Watermain Breaks in Hong Kong: Causes and Consequences

Tayyab Ahmad
Department of Civil and Architectural Engineering, Qatar University, Doha, Qatar
tayyab@qu.edu.qa

Ibrahim Shaban
Mechanical and Aerospace Engineering Department, UAE University, Al Ain, United Arab Emirates
ibrahim.shaban@uaeu.ac.ae

Tarek Zayed
Department of Building and Real Estate, Polytechnic University Hong Kong, Hung Hom, Hong Kong
tarek.zayed@polyu.edu.hk

Abstract

Watermain failure is a complex problem associated with significant socio-economic and environmental impacts. The complexity of this problem originates from many factors of physical, operational, and environmental nature. These aspects have varying contribution towards watermain breaks depending on the regional context. This, therefore, requires specialized studies for each individual region. This study aims at adopting the text mining approach to investigate the aspects contributing to the failure of watermains in Hong Kong (HK) and the socio-economic and environmental consequences of these failures. In this regard, a sum of 94 media articles discussing HK-based watermain failures from 1984 onwards are studied. The findings showed that the aging pipes, hilly terrain, ground settlement, excavation works, and high-water pressure, are the most repeated failure causes in the media. The watermain bursts in HK are found to result in traffic disruptions and incidents, loss of water supply, loss of business activity, flooding inside buildings, cave-in incidents, etc. The inquiry has resulted in a network of interrelationships among consequences of main breaks indicating that these breaks are complex occurrences where chains of events lead to significant socio-economic and environmental impacts. This demonstrates the need of resilient Water Distribution Network (WDN) in HK and also the need of rigorous risk management to deal with the threats related to main failures. The causes behind breaks identified in this study can lead to the modelling of HK-based WDN helping forecast the occurrence of such events. The consequences of breaks identified in this study can help formulate risk management frameworks for HK-WDN.

Keywords: Water Distribution Network; Hong Kong; Break; Media report; Causes; Consequences

1 Introduction

Owing to the critical use of freshwater in daily life, well-conditioned watermains are needed to address the basic needs of society. Watermain failures lead to a multitude of problems, such as water supply disruptions, water waste, damage to nearby utilities, traffic gridlocks, and high maintenance expense from taxpayers' money. Hong Kong City, popular for its highest population density worldwide, has over 1,000,000 watermain assets (i.e., the number of pipes). Approximately, 85% of these assets transmit freshwater for drinking uses, and 15% are used to carry salt water for toilet flushing purposes. Although, the Water Supplies Department of Hong Kong (WSD-HK) pays reasonable attention to reducing the water losses from watermain leakages and breaks, at least until

2018, a high amount of water wastage from main failures was reported. In 2018, a Hong Kong-based watchdog claimed that the WSD-HK spent almost HK $530 million to control the frequent leakage incidents around the city. Over the last two decades, news media has actively reported the occurrences of main breaks across Hong Kong indicating socio-economic and environmental impacts of such failures.

Watermain failure studies are highly contextual primarily because of the different ages, materials, and environmental conditions of watermains. Studies have been conducted before to investigate the watermain failure in other regions such as Canada, USA, and the Netherlands; however, there is a general lack of such studies for HK-based WDN. Owing to the contextual nature of these studies, the practical application of these studies is often limited to their subject regions. The lack of research on HK-WDN needs attention.

With the focus on Hong Kong, the aim of this study is to help improve the resilience of HK-WDN and reduce the damages resulting from its failures. Accordingly, two key objectives are proposed. First, to study the causes of watermain failure in Hong Kong. Secondly, to study the consequences of watermain failure in Hong Kong. To achieve these objectives, text mining approach is used to analyse HK-based media and governmental reports.

Achieving the study's aim has significant theoretical and practical implications. Theoretically, the study will inform the factors contributing to main failure. These factors can further be employed in future studies for modelling the main failure. Also, a detailed account of the consequences of main failure will be useful in practice, to develop risk management measures which can be employed for HK-WDN.

The organization of this paper is such that, first a brief account of previous studies is provided in the literature review. This is followed by an explanation of the methodology employed, which will be followed by a detailed account of findings. Lastly, the study is concluded with an account of its limitations and directions for future studies.

2 Literature Review

The review of relevant studies indicates that the failure factors for watermains can be broadly categorized as pipe, soil, operational, and environment-related (see **Table 1**). The pipe-related factors are diameter, material, length, age, manufacturing defects, thickness, connection methods, and installation methods. Soil-related factors include bedding condition, soil properties, backfilling material, buried depth, and external protection. Operation-related factors include pressure head, water use rate, water quality, and internal corrosion. Lastly, environment-related factors include ground water level, precipitation, rain deficit, temperature, humidity, frost load, number of road lanes, location, population density, and street block length. Depending on the regional context of a WDN, some of these factors contribute more towards the failure of watermains than others.

Few studies have been conducted with attention towards watermain failure in Hong Kong. Shi, Zhang, and Ho (2013) conducted a spatial analysis of watermain failure in Hong Kong. The study revealed quantitative relationships between failure rate and pipe diameter, pipe age, material and temperature. Zhou, Ng, Yang, and Xu (2020) provided an approach to mine news articles to delineate infrastructure failure interdependencies and associated stakeholders. In this study, interdependencies in HK's watermain failure were identified and 25 associated stakeholders were also identified.

Table 1: Factors frequently associated with watermain failure

Reference	Kabir, Tesfamariam, Loeppky, and Sadiq (2016)	Fares and Zayed (2010)	Jafar, Shahrour, and Juran (2010)	Najjaran, Sadiq, and Rajani (2006)	Tesfamariam, Rajani, and Sadiq (2006)	B Rajani and Tesfamariam (2005)	Park (2004)	Balvant Rajani and Makar (2000)	Fan, Wang, Zhang, and Yu (2022)	Le Gat and Eisenbeis (2000)	Al-Barqawi and Zayed (2008)	Yannopoulos and Spiliotis (2013)	Rezaei, Ryan, and Stoianov (2015)
Diameter	x	x	x		x	x	x	x	x	x	x	x	x
Material	x	x	x	x	x	x	x	x	x		x	x	x
Length	x	x	x		x	x		x	x			x	
Age	x	x	x	x	x	x		x	x		x	x	x
Manufacturing defects	x												
Thickness					x	x							
Connection method												x	
Installation method													x
Bedding condition		x	x	x	x	x	x	x					
Soil properties	x	x	x	x	x	x	x	x	x	x			x
Backfilling material		x	x	x	x	x	x						
Buried depth	x	x	x	x	x	x	x						
External protection		x					x				x		
Pressure head		x	x	x	x	x		x			x	x	
Water use rate		x											
Water quality		x					x						
Internal corrosion		x	x		x	x							
Ground water level											x		
Precipitation	x												
Rain deficit	x												
Temperature	x			x	x	x		x	x				x
Humidity										x			
Frost load	x						x	x					
Number of road lanes											x		
Location	x	x	x	x	x	x					x		
Population density									x				
Street block length	x												

Some studies are also conducted regarding the consequences, damages or risks associated with watermain failure in different regional contexts. Pietrucha-Urbanik and Studziński (2019) conducted qualitative risk analysis of watermain failure in terms of water supply safety for a city in southern Poland. Fluctuations in the water supply was considered as the key consequence of main failure. In a study conducted by Laakso, Ahopelto, Lampola, Kokkonen, and Vahala (2017), the consequences of water and wastewater pipe failure were estimated for Helsinki region. In a study conducted for main breaks in the US, some of the significant consequences of main breaks were analyzed including property damage, health risks, and water losses (Yerri et al., 2017). Similar to the factors contributing to main failure, the consequences associated with main failure also vary from region to region, necessitating a specialized inquiry for Hong Kong region.

3 Methodology

The study employs a qualitative methodology where the causes and consequences of main failure are identified and analysed using text-mining of news media articles. The collection process of media reports is about selecting suitable media sources, determining relevant keywords for search process, and extracting the articles. Two key factors influencing the selection of media and news sources are reliability (i.e., need of verifying legitimacy of the sources) and collection burden (i.e., sources and efforts required to collect and store data through news sources) (Nam & Seong, 2019; Zhou et al., 2020). Integrated news engines such as Google News, Wise News, and Factiva are less time-consuming to retrieve than the news reported in individual newspapers. Accordingly, for this study, media and news articles are searched on 'Factiva' database. The search was constrained to Hong Kong region and English articles, however, no constraint on the publication time was applied.

Keyword logic used to search for articles: ("Watermain" OR "Water pipe" OR "Water infrastructure" OR "Water distribution network") AND ("failure" OR "break" OR "deterioration" OR "burst" OR "leak")

As a result of the preliminary search, 320 articles were obtained which were subjected to content analysis in NVIVO-12 application, where 94 articles met the criteria of relevance. The shortlisted articles are mostly published in 'South China Morning Post', 'The Standard', 'China Daily', 'Hong Kong Government News', 'Foreign Affairs', and 'XNEWS'.

The shortlisted articles were thoroughly reviewed and based on inductive and deductive thinking, 2 key themes were developed. The themes emerging from these shortlisted articles are about (1) causes of watermain failure and (2) sequence of damages from main failures. These themes are discussed in the next section.

4 Results and Discussion

4.1 Watermain Failure trends in Media reports

Watermain failures can be categorized as bursts and leaks. A leakage is a minor failure that needs tools and equipment to locate. On the contrary, burst are breaks in the mains resulting in flooding of water.

Upon analyzing the media reports extracted from Factiva database, it was found that the discussion on watermain failures have been covered only from 1984 onwards (Fig. **1**). Until 2003, very few articles reported main breaks and only from 2004 onwards multiple breaks have been reported in news articles each year. However, after year 2016, the number of such reports per year has, subsided.

The trends in bursts and leaks of HK-WDN are plotted (see Fig. **2**) in accordance with the data publicly shared by WSD (WSD, 2022a). When compared to the peak number of main leaks for year 2000 (number of leaks=22,428) and 2002 (n=23,729), the leaks have significantly reduced since 2016. Similar trends are also observed in terms of the number of bursts. This reduction in leaks and bursts can be associated with the regional attempts to repair and replace 3000 km of aged watermains to avoid the risk of failure (WSD, 2022b).

Five or less than five main failures reported in media for each year are insignificant compared to the actual number of main failures each year. This can be attributed to the fact that media reports cover the disruptive failures only (i.e., failures that cause either socio-economic or environmental impacts). This indicates that very few of the main failures in HK WDN are associated with noteworthy damages to property and service disruptions.

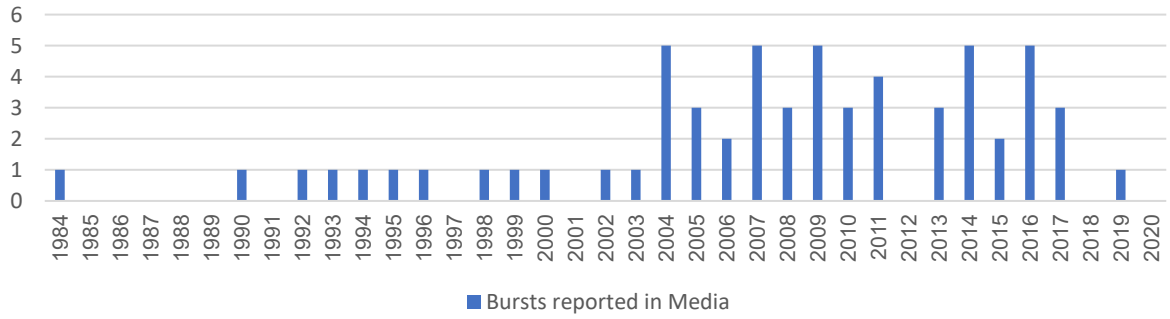

Fig. 1: Temporal trend of watermain breaks reported in news articles

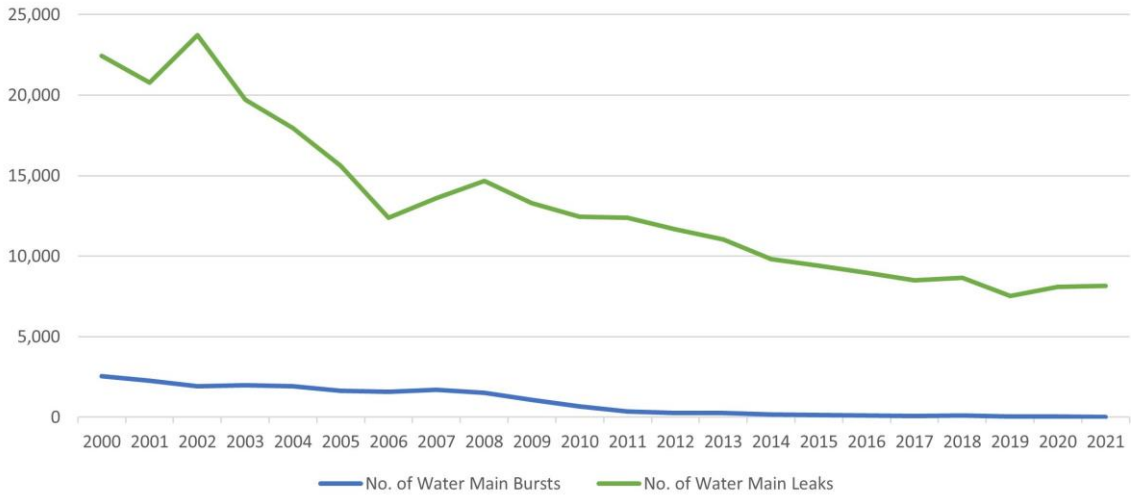

Fig. 2: Temporal trend of watermain breaks in Hong Kong

4.2 Causes of Watermain Failure in Hong Kong

As identified from news articles, the main causes of watermain breaks in Hong Kong include 'Aging watermains' (number of occurrences in media reports=9), 'Hilly terrain of Hong Kong' (n=2), 'Ground settlement' (n=2), 'Damage from excavation works' (n=2), 'High water pressure' (n=2), 'Road traffic' (n=1), 'Pressure from human crowd' (n=1), 'Frequent roadworks' (n=1), 'External loading and vibration' (n=1), 'Deformation of building foundations' (n=1), and 'Lack of coordination between Water Supplies Department and Transport Department' (n=1).

Some of the causes of main breaks are interlinked and are specific to Hong Kong because of its geography. Hong Kong's WDN has been developing according to demand. The system is massive and complex, measuring about 7,800 kilometers in total length. The hilly terrain of Hong Kong leads to relatively high-water supply pressure. For optimal use of scarce land resources in Hong Kong, service reservoirs are typically built at high level. The high-water pressure resulting from hilly terrain of Hong Kong contributes to main failure. While reporting about this issue, an article stated, "given the hilly terrain of Hong Kong, the water pressure of our water supply networks generally ranges from 60 to 80 meters, higher than the 40 meters or so of Singapore and other places by a margin of 50 per cent to 100 percent. High water pressure increases the risk of watermain bursts."

A significant area in Hong Kong is comprised of artificial islands. Ground settlement in such a topography can be more intense and frequent which according to an article has resulted in main breaks. Since WDN in Hong Kong is mostly occurring underneath the road network, the coordination between WSD and Transport Department seems immensely important. More so, as the lack of coordination between these two departments is reported as a cause of main breaks. Road and basement excavations in two reports are

found to be directly responsible for main breaks. Roadworks also indirectly affect the vulnerability of watermains as they add to the external loading and vibrations which can lead to main failure.

Some of the watermains bursting in Hong Kong are more than 30 years old. Monitoring the health of watermains and replacing old mains in Hong Kong is challenging because of its complex urban development. As reported in a news article, "improving the buried infrastructure in a dense environment like Hong Kong is sometimes like threading the eye of a needle. You do not have the luxury of simply opening up the road and laying a new pipe to replace the old."

These causes of main failure in Hong Kong indicate the context-specific nature of this problem. The high population density, land scarcity, and hilly terrain of the region are unique challenges which contribute towards the failure incidents of HK-WDN. Previous studies conducted in different regional contexts have also indicated age, water pressure, road traffic, and population density as factors contributing to main failure (Fan et al., 2022; Rifaai, Abokifa, & Sela, 2022; Shirzad, Tabesh, & Farmani, 2014). The damages resulting from the myriad of failure causes have severe impact on society and economy as explained in the next section.

4.3 Sequence of Damages from Watermain breaks

A key theme resulting from the analysis of news articles is about the sequence of damages and disruptions resulting from watermain failure in Hong Kong. Considering the content of news articles, this is the most important theme as articles have been mostly focused on the socio-economic losses and disruptions resulting from watermain breaks. **Fig. 3** indicates the damages and disruptions resulting from watermain failure in Hong Kong. The thickness of links (i.e., network edges) among different factors indicates the number of news articles indicating a certain sequence of events. For instance, many of the news articles (n=28) have indicated that 'watermain break' leads to 'traffic disruption', however, few articles (n=4) have discussed 'watermain break' leading to 'gas pipe rupture'. The mutual association of the factors (see **Fig. 3**) indicates that watermain breaks in Hong Kong lead to complex socio-economic problems.

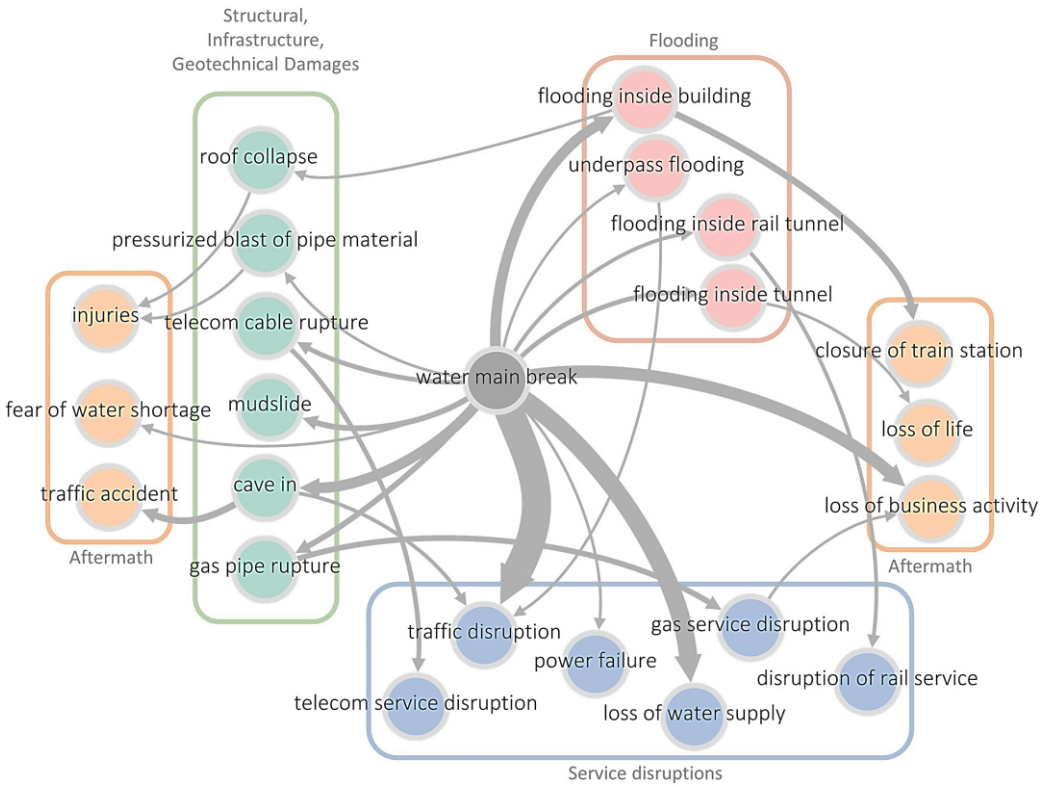

Fig. 3: Sequence of damages and disruptions from watermain breaks

The events resulting from main breaks and their subsequent effects on other events have been classified into four groups as shown in **Fig. 3**. The most frequent mention in news articles is that of service disruptions including traffic, railway, and utility disruptions. Traffic disruptions have single-handedly attracted most attention from news articles. Several structural, infrastructure, and geotechnical damages have also been reported in articles. These damages are a significant cause of service disruptions, as typically the former leads to later.

Flooding of buildings, underpasses, and tunnels from main breaks have also been largely reported. Watermain breaks either directly or by subsequent damages and disruptions lead to socio-economic losses such as injuries, casualties, panic, loss of business, and traffic accidents. Most of the reported damages are of built assets and surprisingly very few articles have indicated the occurrence of main bursts leading to injuries and deaths. Even in such accounts there are very few instances when the pressurized blast of pipe material leads to injuries. Most of the injury and casualty accounts are associated with roof collapses and flooding from main failures. Unsurprisingly, most of the damages and disruptions from main breaks are to road infrastructure or the utilities underneath roads. This is because Water Distribution Network in Hong Kong is mostly buried underneath the road infrastructure.

For Hong Kong, the average duration of fresh water supply interruption caused by main bursts in 2016 is 4.3 hours and in 2020 is 9 hours. The quantity of fresh water drained away because of main leaks in 2019 and 2020 was about 0.02% of the total annual water supplied (ENB, 2021). This indicates a significant environmental damage resulting from main breaks. In a study conducted for main breaks in US, some of the significant consequences of main breaks were also indicated as travel delays, property damage, health risks, and water losses (Yerri et al., 2017).

5 Conclusion

This study reviewed the media reports to identify the causes and consequences of watermain breaks in HK-based Water Distribution Network (WDN). Over the last two decades, Hong Kong news media has repeatedly reported the loss of life, injuries, loss of business activities, traffic disruptions and disruption of utilities (freshwater, telephone, and power) because of watermain failures. These losses are outcomes of mudslides, cave-in, and structural collapses resulting from main breaks.

Media reports are particularly useful when reporting the sequence of damages. Large scale and multi-regional studies conducted using the media reports can provide a high-resolution understanding of the damages from the main breaks and how they are interrelated. Studying such networks using the complexity theory can help develop effective risk management measures.

The limitations of this study lie within the data source used i.e., media reports. Damages which are not of socio-economic significance are typically not found in the media reports. Similarly, many deteriorating factors which are investigated in previous studies are not reported as failure causing factors in media reports. Hence, the news media seems to uncover some causes and consequences of main failure, yet leave the others unaddressed. Future studies regarding HK-WDN need to account for the limitations of this study by also resorting to other means of factor identification. The causes of main breaks identified in this study can help develop failure models of HK-based WDN helping forecast the occurrence of such events. The consequences of breaks identified in this study can help formulate risk mitigation measures for HK-WDN.

References

Al-Barqawi, H., & Zayed, T. (2008). Infrastructure management: Integrated AHP/ANN model to evaluate municipal water mains' performance. *Journal of Infrastructure Systems, 14*(4), 305-318.

ENB. (2021). *Examination of Estimates of Expenditure 2021-22*. Retrieved from https://www.isd.gov.hk

Fan, X., Wang, X., Zhang, X., & Yu, P. A. X. B. (2022). Machine learning based water pipe failure prediction: the effects of engineering, geology, climate and socio-economic factors. *Reliability Engineering & System Safety, 219*, 108185.

Fares, H., & Zayed, T. (2010). Hierarchical fuzzy expert system for risk of failure of water mains. *Journal of Pipeline Systems Engineering and Practice, 1*(1), 53-62.

Jafar, R., Shahrour, I., & Juran, I. (2010). Application of Artificial Neural Networks (ANN) to model the failure of urban water mains. *Mathematical and Computer Modelling, 51*(9-10), 1170-1180.

Kabir, G., Tesfamariam, S., Loeppky, J., & Sadiq, R. (2016). Predicting water main failures: a Bayesian model updating approach. *Knowledge-Based Systems, 110*, 144-156.

Laakso, T., Ahopelto, S., Lampola, T., Kokkonen, T., & Vahala, R. (2017). Estimating water and wastewater pipe failure consequences and the most detrimental failure modes. *Water Supply, 18*(3), 901-909. doi:10.2166/ws.2017.164

Le Gat, Y., & Eisenbeis, P. (2000). Using maintenance records to forecast failures in water networks. *Urban water, 2*(3), 173-181.

Najjaran, H., Sadiq, R., & Rajani, B. (2006). Fuzzy expert system to assess corrosion of cast/ductile iron pipes from backfill properties. *Computer-Aided Civil and Infrastructure Engineering, 21*(1), 67-77.

Nam, K., & Seong, N. (2019). Financial news-based stock movement prediction using causality analysis of influence in the Korean stock market. *Decision Support Systems, 117*, 100-112.

Park, S. (2004). Identifying the hazard characteristics of pipes in water distribution systems by using the proportional hazards model: 1. Theory. *KSCE Journal of Civil Engineering, 8*(6), 663-668.

Pietrucha-Urbanik, K., & Studziński, A. (2019). Qualitative analysis of the failure risk of water pipes in terms of water supply safety. *Engineering Failure Analysis, 95*, 371-378. doi:https://doi.org/10.1016/j.engfailanal.2018.09.008

Rajani, B., & Makar, J. (2000). A methodology to estimate remaining service life of grey cast iron water mains. *Canadian Journal of Civil Engineering, 27*(6), 1259-1272.

Rajani, B., & Tesfamariam, S. (2005). Estimating time to failure of ageing cast iron water mains under uncertainties, ICE Water Manag. *J, 160*(2), 83-88.

Rezaei, H., Ryan, B., & Stoianov, I. (2015). Pipe failure analysis and impact of dynamic hydraulic conditions in water supply networks. *Procedia engineering, 119*, 253-262.

Rifaai, T. M., Abokifa, A. A., & Sela, L. (2022). Integrated approach for pipe failure prediction and condition scoring in water infrastructure systems. *Reliability Engineering & System Safety, 220*, 108271.

Shi, W. Z., Zhang, A. S., & Ho, O. K. (2013). Spatial analysis of water mains failure clusters and factors: A Hong Kong case study. *Annals of GIS, 19*(2), 89-97. doi:10.1080/19475683.2013.782509

Shirzad, A., Tabesh, M., & Farmani, R. (2014). A comparison between performance of support vector regression and artificial neural network in prediction of pipe burst rate in water distribution networks. *KSCE Journal of Civil Engineering, 18*(4), 941-948.

Tesfamariam, S., Rajani, B., & Sadiq, R. (2006). Possibilistic approach for consideration of uncertainties to estimate structural capacity of ageing cast iron water mains. *Canadian Journal of Civil Engineering, 33*(8), 1050-1064.

WSD. (2022a). Number of Water Main Bursts/Leaks. Retrieved from https://www.wsd.gov.hk/en/core-businesses/major-infrastructure-projects/risk-based-improvement-programme-of-water-mains/number-of-cases-includes-damage-by-other-parties-/index.html

WSD. (2022b). Replacement and Rehabilitation Programme of Water Mains. Retrieved from https://www.wsd.gov.hk/en/core-businesses/major-infrastructure-projects/r-r-projects/index.html

Yannopoulos, S., & Spiliotis, M. (2013). Water distribution system reliability based on minimum cut–set approach and the hydraulic availability. *Water resources management, 27*, 1821-1836.

Yerri, S. R., Piratla, K. R., Matthews, J. C., Yazdekhasti, S., Cho, J., & Koo, D. (2017). Empirical analysis of large diameter water main break consequences. *Resources, Conservation and Recycling, 123*, 242-248. doi:https://doi.org/10.1016/j.resconrec.2016.03.015

Zhou, S., Ng, S. T., Yang, Y., & Xu, J. F. (2020). Delineating infrastructure failure interdependencies and associated stakeholders through news mining: The case of Hong Kong's water pipe bursts. *Journal of Management in Engineering, 36*(5), 04020060.

Cite as: Ahmad T., Ibrahim Shaban I. & Zayed T., "Watermain Breaks in Hong Kong: Identifying Causes and Consequences", *The 2nd International Conference on Civil Infrastructure and Construction (CIC 2023)*, Doha, Qatar, 5-8 February 2023, DOI: https://doi.org/10.29117/cic.2023.0187