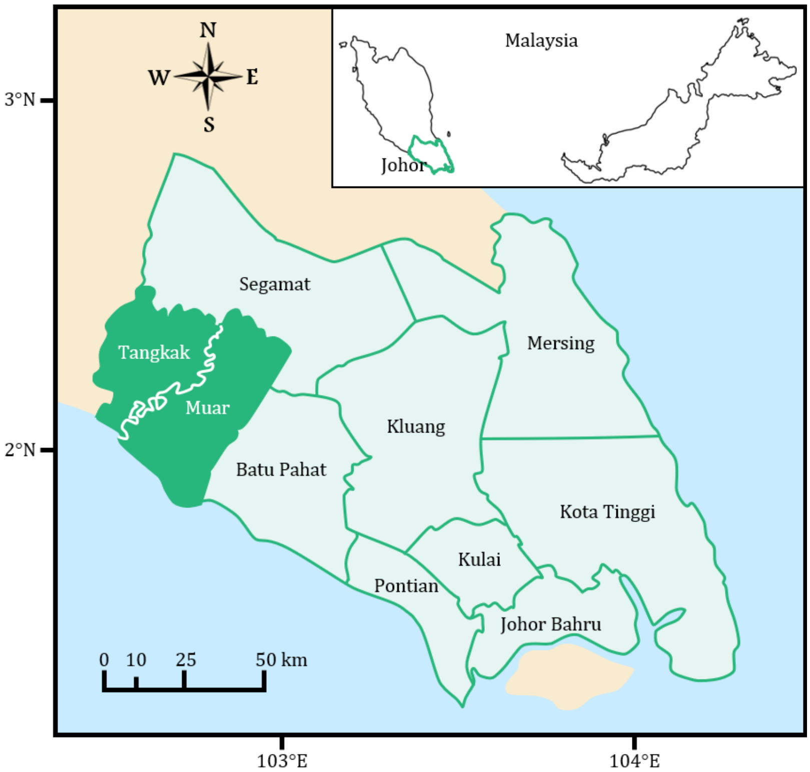

Fig. 4 *Incidences of pipe bursts in districts of Muar and Tangkak in Johor are linked with water losses. Inset map shows location of Johor state within Malaysia*

2. Materials and Methods

In 2022, there are as many as 425 cases of pipe bursts in Muar and Tangkak. The total cost of repair is a whopping RM 2,869,973.31. This has provided the motivation to assess how pipe leaks or bursts influence level of NRW, which implicate further losses.

2.1 Study Area

Due to overwhelming number of district metered areas (DMAs) within the state of Johor, the study focuses on two districts with available pipe burst case and NRW data. They are districts of Muar and Tangkak (Fig. 4). Muar and Tangkak has total land area of 135.4 km² [16] and 970.2 km² [17], respectively. Based on 2020 census, population of Muar and Tangkak are 314,776 and 163,449, respectively [18].

2.2 Data and Methods

For this study, monthly data of pipe burst cases and rate of NRW within period of 2018 and 2022 for 29 DMAs within Tangkak and Muar were collected and analysed. The study utilizes R-squared or R^2 to evaluate relationship between NRW and number of burst cases. R^2 is given as

$$R^2 = 1 - \frac{SSR}{SST} \tag{1}$$

where, SSR = sum of squared residuals; and SST = total sum of squares.

According to [19], R^2 is the preferred regression analyses than symmetric mean absolute percentage error (SMAPE), mean absolute error (MAE), mean absolute percentage error (MAPE), mean square error (MSE) and root mean square error (RMSE). R^2 value above 0.6 is considered reasonably accurate in science research [20].

3. Pipe Burst Incidence and NRW

Susceptibility to burst due to size of pipe and material of pipe has been investigated based on cases reported in Muar and Tangkak.

3.1 Susceptibility Based on Pipe Size

Between 2018 and 2022, a total of 2,614 pipe burst incidents involving pipe of sizes 75 mm and 900 mm were reported in the districts of Muar and Tangkak (Table 2).

Table 2 *Cases of pipe burst incidents reported and repaired in Muar and Tangkak between 2018 and 2022*

Diameter of pipe (mm)	Year				
	2018	2019	2020	2021	2022
75	6	4	8	4	7
100	170	192	234	176	149
150	277	265	281	242	214
200	31	38	42	39	25
225	0	0	1	1	0
250	21	22	39	30	16
300	10	8	14	13	11
375	3	1	1	3	2
400	1	0	0	1	0
450	3	3	2	0	1
600	1	0	0	0	0
900	1	1	0	0	0
Total	524	534	622	509	425

Number of pipe burst incidents in Table 2 is translated into annual percentages in Fig. 5. A total of 2,611 pipe burst incidents have been reported in Muar and Tangkak between 2018 and 2022. Every year shows that more than 45% cases reported involved pipe having diameter 150 mm. There is a consistency between number of incidents and size of pipe. Meanwhile, pipe burst cases involving 100 mm dia. pipe attributed to 32.4% ~ 37.6% of the five-year period statistics. This shows that smaller size pipes are more prone to burst. Pipes having diameter of 200 mm, 250 mm, 300 mm account for 5-year averaged of 6.7%, 4.8%, and 2.2%, respectively.

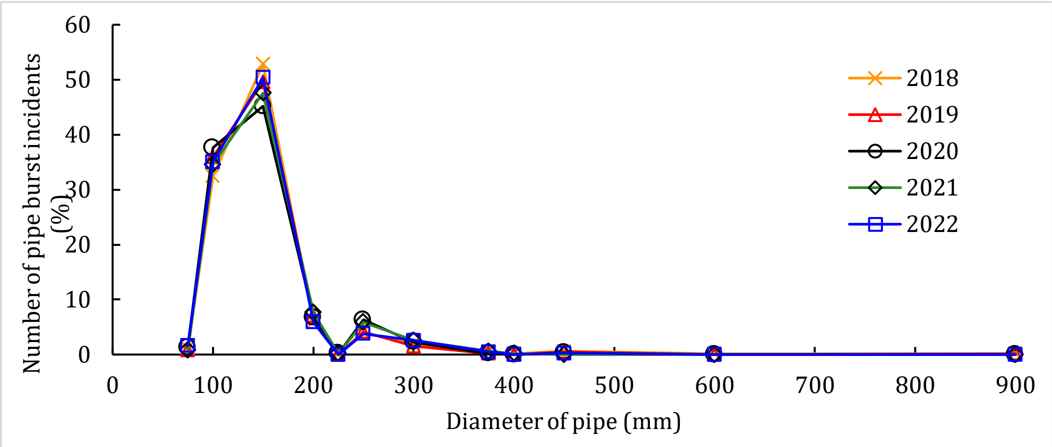

Fig. 5 *Distribution of pipe burst incidents according to size of pipe with diameter between 75 mm and 900 mm*

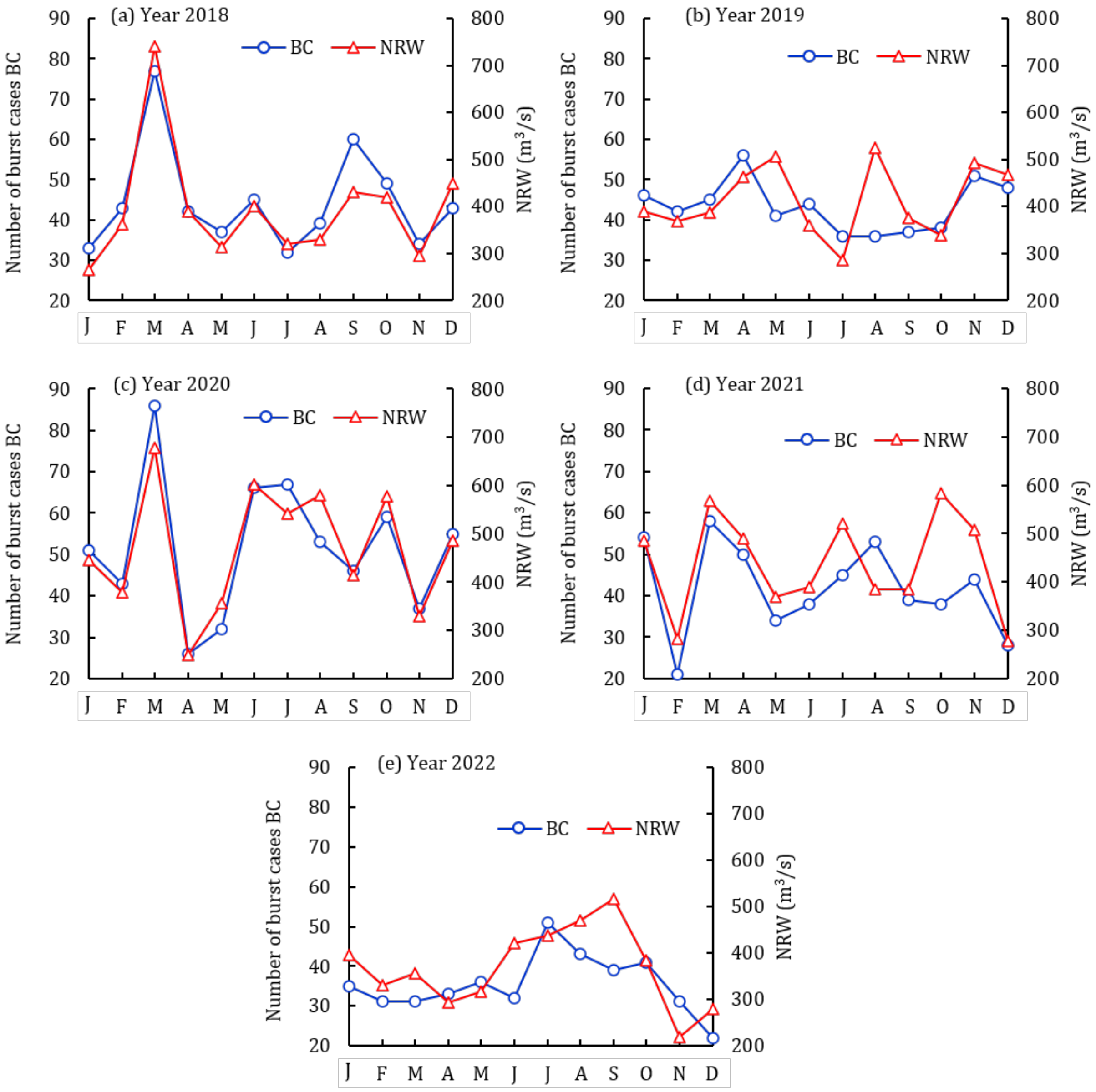

Fig. 6 *Monthly rate of NRW shows consistent trend with number of burst cases within period 2018-2022 of districts of Muar and Tangkak*

3.2 Susceptibility Based on Pipe Material

In state of Johor, most trunk main pipe has size of 350 mm and above and made of MS. Pipes after service tank which typically have size 300 mm and below are of either MS, DI, or uPVC pipes. Analyses have shown that most pipes with diameter 150 mm and 100 mm are prone to burst. These pipes are of typically of MS and DI. However, diameter of pipe has more influence than material of pipes, since leakages involving other pipe sizes with same material are uncommon.

3.3 NRW Due to Pipe Burst

There is a significant linear dependency of NRW rate on number of pipe burst cases BC. Fig. 7 shows that the relationship NRW = 7.08BC + 108.7 is represented by 64.93% of the NRW and BC data. According to [20], this R^2 of 0.6493 is reasonably accurate. Although this relationship is useful in determining NRW, it should be used cautiously. For Muar and Tangkak recorded pipe burst incidences, most cases involved pipe with diameter 100 mm and 150 mm. However, pipe with greater diameter, may further increase NRW. Also, there are other factors that contribute to NRW, especially those unauthorized and unbilled consumptions.

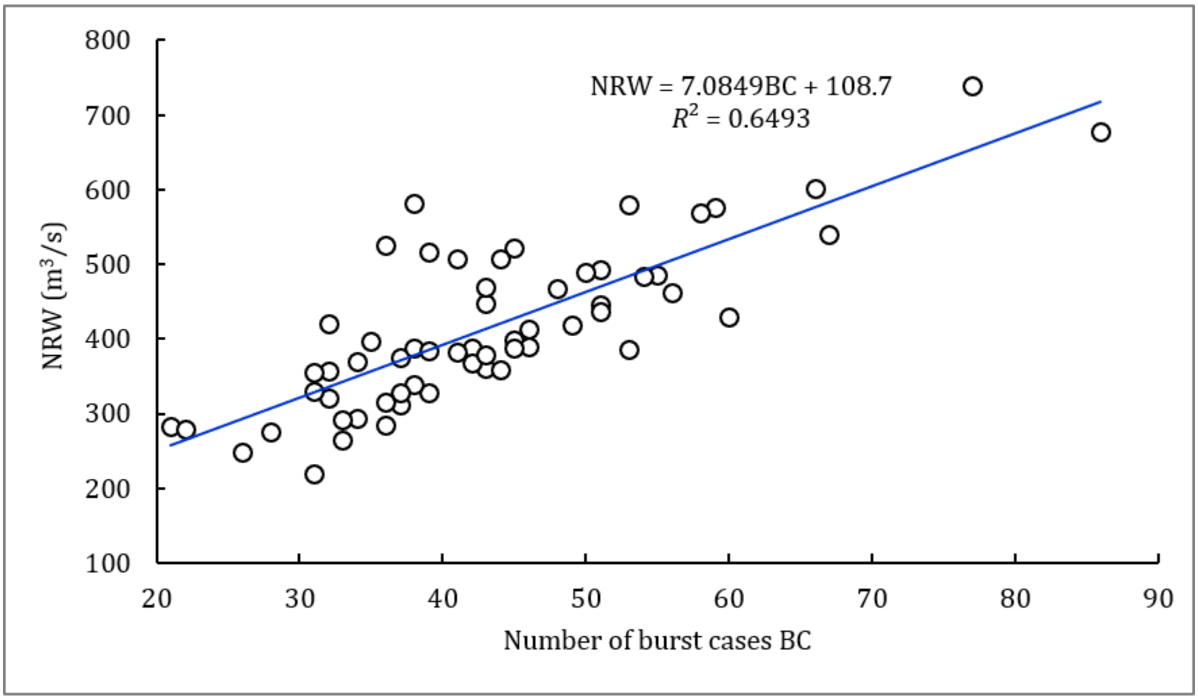

Fig. 7 *NRW is linearly dependent on number of burst cases.*

4. Conclusions

Pipe bursts may occur more frequently in some months than others, which may be due to higher consumption (attributed to drier weather) or heavier traffic (soil) loading, among others. This study which is conducted utilizing 2018 to 2022 data of Muar and Tangkak has shown that 82.1% to 85.6% of pipe burst cases annually involves pipe of size 100 mm and 150 mm. These diameters are typically of MS and DI pipes. Influence of pipe diameter on pipe burst, leading to NRW is more significant than material of pipe. Rate of NRW is also found to be linearly proportional to number of burst cases. NRW is approximately seven-fold the number of burst cases. There are so many aspects that can still be explored regarding the influence pipe characteristics and installation on NRW. Although, this study has looked at how diameter and material of pipe influence pipe burst and NRW, the accuracy can be further improved with inclusion of more pipe burst-related data and covering more locations.

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Conflict of Interest

Authors declared that there is no conflict of interests regarding publication of the paper.

Author Contribution

The authors confirm contribution to the paper as follows: ***study conception and design:*** *Mohd-Dom M, Tan L-W;* ***data collection:*** *Mohd-Dom M, Ngatenah S N B Z;* ***analysis and interpretation of results:*** *Mohd-Dom M, Tan L-W, Md-Yassin A, Chu V H, Tan W-S;* ***draft manuscript preparation:*** *Tan L-W, Mohd-Dom M. All authors reviewed the results and approved the final version of the manuscript.*

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