ANALYZING THE COST-EFFECTIVENESS OF ENHANCEMENT APPROACHES FOR REHABILITATING WATER DISTRIBUTION NETWORK

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ABSTRAK

Pengurusan air lestari telah menjadi matlamat yang popular di dunia. Air bukan hasil (NRW) adalah salah satu bentuk kehilangan air. Terdapat sejumlah besar NRW, terutama di negara-negara membangun. Kerugian sebenar mewakili bahagian NRW yang lebih penting. Kerugian ini memberi kesan negatif kepada ekonomi dan membentuk halangan untuk mencapai kelestarian air. Oleh itu, tujuan kajian ini adalah untuk mengurangkan NRW. Kajian sistematik pertama kali dilakukan untuk mencari teknik dan kaedah yang relevan untuk memulihkan rangkaian pengedaran air (WDN), yang merupakan salah satu kaedah untuk mengurangkan NRW dan untuk mencapai tujuan penyelidikan yang mengurangkan NRW, setelah mengenal pasti pendekatan pemulihan WDN, tinjauan soal selidik di Malaysia dan Mesir dilakukan selama lima bulan dari bulan Jun 2020 hingga Oktober 2020. Tujuan utama tinjauan soal selidik adalah untuk mengenal pasti pendekatan peningkatan kos efektif. Sebanyak 109 responden dari Malaysia dan 67 responden dari Mesir, yang bermaksud sejumlah 176 responden dikumpulkan dan dianalisis. Ukuran sampel sesuai kerana sebahagian besar populasi yang disasarkan adalah di antara pengurus dan pengurus projek yang mempunyai pengalaman sekurang-kurangnya tiga tahun dalam bidang WDN. Penduduk ditentukan berdasarkan syarikat teratas dan pihak berkuasa air kerana penyelidikan ini memfokuskan pada pendekatan peningkatan pemulihan WDN yang maju. Kemudian, peringkat skor alpha, skor min, nilai normalisasi, dan analisis perjanjian Cronbach dilakukan dalam fasa analisis data. Hasil kajian menunjukkan bahawa pendekatan peningkatan kos efektif adalah pengaturcaraan, model, kawalan penyeliaan dan pemerolehan data (SCADA), dan digital berkembar. Selain itu, data dari Malaysia mencadangkan dua pendekatan peningkatan kos efektif: rangkaian zonasi dan algoritma genetik. Kedua teknik ini mungkin memiliki potensi besar untuk negara-negara membangun lain, seperti Mesir. Kemudian akhirnya, setelah mengenal pasti pendekatan kos efektif perbandingan antara pendekatan kos efektif antara Malaysia dan Mesir dilakukan. Memilih teknik yang betul dapat membantu pengamal industri memaksimumkan manfaat pemulihan WDN. Perbandingan akan membantu para penyelidik dan peserta industri untuk mengadopsi dan mengembangkan lagi pendekatan yang disarankan, Perbincangan pendekatan pemulihan peningkatan WDN dapat membantu menyesuaikannya dari negara lain di masa depan. Pemulihan WDN yang betul menyokong pengurangan NRW, yang terutama membantu menuju ke arah pengurusan air lestari di negara-negara membangun

Kata kunci: Pembangunan lestari, kehilangan air, Air bukan hasil, Rangkaian pengagihan air, Pemulihan WDN.

ABSTRACT

Sustainable water management has been a trending goal in the world. Non-revenue water (NRW) is one of the forms of water loss. There is a tremendous amount of NRW, especially in developing countries. The real losses represent the more significant portion of the NRW. These losses negatively affect the economy and formulate a barrier towards reaching water sustainability. Therefore, the aim of the study was to that reduce NRW. A systematic review was first conducted to find the relevant techniques and methods for rehabilitating water distribution networks (WDN), which is one of the methods to reduce NRW and to achieve the research aim which is reducing the NRW, after identifying the WDN rehabilitation approaches, a questionnaire survey in Malaysia and Egypt was carried through five months period from June 2020 to October 2020. The main aim of the questionnaire survey was to identify cost-effective enhancement approaches. A total of 109 respondents from Malaysia and 67 respondents from Egypt, which means a total of 176 respondents were collected and analyzed. The sample size is suitable as most of the targeted population are among the managers and project managers with at least three years of experience in the WDN field. The population was determined based on the top companies and water authorities as the research focuses on advanced WDN rehabilitation enhancement approaches. Then, Cronbach's alpha, mean score ranking, normalization value, and agreement analysis were carried in the data analysis phase. The results show that cost-effective enhancement approaches are programming, models, supervisory control and data acquisition (SCADA), and twin digital. Additionally, the data from Malaysia suggest two more cost-effective enhancement approaches: zoning network and genetic algorithm. These two techniques might possess great potential for other developing countries, such as Egypt. Then finally, after identifying the cost-effective approaches, a comparison between the cost-effective approaches between Malaysia and Egypt was done. Choosing the right technique can help industry practitioners maximize the benefits of WDN rehabilitation. The comparison would help the researchers and industry participants to adopt and further develop the suggested approaches. The discussion of the WDN enhancement rehabilitation approaches can help in adapting them from other countries in the future. Proper WDN rehabilitation supports NRW reduction, which mainly helps move towards sustainable water management in developing countries.

Keywords: Sustainable development, water losses, Non-revenue water (NRW), Water distribution network (WDN), Rehabilitation of WDN.

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LIST OF SYMBOLS

Sf	Significant index
L	Length of the pipe
Q	Discharge in the pipe
C	Hazen-Wil1iam coefficient
D	Diameter of the pipe
m	Meter
m^3/s	Cubic meter per second

LIST OF ABBREVIATIONS

NRW	Non-revenue water
WDN	Water distribution network
RL	Real Losses
AL	Apparent Losses
MNF	Minimum night flow
DMA	District metered area
DASN	National Policy on the Environment
ANN	Artificial neural network
GIS	Geographic Information System
SIV	System Input Volume
SCADA	Supervisory Control and Data Acquisition System
AMR	Automated Meter Readers
ILI	Infrastructure leakage index
AZP	Average Zone Pressure
PRV	Pressure-Reducing Valves
ALC	Active Leakage Control
OCR	Optical Capturing Reading
AI	Artificial intelligence
DSS	Decision Support System
PVs	Performance Variables
PIS	Performance Indicators
RTM	Resin transfer molding
HGA	Hybrid genetic algorithm
CIPP	Cured in place pipes
PR	Pipe ramming
GA	Genetic algorithm
SDPF	Surge damage potential factor
MOGA	Multi-objective genetic algorithm
RDOM-GS	Replacement decision optimization model for group scheduling
P RAWDS	Procedure for rehabilitation analysis of water distribution system
IR	Resilience index

PUTI	Pipe's unitary power
NSGA	Non-dominated Sorting Genetic Algorithm
SMGA	Structured Messy Genetic Algorithm
SPEA	Strength Pareto evolutionary algorithm
PM	Pressure management
SDPF	Surge damage potential factor

CHAPTER 1

INTRODUCTION

1.1 Background

Malaysia and Egypt are developing countries and pursuing for sustainable goals. However, both countries are facing challenges to achieve the set targets (Sarvajayakesavalu, 2015). One of the challenges is the tremendous amount of water losses. Water losses can cause a lot of economic losses (Mutikanga et al., 2009). Water losses should be eliminated in ensuring the sustainability of water resources. Rehabilitation of water distribution network (WDN) is one of the most effective solutions for developing countries to decrease non-revenue water (NRW) (Güngör et al., 2017). This study is exploring the possibilities of rehabilitating WDN to be adopted in decreasing NRW. The following section will discuss the definition and importance of water sustainability, NRW, and the rehabilitation of water distribution network (WDN)

1.1.1 Water sustainability

As time passes, natural resources are being wasted. Without water, mankind will come to extinction. Although water covers most of the planet (Fredrick, 2018), freshwater is less than 10% of the water (Aquatech," 2019). To face this problem, water should be managed accordingly. Having enough water for the current generation without affecting future generations' ability to have enough water is known as having "water sustainability." In other words, water sustainability means that the current and future generations have the accessibility of water to utilize and enjoy (Harris, 2003). In general, sustainable development is the kind of development so that the present could meet their needs without jeopardizing future generations from meeting their needs (Harris, 2003). Water is essential for sustainable development in its most real sense and the full meaning of the word sustainability (Abu-Zeid, 1998). Water is critical to the three dimensions of sustainability: social, economic, and environmental. Water is strongly related to global challenges, including population growth, industrialization, and climate change (Wang et al., 2015). Sustainable development is facing some problems, as it is one way to contextualize the broader sustainable development problem from the critical natural resource view. Water sustainability assessment is essential in the promotion of sustainable development. Integrated River Basin Management (IRBM) is one way to promote sustainable development (Song et al., 2010). Despite that, there are just few water sustainability assessment tools. Finding approaches towards water sustainability is crucial for national economic and social development. Water losses should be decreased to achieve water sustainability.

1.1.2 Non-revenue water

Non-revenue water (NRW) is considered on top of the factors contributing to its services' water supplier development and sustainability. This problem is faced by both developed and developing counties, as the NRW is a trending issue worldwide (González-Gómez et al., 2011). However, the problem is more apparent in developing countries (Kingdom et al., 2006a). The value of NRW is quite considerable. The NRW is considered a critical financial challenge as it affects water sustainability, both in water quality and quantity (Liemberger & Wyatt, 2019). The high level of NRW remains a significant challenge in the WDN of developing counties. The cost of NRW is estimated to be 14 billion USD per year (Al-Omari, 2013). A massive amount of water is being lost, and this amount is in increase due to population growth and the rise in water usage. By numbers, The International Energy Agency has estimated that 34% of all water worldwide becomes NRW. NRW is about 15% in developed counties, ranging between 20% to 70% in developing counties. That is due to the lack of financial resources, technologies, qualified and trained staff, and public awareness (Al-Omari, 2013; Farah & Shahrour, 2018). NRW gains its importance due to several factors. It has an impact on capital and energy costs. Besides, old pipes can be a factor that leads to the pollution of drinking water, leading to serious health risks for consumers (Al-Omari, 2013; Xin et al., 2014).

NRW is the water pumped or produced, but it is lost or unaccounted for in the system, associated with theft, evaporation, false metering, poor data collection, and leakage. In other words, NRW is the unbilled water. NRW consists of unbilled authorized consumption, Real losses (RL), and Apparent Losses (AL). The unbilled authorized consumption is the consumption that is not billed for any particular reason. It is usually a tiny portion of the NRW. It can include firefighting, public hydrants, filling of water tanks, flushing mains, sewers, etc. (Winarni, 2009). AL (also called commercial losses) consists of the unauthorized consumption caused by all types of metering inaccuracies. RL is all losses due to leaks, bursts, and overflow on mains, service connections, and service reservoirs up to the point of customer metering (Winarni, 2009). RL is usually the major component of NRW in developed counties, while the significant element of NRW in developing countries is the AL (Winarni, 2009). Figure 1.1 shows the components of NRW according to International Standard Water Balance (A. Lambert & Hirner, 2000). Figure 1.2 shows the overall process of the NRW from the start when it comes out of the WDN and how it is lost before reaching the customers forming NRW.

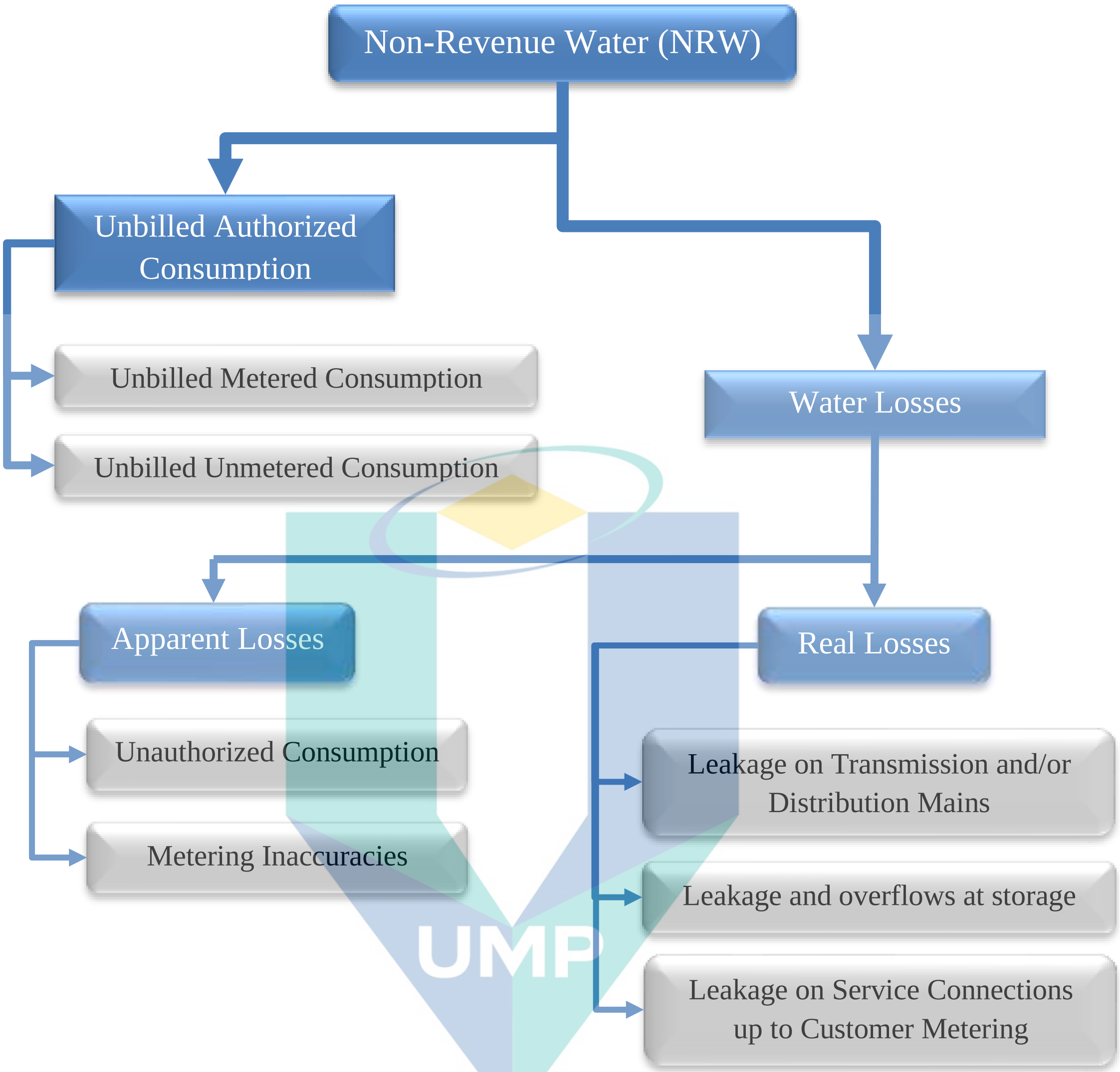

Figure 1.1 Components of NRW (Adopted from International Standard Water Balance)

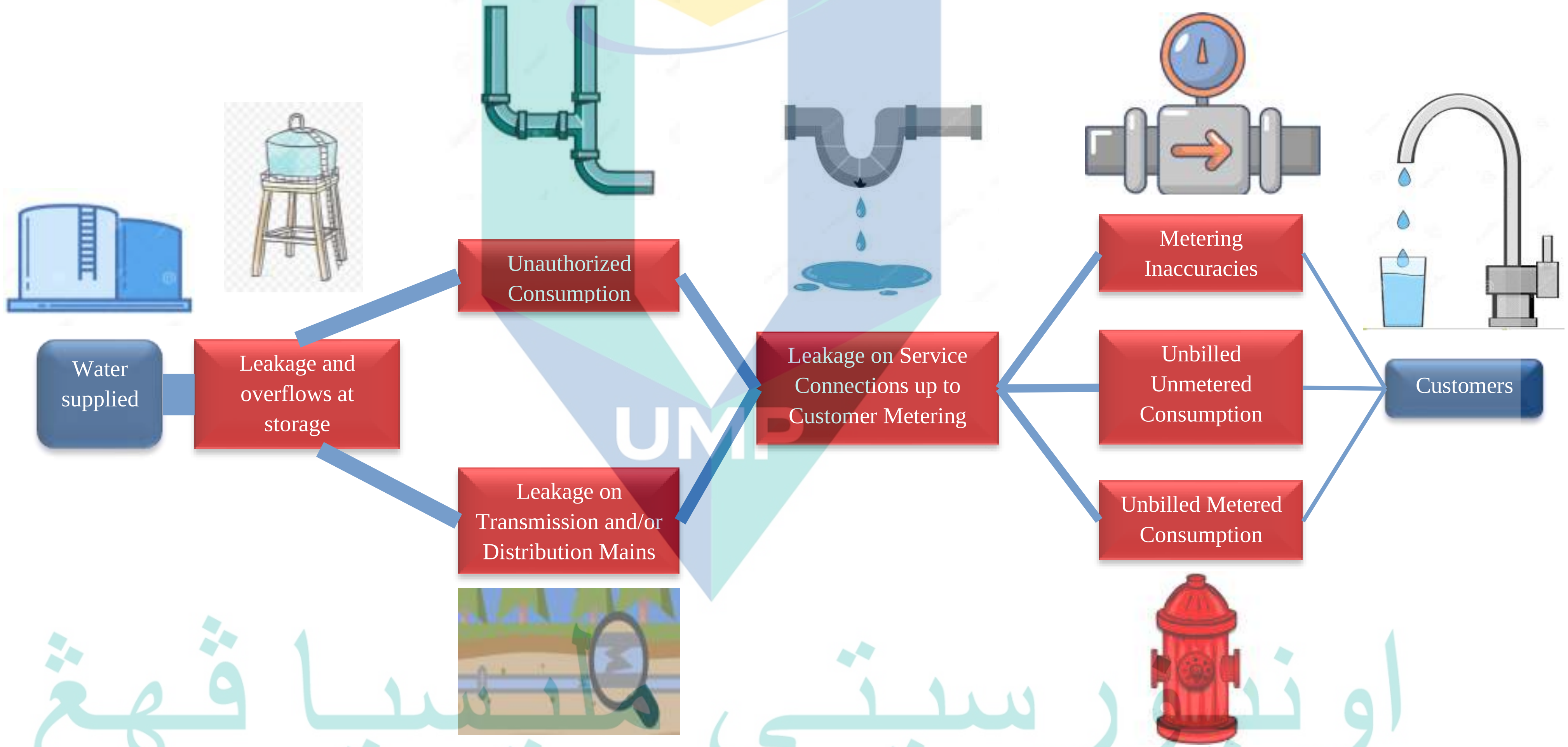

Figure 1.2 NRW components from the start till reaching the customers (the overall process of the NRW)

The measurement of NRW is complicated. There are many methods used to measure the NRW; all of them have limitations and drawbacks. The most used way is the percentage of water produced. Other methods of NRW assessment are minimum night flow (MNF) analysis and water balance. Liemberger & Wyatt (2019) proposed a model for the assessment of NRW. In this model, the more data and the more accurate it is would help in the NRW assessment accuracy. The limitations of MNF analysis are that it is hard to apply when the water supply is intermittent or insufficient, and isolation of district metered areas (DMAs) has not been implemented (Al-Washali et al., 2018). Other methods calculate a factor or set of data within the WDN. For example, the infrastructure leakage index (ILI) is an indicator that includes data on system pressure, length of mains, number and length of service connections, and water balance. These kinds of data are hard to collect (van den Berg, 2015). Sometimes the indicators of NRW are not strongly correlated. Some utilities show low NRW by an indicator and high NRW with another indicator as in the Singapore performance, and the NRW was only 4%. Still, when it comes to NRW per km per day, Singapore's performance falls below. It is recommended to use more than one indicator when evaluating the NRW, as one indicator can sometimes be misleading (van den Berg, 2015). Minimizing NRW is like having a new water source, although the benefits of reducing NRW are much more than the benefits gained from investing in developing new water (Al-Omari, 2013). Reducing operating costs, increased revenues, better water resource efficiency, and expanded water supply lower than new water facilities benefit from reducing NRW (Liemberger & Wyatt, 2019). That is why managers and authorities should consider the reduction of NRW and strategies to reduce it.

There are many drivers of NRW, some are under the control of the utilities, and some are not. Van den Berg (2015) found that the most critical drivers of the NRW that are out of control are: population density per kilometer of network and type of WDN. There are other drivers of NRW, such as utilities located in highly urbanized and dense settlements. The pipe length plays a vital role in the amount of water losses. The drivers under control are how the utility operates their system, utilities that cover their operational and maintenance cost face lower levels of NRW (van den Berg, 2015). Tabesh et al (2018) mentioned four parameters out of 41 to be the most influential parameters towards NRW. These parameters are "poor management increasing apparent losses," "poor training of workers and experts," "lack of timely replacement of devices," and "inappropriate quality selection of pipes and devices." These parameters have the highest priority when coming to NRW risk assessment. It is essential to mention that the data are derived from a questionnaire, so the results can be different if the respondent changes. The low opportunity costs of WL and the high cost of repairs affect the reduction of WL. Van den Berg (2015) found that the country environment in which the utility operates impacts NRW levels. Reducing NRW is regarded as a key to sustainable water management, although it turns out to be challenging. One of the challenges for dealing with NRW is that the NRW components are unknown; therefore, the actions towards solving the problem will not be the best. Another significant issue towards solving the NRW problem is that identifying and implementing the NRW reduction strategies are not simple and requires special attention. The measures towards solving NRW should be taken to stop these vast economic losses that alert many developing countries (Baasha, 2013; Liemberger & Wyatt, 2019). So, in order to study the strategies in the NRW reduction, the strategies for the reduction should be identified.

1.2 The motivation of the study

As a step towards finding approaches in the NRW reduction, the water distribution network (WDN) rehabilitation is one of the methods to decrease RL, especially and NRW in general. WDN is a complicated system consisting of many objects such as pumps, pipes, valves, and a node-set consisting of reservoirs and pipe intersections connections. This network's primary function is supplying water within time and with customers' expected quality (Moosavian & Jaefarzadeh, 2014). However, NRW is one of the challenges that face the WDN. The rehabilitation targets the leakage and pressure of the pipes, which are significant real losses factors. In developing countries, the RL are the primary component of NRW in most countries (Kingdom et al., 2006b) as most they suffer from old infrastructure. There are many challenges to consider in the rehabilitation of WDN (Graeme & Engelhardt, 2001) highlighted three (3) main challenges in rehabilitating the WDN. (1) economic, which are represented in the costs. Costs can be divided into maintenance costs, operating costs, capital costs, and damage costs. (2) the reliability, where it addresses the performance, and the service is available at all the time without interruptions, and (3) water quality, which considers the changes in water chemical properties that are being transported in pipes as it gets older and deteriorates by the time. Rehabilitation is the process that involves the repair or replacement, and therefore the rehabilitation of WDN is the repair or replacement of water pipes within a WDN. The rehabilitation approach should be chosen accordingly so that the rehabilitation outcome is maximized. Maximizing benefits can be achieved by reducing leakage where old and poorly constructed pipes suffer from more leakage. The rehabilitation of WDN needs a well-constructed plan as wrong rehabilitation decisions can waste money and time (Choi et al., 2015); in some cases, the rehabilitated pipes suffered from increased NRW (Noli et al., 2020). WDN rehabilitation would increase service quality and decrease overall NRW by reducing water losses among pipes (Güngör et al., 2017). So, it is essential to have a comprehensive study and suitable rehabilitation plan to overcome these problems.

1.3 Problem statement

Much research was conducted to understand the drivers of the NRW. Van den Berg (2015) used a sample of utilities located in 63 countries. The study was carried out to get the main drivers of the NRW. The study concluded that the main drivers of the NRW are population growth and the nature of the service area; these two factors affect the water quality and quantity, increase the water demand, increase the chance of having water scarcity (Liyanage & Yamada, 2017). The study also mentioned many variables facing water losses, such as system age, soil conditions, the production capacity of the WDN, and topography. Also, this case study in India investigate the significant sources of NRW; it found that 37% of householders do not pay their bills, and some revenue is being shifted towards private providers (Mukherjee et al., 2015). The other case study in Madaba, to determine leakage factors, found that the significant elements of the high levels of NRW, especially in leakage, are bad management, the deterioration of WDN, insufficient data, and unreliable information (Aboelnga et al., 2018a).

After knowing the reasons for NRW, the volume of the NRW is crucial to determine the actual size of the NRW problem. The first study used a technique to determine the volume of NRW by adapting the minimum night flow measurements analysis (Peters & Balfour, 2014). The second method was an empirical method for estimating apparent losses; the empirical method has significant difficulties as it cost a lot of (labor, resources, and time) (Ncube & Taigbenu, 2019). The third method also aimed at calculating the apparent losses. It is a practical method that calculates the apparent losses using the annualized loss expectancy equation; (Al-Washali et al., 2018). Fourth, an artificial neural network (ANN) method was applied by Jang & Choi (2018) and Jang & Choi (2017) to estimate the NRW ratio; The ANN uses the main parameters of the WDN. Fifth, through the water supply direct memory access management, a new application of the particular metering structure analysis to estimate the metering errors. The last method Xin et al. (2014), provides a new methodology to calculate the three primary components of the NRW. Calculating the NRW will help in prioritizing the drivers of the NRW. Therefore, determining if the situation requires attention and give the first insights into the NRW reduction method

After calculating the NRW in the developing countries, it is found that NRW has become a significant issue facing developing countries; it averages from (20%-70%), although it is recommended to be 25% according to the world bank (Kingdom et al., 2006b). In Malaysia, despite the great efforts to reduce the NRW, which was and still part of the Malaysian plan from 2010 till 2015 and from 2015 till 2020, it yet a trending issue. NRW reached 35.3% in 2017, according to the Malaysian government, which means that the NRW is still a trending problem that needs to be addressed. In Egypt, the situation is quite similar; the NRW was concluded to be 30% in 2017 (*HOLDING COMPANY FOR WATER & WASTE WATER*, n.d.). Although the study done by Mohie El Din & Moussa (2016) mentioned that the NRW value could reach 80%. Figure 1.3 shows the NRW values through the period (2014 to 2017) for Malaysia and Egypt. According to a study by the Asian Development Bank in 2010, the most challenging problem in developing countries in reducing NRW is the old WDN; old WDN leads to more leaks and more bursts (Lambert, 2002). Old pipes suffer from the low performance of old WDN, which requires more frequent maintenance work due to leakage and contamination of bacteria. Decreased water quality can cause severe disease burden and counter the aims of a WDN of delivering water to customers with quality (E.J. & K.J., 2005).

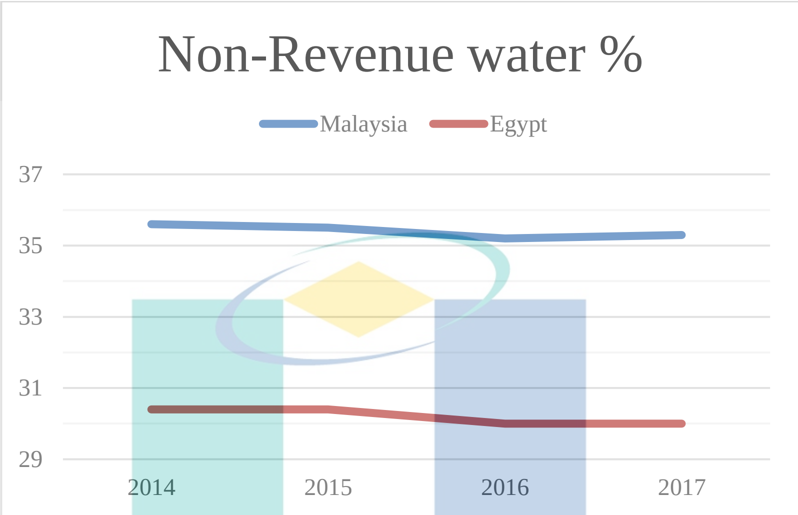

Figure 1.3 Non-revenue water values through the period (2014 to 2017) for Malaysia and Egypt (developed from authorized government cities)

After explaining the issues of high NRW in developing countries, serious steps should be taken towards reducing NRW, so the government can reduce losses and decrease water utility investments. The solutions of NRW should be considered accordingly in order to reduce the NRW effectively. To do that, this study is performed to minimize overall NRW by rehabilitating WDN. The research compares the cost and effectiveness of enhancing rehabilitation approaches between an upper-middle-income economy (Malaysia) and a lower-middle-income economy (Egypt). This research studies the impact of the different incomes on developing counties, which aims to find the best WDN rehabilitation solutions. This comparison will help rank the WDN rehabilitation enhancement approaches, suggest rehabilitation enhancement approaches for developing counties, and recommend some ideas to make some approaches adaptable.

1.4 Objective and scope

1.4.1 Research questions

The research questions in this study are :

[1] What are the approaches for enhancing WDN rehabilitation?

[2] Which enhancement approaches are cost-effective in WDN rehabilitation?

[3] What is the difference between cost-effective enhancing approaches between Egypt and Malaysia?

1.4.2 Research aim and objectives

To answer the research questions, the research objectives arise. The aim of the study is to establish the best solutions for the rehabilitation of WDN in developing countries. To achieve that aim, the research objectives are:

i. Identifying the enhancement approaches of WDN rehabilitation

ii. Determining the cost-effective enhancing approaches for the WDN rehabilitation

iii. Comparing the cost-effective enhancing approaches between Egypt and Malaysia

1.4.3 Research scope

The Scope of the study is in Malaysia and Egypt. The questionnaire survey was collected from both countries during five months period from June 2020 till October 2020. The data was collected from all the regions in both countries. From Malaysia data was collected from: 1)Northern Region (Perlis, Kedah, Pulau Pinang & Perak), 2)Central Region (Selangor & WP Kuala Lumpur), 3)Southern Region (Negeri Sembilan, Melaka & Johor), 4) East Region (Pahang, Terengganu & Kelantan), 5)East Malaysia (Sabah & Sarawak). From Egypt: 1) Greater Cairo Regional Unit (Cairo Governorate - Giza Governorate - Qalyubia Governorate), 2) Alexandria Regional Unit (Alexandria Governorate - Beheira Governorate - Matruh Governorate), 3)Delta Regional Unit

(Damietta Governorate - Monufia Governorate - Gharbia Governorate - Kafr El Sheikh Governorate - Dakahlia Governorate), 4) Suez Canal Regional Unit (Sharqia Governorate - Port Said Governorate - Ismailia Governorate - Suez Governorate - North Sinai Governorate - South Sinai Governorate), 5) North Upper Egypt Regional Unit (Minya Governorate - Beni Suef Governorate - Faiyum Governorate), 6)Asyut Regional Unit (Asyut Governorate - New Valley Governorate), 7) South Upper Egypt Regional Unit (Sohag Governorate - Qena Governorate - Luxor Governorate - Aswan Governorate - Red Sea Governorate). The respondents must meet the two selecting criteria to get selected to participate in the survey: (1) having experience in the water industry, (2) having experience in WDN projects. The targeted are engineers that are in the field of water distribution networks. The chosen respondents are from top-tier companies and water authorities regarding managers and decision-makers as the rehabilitation process is costly and usually adapted by these types of companies.

1.4.4 Research significant

This study provides a clear vision for current practices and the enhancement approaches used in rehabilitation by comparing the different enhancing rehabilitation approaches. That can assist government authorities and engineers in the rehabilitation process. The research will provide a better vision towards different enhancing approaches used in the rehabilitation of WDN.

By choosing the suitable rehabilitation method in reducing water losses, which is represented in one of the problems that face WDN and an essential factor in NRW, it will benefit from improving water quality and its impact on hydraulic capacity system structure but will also decrease overall NRW. NRW has been pointed to as one of the significant problems facing water sustainability and facing sustainable development in general, so reducing water losses has a substantial return on the developing countries

Addressing the NRW problem has a significant return on the developing countries as reducing the NRW helps cities and regions achieve sustainable development goals. In Malaysia specifically, as it has many benefits; firstly, The National Policy on the Environment (DASN) is one of Malaysia's national policies that target the continuous economic, social, and cultural progress and enhancement of the quality of life of Malaysians through environmentally sound and sustainable development. Secondly, according to the 11th Malaysia Plan 2016 – 2020: Strategic thrusts #6 (i.e., pursuing green growth for sustainability and resilience) on conserving terrestrial and marine areas. , the reduction of NRW is a part of the 11th Malaysian plan 2016-2020. The reduction of NRW would help in achieving the sustainable and economic goals of the country

1.5 Conclusion

The introduction chapter aimed to give a general presentation of the whole thesis; it gave a brief background on the general topic and the main objectives of the research. The problem statement was clearly defined, which formulated the research questions. To answer the research questions, the research aim and objectives were formulated. Finally, the research significant was concluded to demonstrate the benefits of achieving the research objectives and to highlighting the research contribution upon surpassing and detecting the research questions; the primary purpose of determining the research significance is to show that the research is worth being carried and has a lot of potential and treasures outcomes.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

After giving the research background, induction the problem statement, formulating the research questions, research objectives. The second chapter will discuss the literature review related to the problem statement and research questions. The literature related to the NRW and the rehabilitation of WDN will be discussed. First, reviewing literature about methods to reduce NRW. That would ensure that the rehabilitation of WDN is an effective way to decrease NRW. Second, reviewing the literature related to the rehabilitation of WDN. Third, reviewing the literature related to the enhancement approaches of WDN rehabilitation. Fourth, the literature of cost-effectiveness studies related to WDN and NRW were reviewed. And lastly, mentioning the literature from the Malaysia and Egypt sides would help conclude the research gap. Rehabilitation of WDN is an essential step towards reducing NRW. The following literature highlights the main findings on both topics

2.2 Methods to reduce NRW

There are many solutions discussed in the NRW reduction; this indicates how important and critical is the NRW problem. The methods aim to reduce the apparent losses or real losses, or both. Therefore, decreasing the overall NRW There are a total of 16 strategies in the NRW reduction. The following Figure 2.1 summarizes the overall results for the NRW reduction strategies.

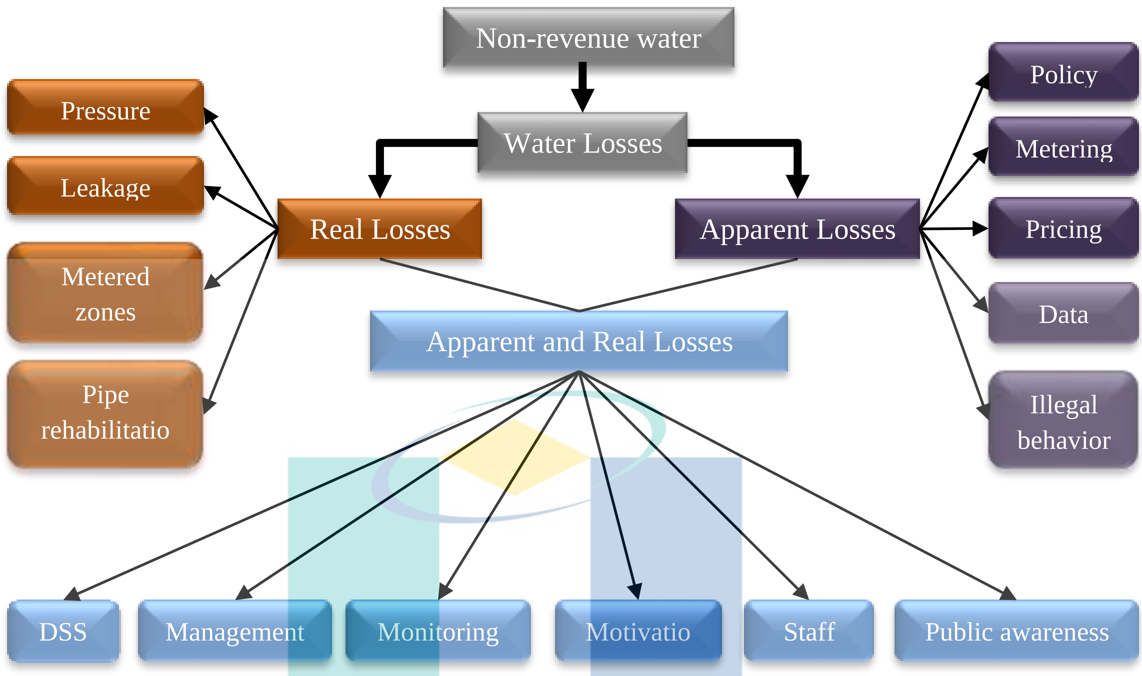

Figure 2.1 Methods to reduce Non-Revenue Water

2.2.1 Management

Management is critical for any business to succeed. Without consistent, proper management leads to many water losses (Aboelnga et al., 2018a). The management solution is a crucial way to reduce NRW. NRW is considered a threat to WDN management (Bhagat et al., 2019; Hussein et al., 2017; Kamarudin & Ismail, 2016; Yi et al., 2017), reflecting the performance of the WDN (Kamarudin & Ismail, 2016). WDN management includes many activities. 1) asset management (Mugisha, 2013). 2) Dynamic modeling, based on a method that selects the best management activities (Karimlou et al., 2020). 3) Operation and maintenance, applied to boreholes and handpumps within a WDN (Silombela et al., 2018). 4) Record-keeping of WDN is essential for WDN management (Silombela et al., 2018). 5) Programs such as Geographic Information System (GIS) and management information system (MIS) tools help in decision making and the management of WDN (Ndirangu et al., 2013). 6) Budget as its important towards prioritizing NRW activities (Gambe, 2015). 7) Some WDN needs to shift away from this traditional top-down approach towards a bottom-up approach, emphasizing multiple-stakeholders' involvements (Lai et al., 2017). 8) Organizations which to control the activity of water utilities (González-Gómez et al., 2011). 9) The change from a "Supply" Management mode" to Water Demand" Management mode. 10) A smart network is an effective way of NRW management (Al-Washali et al., 2019). In conclusion, effective management towards the WDN, water resources, and water losses can result in leakage and NRW reduction and the protection of public health (Aboelnga et al., 2018a; González-Gómez et al., 2011; Karadirek, 2016; Saadr & Anuar, 2019; Silombela et al., 2018).

2.2.2 Monitoring

The performance of a WDN depends on many factors, such as environmental, physical, and operational. Ensuring continuous monitoring of each factor of the WDN is required (Güngör et al., 2019; Saadr & Anuar, 2019). As the System Input Volume (SIV) increases, the need to monitor increases. The volume and performance indicators are directly proportional to SIV. It is necessary to measure all the NRW components to get better performance. Increasing water distribution network performance by using pressure management and database integration. The main objectives of monitoring the WDN are monitoring the network flow, volume, pressure levels, and pumps (Ociepa & Ociepa, 2019; Silombela et al., 2018). Monitoring can be achieved by a set of hydraulic sensors that measure water flow and pressure (Farah & Shahrour, 2017). Supervisory Control and Data Acquisition System (SCADA) is one of the most used programs in monitoring the WDN (Güngör et al., 2017, 2019; Rajasekhar et al., 2018). Another method of monitoring the WDN is Automated Meter Readers (AMRs), which record the water flow at each hour (Farah & Shahrour, 2017). Monitoring is not just on WDN, but it can be applied to any NRW program (González-Gómez et al., 2011; Hussein et al., 2017). Monitoring network performance can help detect excessive flows and water consumption from failures or theft (Ociepa & Ociepa, 2019). Another benefit is that it reduces the amount of leakage, limiting the WL and overall NRW (Hussein et al., 2017; V. Kanakoudis et al., 2013; Vasilis Kanakoudis, Tsitsifli, Samaras, et al., 2015; Ociepa & Ociepa, 2019). Also, both (Kadu & Dighade, 2015; Ociepa et al., n.d.) says that enough motoring can reduce leakage.

2.2.3 Policy

Policy rules and regulations of water usage are essential factors that can assist in reducing the NRW. The policy can have a role in reducing NRW. They can raise the public's awareness towards reducing NRW and prioritize the control of NRW through a political program (González-Gómez et al., 2011; Mukherjee et al., 2015). When considering policy, many issues face it, such as Tariffs, pricing, and sectoral water management. Those kinds of policy issues need to be addressed by policymakers (Malek et al., 2013). In conclusion, the policy can be a method in the NRW reduction as it depends on the people's behavior towards water usage. Also, the policymakers can involve in the reduction plan of NRW.

2.2.4 Staff competency

According to Kadu & Dighade (2015) findings, there are 41 parameters for the NRW. The " poor training of labor" is one of the most critical parameters. Having qualified staff to operate the WDN and implementing the NRW reduction strategy is essential (Mugisha, 2013; Ndirangu et al., 2013). Staff should realize the importance of NRW (Kanakoudis, et al., 2015). Despite that, 64% of staff did not have a clear understanding of the management of NRW Yi et al (2017); this indicates a gap between staff and NRW. NRW should be considered as a serious problem that faces the whole country. There is still staff that is not familiar with the ILI. That results in losses in the WDN and lousy management of the NRW (Silombela et al., 2018). So, ensuring having high-quality trained staff is crucial to be part of any NRW reduction strategy.

2.2.5 Pressure

The typical function of the pressure within a WDN is for moving water within the system. The flow speed is directly proportional to the pressure. There is a strong relationship between pressure and leakage or NRW in general as the pressure increases the water leakage (Kadu & Dighade, 2015; Mugisha, 2013). Network pressure is a vital parameter in the calculation of RL because it has a direct impact on NRW (Aboelnga et al., 2018a; Dalton, 2019; Hoko & Chipwaila, 2017; Hussein et al., 2017; V. Kanakoudis & Gonelas, 2016; Mugisha, 2013; Yi et al., 2017). Network pressure should be continually measured to maintain pressure within a WDN by calculating the Average Zone Pressure (AZP) (Aboelnga et al., 2018a). Intermittent supply (peak hours) and the sudden change in the flow velocity in the pump are the leading causes of high pressure in a WDN (Aboelnga et al., 2018a; Rajasekhar et al., 2018). Pressure directly impacts the leakage rate and the number of bursts (Dziyauddin et al., 2018; González-Gómez et al., 2011; Ociepa & Ociepa, 2019; Silombela et al., 2018). Pressure Management (PM) effectively maintains the pressure within the WDN (Aboelnga et al., 2018a; Fiut & Patience, 2013; Gonelas & Kanakoudis, 2016; González-Gómez et al., 2011). One of PM's essential methods is installing Pressure-Reducing Valves (PRV) (Hoko & Chipwaila, 2017; V. Kanakoudis et al., 2016). However, there are other methods of PM, such as (1) Rezoning the area supplied to match the input head to the topography to minimize system losses; (2) Matching pump output curves to match distribution demands closely; and (3) Installing brake pressure tanks

Pressure management (PM) can result in massive economic savings (Fiut & Patience, 2013; Güngör et al., 2019). For example, PM can save up to 31419182 RM after 15 years of implementation (V. Kanakoudis & Gonelas, 2016). PM reduces WL that exists from leakage and therefore reduces NRW (Aboelnga et al., 2018a; Fiut & Patience, 2013; Güngör et al., 2019; Ociepa & Ociepa, 2019). It also reduces the frequency of bursts, resulting in fewer repairs, enables better service, and helps utilities face drought conditions (Fiut & Patience, 2013; Güngör et al., 2019; V. Kanakoudis & Gonelas, 2016). Not only that, but a reduction in pressure could save power, reduce repair costs, and increase the quantity of water within a WDN. A pressure management program was applied in Maraval and Maloney (Peters & Balfour 2014) to confirm these results. Reducing the pressure in an entire network could result in:

1. Reducing water losses due to leakage, which means more water savings
2. Reducing dissipated energy in the system
3. Making the network more efficient and reliable. (Ociepa et al., n.d.; Popa-Albu et al., 2019; Saldarriaga et al., 2010)
4. Applying a pressure network framework is a significant way to reduce NRW (Aboelnga et al., 2018a)

AZP allows calculating the pressure in a system; it can be misleading for measuring the leakage. Therefore, adding a PM tool to the Active Leakage Control (ALC) strategy, which extends the lifetime and reduces the main breaks frequency, is recommended (V. Kanakoudis et al., 2013).

2.2.6 Staff motivation

The motivation can act like the fuel that will make the car move. However, it is not well known that the lack of motivation can affect the WL (Bhagat et al., 2019; González-Gómez et al., 2011; Yi et al., 2017). Lack of motivation can contribute to more leakage and decrease assets' lifetime (Aboelnga et al., 2018a). So, it is so vital to encourage working staff (Ndirangu et al., 2013). One of the methods to increase motivation is by promised incentives. Also, companies should have incentives for reducing NRW (Mugisha, 2013). The effect of incentive payments on NRW depends on the interactive effects of staff inputs, service coverage, and water supplied per connection (Mugisha, 2013). It was found that utilities with promised incentive payments have better chances of improving their billing efficiency (Mugisha, 2013), decreasing WL and water leakage (Aboelnga et al., 2018a; Bhagat et al., 2019; Yi et al., 2017), and would likely decrease NRW (González-Gómez et al., 2011). Although the higher levels of promised incentives promote the reduction of NRW, it must be known that high levels of promised incentives should involve a smart balance between the benefits of NRW reduction and incentive payments (Mugisha, 2013). It was suggested to design an incentive plan that studies possible interaction effects of staff inputs involved, service coverage levels, and water production (Mugisha, 2013).

2.2.7 Public awareness

Public awareness plays an essential role in facing the NRW. Public activities can result in significant water and revenue losses. The public has many bad habits that contribute to the increasing NRW, which can be in the drawing and storing excess water and throwing away the previously stored water, some residents internationally vandal meters (Rajasekhar et al., 2018). Failures represented in leakage and bursts can be observed and ignored by the public instead of reporting it, as most of the public do not save water service providers' phone numbers (Aboelnga et al., 2018a; Lai et al., 2017). There is a lack of awareness of NRW and how crucial it maybe be for the country. Even most of the public may not understand the term NRW, as it is a technical word used in water-related sectors and is not used between customers (Lai et al., 2017).

To increase public awareness, actions should be taken. Water utilities should conduct awareness programs for the public to introduce the importance of WDN and NRW (Lai et al., 2017; Rajasekhar et al., 2018), contributing to the decrease of WL and therefore decreasing overall NRW. González-Gómez et al (2011) suggested that policymakers can help the public be aware of how important it is to reduce NRW. Also, Lai et al (2017) recommended more research to be applied to this topic.

2.2.8 Water metering systems

Water metering is the measuring of water use. Water meters measure the volume of water consumed by the customers supplied by the WDN. Water meter problems cause a huge water loss and contribute to a significant component of AL (Bhagat et al., 2019; Hoko & Chipwaila, 2017; V. Kanakoudis et al., 2016; Moahloli et al., 2019; Özdemir, 2018; Yi et al., 2017). In many cases, the percent of meters with errors exceeds 50% (Hoko & Chipwaila, 2017; Özdemir, 2018). The causes of metering inaccuracies are age, total registered volume (V. Kanakoudis et al., 2016; Moahloli et al., 2019), or even the absence of water meters (Mukherjee et al., 2015). In general, this issue is essential and severe (Lai et al., 2017). Therefore, water supply companies should fix and replace these meters as part of the NRW program to increase their accuracy and reliability (González-Gómez et al., 2011; Rajasekhar et al., 2018).

Meters should be replaced from time to time by introducing meter replacement programs (Hoko & Chipwaila, 2017; Moahloli et al., 2019). There is a relationship between water meterage and the volume of water registered and accuracy; many old meters need to be replaced (Özdemir, 2018). Moahloli et al (2019) determined that the optimal replacement period to be 9,12,16 years and total registered volume of 3971, 5162, and 6750 Kiloliters at discount rates of 10%, 8%, and 6%, respectively. The meter accuracy should also be checked. That can be achieved by installing a calibrated "check" meter downstream of the meter; AMR can be applied for reading meters (Rajasekhar et al., 2018).

Solving metering issues can result in improving the city revenue collection efficiency and improve water billing resulting in reducing AL and overall NRW (Gambe, 2015; Hoko & Chipwaila, 2017; V. Kanakoudis et al., 2016; Ociepa & Ociepa, 2019), which will improve the overall water service. Applying the prepaid smart watering system can be so expensive, which will affect the local authority and poor urbanites. Although this system has its benefits, its timing needs to be considered (Gambe, 2015). Also, using water meters with radio devices can enable all meters in each zone to be read simultaneously (Ociepa & Ociepa, 2019). Alarms for meter inspection and replacement at the suggested meter replacement periods are also recommended (Moahloli et al., 2019). Lastly, industry practitioners can easily use Optical Capturing Reading (OCR) to quickly identify water meters (Rajasekhar et al., 2018).

2.2.9 Illegal behavior

Another AL reduction strategy is preventing illegal behavior from occurring, including water theft (which can be higher in poor areas) Mugisha (2013), meter reading connivance/tempering (González-Gómez et al., 2011; Mugisha, 2013), illegal water connections (González-Gómez et al., 2011; Yi et al., 2017), and bribery (González-Gómez et al., 2011; Mugisha, 2013). Some of these illegal behaviors are hard to prevent because they can directly benefit water distributors' staff. This illegal behavior is because some staff may benefit from illegal actions (González-Gómez et al., 2011). For example, a study has identified that 73% of the water unit staff admitted to taking bribes for lowering meter reading about half or all the time (González-Gómez et al., 2011). On the other hand, meter tampering and illegal connections are a substantial contributing factor to the high AL values and overall NRW rate (Vasilis Kanakoudis, Tsitsifli, Kouziakis, et al., 2015; Ndirangu et al., 2013; Yi et al., 2017). Local solutions in NRW management through North-South Water Operator Partnerships The Nakuru case (Dalton, 2019; Gonelas & Kanakoudis, 2016; Saadr & Anuar, 2019). Therefore, dishonest behaviors should be controlled (Ociepa & Ociepa, 2019). Some approaches to control dishonest behaviors include imposing strict penalties on water theft V. Kanakoudis et al (2016), detecting illegal connections, checking meters with zero or below-average readings, and detecting tamper activities (Fiut & Patience, 2013). On the other hand, pre-payment metering can identify illegal connections and prevent meter tampering (Mukherjee et al., 2015).

2.2.10 Data

To deal with the NRW problem effectively, data should be managed effectively. The main issues associated with AL for data management is data handling errors and unavailability of data (Bhagat et al., 2019; Hussein et al., 2017; V. Kanakoudis et al., 2013; Vasilis Kanakoudis, Tsitsifli, Kouziakis, et al., 2015; Lai et al., 2017; Liemberger et al., 2012; Yi et al., 2017). Data mismanagement can also affect data availability on unbilled authorized consumption, unauthorized consumption, and metering errors (V. Kanakoudis et al., 2013; Kanakoudis, et al., 2015). Lack of data can lead to making misassumptions when managing WDN (González-Gómez et al., 2011; Rajasekhar et al., 2018; Saadr & Anuar, 2019; Saldarriaga et al., 2010). Missing data can also cause other issues such as difficulties in executing water balance analysis (V. Kanakoudis et al., 2013; Kanakoudis, et al., 2015), misassumptions of network connections, and challenges in implementing NRW reduction strategies, including replacing and rehabilitating pipes (Liemberger et al., 2012).

To face this unavailable data problem, an effective and reliable data management system should be introduced. Introducing a sophisticated data management system can help water distributor companies develop NRW reduction programs (Aboelnga et al., 2018a; Hussein et al., 2017). Alternatively, artificial intelligence (AI) tools have shown potential in dealing with missing data (Bhagat et al., 2019). The District metering areas (DMA) can be one of the methods that can also help in data availability. It depends on dividing the network into sections, resulting in easier data management (Dalton, 2019).

2.2.11 Water pricing

The pricing is regarded as one of the key factors that slow down the NRW program applicant as it directly impacts the NRW's actual value (V. Kanakoudis et al., 2016; Yi et al., 2017). A fixed charge pricing involves billing consumers regardless of whether the corresponding water volume has been consumed or not (V. Kanakoudis et al., 2013). It can provide false insights on the actual volume of the NRW and socially unfair (Bhagat et al., 2019). While the fixed charge pricing allows water distributors to recover the loss of revenue, the approach might result in utility provides having a good excuse for not doing anything towards NRW reduction (Bhagat et al., 2019; V. Kanakoudis et al., 2013; Kanakoudis, et al., 2015), In fact, sometimes, the NRW is recorded to be negative (Vasilis Kanakoudis, Tsitsifli, Samaras, et al., 2015). The minimum charge difference (MCD) is the difference between the water volume charged to the customers and the water volume recorded by their water meters (V. Kanakoudis et al., 2013). Therefore, actions should be taken to face these pricing issues (V. Kanakoudis et al., 2016).

A socially fair water pricing policy must avoid these problems (Tsitsifli et al., 2017). One of the policies includes using a novel methodological framework to develop a socially fair pricing policy based on the average water price (Gonelas & Kanakoudis, 2016). The volumetric water pricing model aims to reduce the price burden on urban low-income households while discouraging the middle- and higher-income households from free-riding on the water subsidy (Mukherjee et al., 2015). Socially fair pricing can recover in water's cost production (Mukherjee et al., 2015). It will also consider the medium and low-income households, discourage the sharing of connections as the consumer price will not decrease by increasing the consumption (Mukherjee et al., 2015). Finally, it will likely reduce NRW (Kanakoudis, et al., 2015; Mukherjee et al., 2015). On the other hand, lowering water prices generally reduces a network’s performance (González-Gómez et al., 2011). Nevertheless, it is recommended that the pricing policy should be updated every three years (Tsitsifli et al., 2017).

2.2.12 Leakage

Leakage is one of the most critical drivers of NRW, which is the main component of RL. Leakage can occur in the different parts of the WDN (transmission pipes, distribution pipes, joints, valves, and fire hydrants) (Hussein et al., 2017). Leakage directly impacts wasting both money and natural resources and creating risk to public health (Hussein et al., 2017). The high leakage levels can cause more than 25% of the wasted energy used (Kanakoudis, et al., 2015). So, it is necessary to overcome this problem. Estimating leakage is always the first step towards leakage management. Several methods can be used to assess the leakage, such as the total integrated flow method and the total night flow method (Hussein et al., 2017).

Artificial Intelligence (AI) tools can predict the leakage before taking place (Bhagat et al., 2019). The Infrastructure Leakage Index (ILI) is the current annual RL ratio to unavoidable annual RL, showing how good the WDN performing (Yi et al., 2017). Leak detection programs can play an essential role in identifying hidden and unreported leakage within the WDN (Aboelnga et al., 2018b). SMARTBALL is one of the useful devices used to detect leaks (Zaini & Rasam, 2019). Active Leakage Control (ALC) is one of the most effective ways of seeing and locating leaks. ALC activities consist mainly of flow metering and leak localizing, locating, and pinpointing. Many other techniques are used to detect leaks, such as noise loggers, leak noise correlators, ground microphones, sounding sticks acoustic correlation, the Sahara method, aerial surveys, thermal imaging, helium tracing (V. Kanakoudis et al., 2016).

Case studies show the magnificent benefits of implementing leakage management in reducing NRW (Farah & Shahrour, 2017; Fiut & Patience, 2013; V. Kanakoudis et al., 2013; Kanakoudis, et al., 2015). For example, the ALC program can result in reducing overall NRW from 43% (January–May 2015) to 7% (January–May 2016) (Farah & Shahrour, 2017). The installation of the advanced leakage equipment will ensure reliable accuracy and the early identification of leakage (Dziyauddin et al., 2018; Güngör et al., 2017; Ndirangu et al., 2013; Ociepa & Ociepa, 2019). One of the disadvantages of repairing leakages can negatively impact citizens' welfare in the short term (González-

Gómez et al., 2011). Also, the SMARTBALL technique in detecting leaks is expensive (Zaini & Rasam, 2019) as the number of connections is possible leakage points. Hussein et al (2017) suggested that utilities should reduce the number of connections to reduce WL. Rajasekhar et al (2018) recommended proper documentation of leakage components (Reported Leakage, Unreported Leakage, and Background Leakage) in the utility plan of the NRW program. To get the actual leakage time occurrence, the Water Balance analysis (WB) should be performed in short periods than one time a year (Kanakoudis, 2015).

2.2.13 Metered zones

District metering area (DMA) is a defined area of the WDN isolated by boundary valves, such that water volume entering and leaving the area can be metered. DMA's function is to divide the network into sections to make it easier to manage. DMA is an excellent weapon against leakage, as the leaks and bursts can be determined faster by narrowing the area of failure (Hussein et al., 2017). DMA enables monitoring of the pressure and flows in the area to identify the most challenging zones (Güngör et al., 2019). DMA enables the management of each zone's pressure by determining the suitable amount of pressure for each zone. DMA is an effective way to reduce WL as it helps identify leaks and bursts faster (Aboelnga et al., 2018b; Ociepa & Ociepa, 2019; Özdemir, 2018). DMA is considered one of the methods to face the NRW, which reduces NRW (Dalton, 2019; Hussein et al., 2017; Lai et al., 2017; Noli et al., 2020; Saadr & Anuar, 2019; Yi et al., 2017). Thus, DMA has a significant investment return because it increases water distribution network performance by integrating pressure management and database (Güngör et al., 2019).

There are some constraints in the designing phase of DMA, such as (traditional engineering design criteria and reluctance to close valves, so many closed valves, low network pressure, and critical points, intermittent supply), which can reduce the water quality. However, most of these constraints can be overcome by a set of solutions: introducing DMAs in pilot areas, restoring supply temporarily in areas of intermittent supply, using a network model or pressure loggers to assess the effect on customer service levels, and by education and awareness training. Water quality problems can be faced by a regular flushing program or re-designing the DMA boundary. V. Kanakoudis et al (2016) suggested hydraulic simulation software and applying different scenarios that will help in the design of DMA.

2.2.14 DSS tools

The Decision Support System tool (DSS) is a tool developed by the WATERLOSS (a consulting company that provides a range of services within the NRW projects). One of the aims of this tool is to deal with the overall of the NRW (not just one component of the NRW) as one of its functions. It is the only method that deals with overall NRW. One of the reasons for WATERLOSS project to develop the tool is to make water operators realize how big the problem of NRW is and motivate them to take appropriate actions towards reducing it (Vasilis Kanakoudis, Tsitsifli, Samaras, et al., 2015). The application of the DSS is based on six steps, which are 1) Monitoring the system's Performance Variables (PVs) and Indicators (PIs); 2) Definition of objectives regarding the NRW and evaluation of PVs and PIs; 3) Induction of NRW reduction measures; 4) Prioritization of the measures; 5) Detailed design of measures, and 6) Implementation of the measures.

The DSS is considered to a user-friendly tool that effectively provides a list of prioritized NRW reduction measures that address the actual causes of the NRW based on the WB analysis (Banovec et al., 2015; V. Kanakoudis et al., 2016; Vasilis Kanakoudis, Tsitsifli, Cerk, et al., 2015; Kanakoudis, et al., 2015), DSS helps in the management of the WDN. It also has a self-learning program that binds the user's data and the NRW reduction methods database, making it easy to add more NRW reduction measures. So, from its main features that it is very flexible, it can include an indicator system to identify the status of the WDN (Kanakoudis, et al., 2015). The DSS tool has a lot of limitations (Banovec et al., 2015). The lack of data on NRW reduction measures makes it impossible to implement (Kanakoudis, et al., 2015). As such, a firm classification of NRW reduction measures is necessary, which includes 1) a description of all possible NRW reduction measures 2) encoding the defined measures effectively to the DSS tool (Banovec et al., 2015; Kanakoudis, et al., 2015).

2.2.15 WDN rehabilitation

There are many challenges in rehabilitating WDN. When it comes to the WDN, the pipe (condition, corrosion level, and flow quality) needs to be known so that a suitable rehabilitation process can take place (Selvakumar & Tafuri, 2012). These factors needed to be available in sufficient detail to determine a problem within the pipe (structural, hydraulic, and water quality). There are many challenges before the rehabilitation process. A lack of understanding in the rehabilitation approaches is one of them (Selvakumar & Tafuri, 2012; Tafuri & Selvakumar, 2002) found that an experienced engineer in WDN can select the suitable rehabilitation process, but this step can take a long time who are not familiar with the rehabilitation technologies. Sometimes the experienced engineer may be unfamiliar with new rehabilitation approaches. Not only that but Selvakumar & Tafuri (2012) conducted that the selected rehabilitation approaches must be accepted by the utility to be considered.

After determining the suitable rehabilitation technique, choosing either to rehabilitate the pipe considering the rehabilitation costs or not to rehabilitate and save the rehabilitation costs but face more repair and maintenance costs in the future as stated (Shamir & Howard, 1979). There are other factors to consider during the rehabilitation, such as (system condition, how critical is the repair needs, the availability of funding, and the state of each element in the WDN. Selvakumar & Tafuri (2012) mentioned that the assessment of water pipes in the WDN is exceptionally costly and challenging. Using algorithms can help determine the decision (Wilson et al., 2003). After the rehabilitation, it is recommended to have long-term monitoring of the rehabilitated pipes' performance (Selvakumar & Tafuri, 2012). These are some of the main challenges in the rehabilitation of WDN.

2.2.16 Different rehabilitation enhancement approaches

This section is for reviewing the different rehabilitation enhancement approaches used across the various papers. Muhmmed et al (2017) viewed more than 27 rehabilitation methodologies based on the graph theory clustering concept. Three based strategies were considered in a network:

1. Rehabilitation of some pipes inside a WDN
2. Rehabilitation of pipelines in paths supplying water to WDN
3. The combination of the two methods

The best strategy was the third one, as it could generate a solution with minimum cost and without pressure issues. Not only that, but the third strategy was compared with the other two approaches (whole search space and engineering judgment-based optimization strategies). The results pointed out that the third strategy remained the best strategy, as well. Using the cluster method helps in identifying problems within a WDN and in making the rehabilitation process ease. It finds optimal solutions. Muhmmed et al (2017) recommended using more strategies in analysis to get a better overall result. His study compares the cost of the resolution/replacement situations and suggests the most suitable decision to effectively use their resources. This method is better for small to medium-size systems. It used the likelihood of water pipes failure to predict pipes' deterioration over time and remaining lifetime. Through it, the time of rehabilitation can be determined. It also provides compares the impact of different rehabilitation on both cost and lifetime. The method can also be applied to larger WDN if the adjustments and data are available, even it will not be like the small or medium-sized WDN results (Francisque et al., 2017; Salehi, Tabesh, et al., 2018) proposed a method for determining a future road map for WDN rehabilitation. When planning rehabilitation, this method can be applied to WDN with operational failure.

The hybrid risk-based decision-making method is a methodology that helps in prioritizing the rehabilitation of pipes. Using this method could help determine actual rehabilitation plans even though there is a lack of data accuracy. It helps in identifying and prioritizing a rehabilitation plan. The study found out that template-based analysis can be used in the planning phase of rehabilitation. It is preferable to apply a locally based analysis. From this method, constraints are that in many cases, there is limited access to accurate operational data, which sometimes makes it harder to use it effectively. Saldarriaga et al (2010) presented a new approach to solve the problems of rehabilitation.

This approach uses two hydraulic parameters (the resilience index of the WDS and the unitary power of a pipe) to select the essential pipes to be replaced by other new and more substantial pipes. The resilience index helps increase the resilience index of the WDN, while the selection of pipes for replacement is based on the unitary power value. Many papers already lowering the pressure in the whole WDN system would lead to decreasing leakage and energy. Which leads to a more efficient and reliable WDN. Reducing leakage results in

1. More reduction in overall NRW,
2. Optimum pressure surface
3. Improve hydraulic performance
4. Energy efficiency
5. Preserves its resilience at an acceptable level

From the points above, Cleary concludes that it is a very efficient and helpful tool for designing and planning the rehabilitation of WDN. Its advantages over other approaches are that it does not require any historical information about the pipe; it only needs a calibrated model of the WDN.

This approach does not follow a formal optimization method, which means that rehabilitation decisions may not be optimal. Roshani & Filion (2014) presented a multi-objective optimization method to generate a solution for leakage. This method can take to 10 generations to create solutions. The results of these methods are that leakage rates are reduced by 80%. The decision support tool developed by Marlow et al (2015) helps managers determine rehabilitation techniques with correct decisions of renovating or replacing cast-iron pipes. A traditional rule-based expert system was considered appropriate, which incorporates structural and economic risk models. This approach reduces the risk of using Trenchless techniques. Shahata & Zayed (2012) classified the rehabilitation techniques into three categories

1. Repair (i.e., Open trench)
2. Renovation (i.e., Slip lining)
3. Replacement (i.e., Pipe bursting)

Such as a new rehabilitation decision tree was developed. The breakage analysis helped predict the rehabilitation intervals, while the economic analysis was for interest and infliction rates. Findings can assist in acquiring and analyzing data in WDN rehabilitation. The different rehabilitation approaches used are helpful in the reduction of the NRW. Although, studies recommended more and more in-depth studies as some had some limitations in cost or availability or applicability, or generalizability

2.3 NRW and WDN rehabilitation

Old pipes that passed their lifetime have a higher failure rate, more leakage, bursts, and low-quality service (Güngör et al., 2017; Hoko & Chipwaila, 2017; Özdemir, 2018). To overcome these problems, the rehabilitation of pipes was from the possible choices that target physical losses (Banovec et al., 2015; Ndirangu et al., 2013; Özdemir, 2018). The rehabilitation of water pipes is one of the methods that is used to solve the NRW problem. The rehabilitation of pipes is the activity of the replacement or repair of pipes within a WDN.

Resilience index (IR) is one method of selecting the most critical pipes to be replaced. Moreover, a pipe's unitary power (PUTi) is also used to prioritize the pipes to be rehabilitated. The PUTi corresponds to the discharge that flows through a specific pipe, multiplied by the difference between the piezometric head at the pipe's initial and final nodes (Saldarriaga et al., 2010). GIS can be used in locating and prioritizing pipes to be rehabilitated as well. (Ndirangu et al., 2013)

There are many benefits to the rehabilitation of WDN. For example, it reduces pipe leakage by reducing the failure rate from an average of 350/year failure rate to one fault in three years (Güngör et al., 2017). WDN rehabilitation also decreases NRW in systems by increasing water and energy saving, improving system performance and reliability, increasing hydraulic performance, and maintaining optimum pressure (Güngör et al., 2017; Saldarriaga et al., 2010). Another advantage of WDN rehabilitations is that it does not require historical information about pipe bursts, usually a problem in emerging economies (Saldarriaga et al., 2010). It only needs a calibrated model of the WDN, which is easier to attain than historical data.

However, rehabilitation requires a considerable budget. In the case of a limited budget, the rehabilitation process should stop whenever any of these two criteria are met: (1) when 60 diameter changes are done or (2) when rehabilitation cost exceeds the budget (Saldarriaga et al., 2010). Besides, replacing pipes can sometimes increase the NRW (Noli et al., 2020). Therefore, WDN rehabilitation should involve minimal time to maintain WDN service quality (Özdemir, 2018). There are plenty of studies that focused on reducing NRW. However, a limited number of studies focusing on the rehabilitation of the WDN as a method of reducing NRW. There is a clear gap in addressing rehabilitation as a method of reducing NRW. Choosing the WDN rehabilitation as a method of lowering NRW is because the rehabilitation of WDN has many benefits, including:

1. Economical, which are represented in the costs. Costs can be divided into maintenance costs, operating costs, capital costs, and damage costs. Where rehabilitation can reduce these costs in the future
2. Technically, where it addresses the performance, and the service is available at all the time without interruptions, as the old pipes result in lower performance and can pressure problems with the high-water demand that can cause service interruption.
3. Water quality considers the changes in water chemical properties transported in pipes as it gets older and deteriorates over time. Furthermore, rehabilitation increases water quality. (Wang et al., 2015)

2.4 Non-revenue water in Malaysia

Malaysia is one of the developing countries suffering from a high percentage of the NRW, which averages 35% (Yazid et al., 2017). The presence of the NRW in its considerable amount has a critical impact on water utilities' efficiency and is a challenge for the water utilities to face (Kamarudin et al., 2016). One of the causes of that challenge is the pipeline and meter replacements, as the water infrastructure mapping in Malaysia is incomplete. Also, insufficient financial resources are a common problem in developing countries, including Malaysia. One additional point is that there is no motivation for cost savings and productivity improvement for water utilities as the rehabilitation requires extensive funding and investment from the government (See & Ma, 2018). The government recognizes the problem of the NRW and intends to address the issue (Kamarudin et al., 2016). The rehabilitation of WDN is one of the possible solutions to reducing the level of water losses and overall NRW. Replacing an aging water pipe network and customer meters constitutes one possible solution to reducing the level of water losses in distribution. According to the Malaysian plan to decrease NRW, The rehabilitation of old pipes and the management of a proper NRW reduction strategy are effective solutions (Saadr & Anuar, 2019). The rehabilitation of WDN in Malaysia can decrease Real Losses' volume (Yazid et al., 2017). Therefore, finding WDN enhancement cost-effective rehabilitation approaches can help the water authorities in Malaysia to eventually decrease the NRW

2.5 Non-revenue water in Egypt

Moving to the Egypt position of the NRW. Egypt is one of the lower-middle-income countries that faces NRW, which is typical in developing countries. First, there is a current shortage of 13.5 Billion cubic meters per year, with the expectations to increase over time. Omar & Moussa (2016) concluded that water shortage by 2025 would be 26 billion cubic meters per year. Additionally, Egypt's water authorities face many problems facing the NRW (Mohie El Din & Moussa, 2016). The NRW, in many cases, can reach 80%, and one of the reasons behind that is the significant losses in the WDN (Mohie El Din & Moussa, 2016). There are many challenges in the NRW reduction program; the lack of local data is often a potential barrier to water authorities (Jussah et al., 2020). The management of NRW and activating the demand management are two of the solutions for the WDN. the rehabilitation of water pipes is one of the options to decrease the NRW (Jussah et al., 2020). El-Ghandour & Elbeltagi (2018) indicated that particle swarm optimization is the best for assessing the WDN. The rehabilitation of WDN will upgrade the old infrastructure of the WDN, which is considered one of the leading causes of the high NRW (Mohie El Din & Moussa, 2016). Therefore, finding cost-effective approaches in WDN rehabilitation is considered a critical step towards NRW reduction in Egypt.

2.6 Cost-effectiveness analysis

The cost-effective analysis (CEA) is one method to test the value of money; it is one of the best methods used before critical economic decisions. Regarding the CEA in the WDN field, some studies carried the CEA as part of their data analysis in the WDN. According to (Aulong et al., 2009) study which aimed to resolve future water deficits. The study had two case studies. The results of the CEA analysis that desalination of karstic submarine springs water or sea water would achieve the objective (resolve the future water deficits) without unduly high costs. One of the benefits of the CEA is for ranking alternative measures according to their C/E ratio (Aulong et al., 2009). Another study (Gerasidi et al., 2003) was used to overcome the water deficit on Paros island. The results of the study can be considered as a first step towards formatting an economically efficient and effective water management plan (Gerasidi et al., 2003). The final study was used in the field of WDN is (Hendrickson & Horvath, 2014), which was used to find solutions towards reducing greenhouse gas in the WDN. The study created a comprehensive model that determines the cost-effectiveness of greenhouse gas reduction opportunities in the WDN

2.7 Conclusion

2.7.1 Summary

The related literature was discussed in the above sections to overview past work on NRW and WDN rehabilitation and their relationship. Table 2.1 shows a sample of the primary literature findings. The literature discussing NRW is focused on NRW solutions. There are many methods to deal with NRW. the causes of NRW and NRW reduction strategies must be measured, analyzed, and compared when developing NRW reduction programs. Reducing NRW requires identifying the significant causes of NRW in a local context accurately because there are differences in the leading causes of NRW in each situation. For example, AL is suggested to be higher than RL in developing countries, while RL represents the major component of NRW in developed countries. The proposed strategies should then focus on addressing the major causes, reviewing the advantages, disadvantages, and limits of each strategy. Understanding the NRW problem will help develop NRW programs that fit each case.

In this WDN rehabilitation section, the aim was to review and analyze past work in this field. After identifying the enhancement approaches for rehabilitating WDN. Most of the proposed enhancement approaches had constraints. The first constraint is that the high price/funding constraints. The second constraint is the approaches ' generalizability, which includes many issues like limitations of applications, some assumptions, delivering water, flow demands, and head conversation. While this type of constraint may not have a solution when the research is done, current technology might overcome that constraint. While the third constraint is that the unavailable data to validate the proposed technique, this sort of data must be available for researchers/students or anyone who studies in this field. Finally, the fourth is that there can be associated with the applicability of the approaches. The list of techniques can assist industry practitioners in reducing NRW through rehabilitating WDN.

2.7.2 Research gap

After reviewing the following literature, a noticeable shortage can be detected in the rehabilitation's usage to reduce the NRW. Although there are many techniques to reduce NRW, the literature on using rehabilitation to reduce the NRW is limited. For developing countries, the rehabilitation of WDN is an effective way to deal with NRW due to old infrastructure and increased leakage and RL. Focusing on the use of rehabilitation as a method of reducing NRW helps in solving these issues. Besides, although there are many studies in the rehabilitation of WDN. The research gap can be identified as no study has compared the rehabilitation enhancement approaches according to their cost and effectiveness to rank them.

Table 2.1 Literature sample Findings

Paper	Year	Aim	Findings
Local solutions in Non-Revenue Water management through North-South Water Operator Partnerships: The case of Nakuru	2013	Reducing NRW to the local situation through a pilot	Programs such as Geographic Information System (GIS) and management information system (MIS) tools help in decision making and the management of WDN
Assessment of non-revenue-water and its reduction measures in Urban water distribution systems	2018	Providing a review on assessment of present levels of NRW and a strategy to be implemented for reducing NRW	Supervisory Control and Data Acquisition System (SCADA) is one of the most used programs in monitoring the WDN
Non-revenue water and cost recovery in urban India: The case of Bangalore	2015	Examines the issue of non-revenue water (NRW) in urban India, taking the city of Bangalore as a case study	Policy makers can raise the public's awareness towards reducing NRW and prioritize the control of NRW through a political program
Applying incentives to increase revenue water in urban systems	2013	Utilizes cross-sectional data from utilities of the National Water and Sewerage Corporation of Uganda to test application of extrinsic incentive theory on non-revenue water (NRW) reduction	”Poor training of labor” is one of the most critical parameters facing the NRW problem
Water leakage management by district metered areas at water distribution networks	2018	Design a district metered area (DMA) at water distribution network (WDN) for determination and reduction of water losses in the city of Malatya, Turkey	There is a relationship between water meterage and the volume of water registered and accuracy; many old meters need to be replaced

Table 2.1 Countinued

Paper	Year	Aim	Findings
Applying incentives to increase revenue water in urban systems	2013	Utilizes cross-sectional data from utilities of the National Water and Sewerage Corporation of Uganda to test application of extrinsic incentive theory on non-revenue water (NRW) reduction	Another AL reduction strategy is preventing illegal behavior from occurring, including water theft (which can be higher in poor areas)
Component analysis for optimal leakage management in Madaba, Jordan.	2018	Provide a structured analysis to determine the volume of leakage and its components in Madaba's water distribution network	Failures represented in leakage and bursts can be observed and ignored by the public instead of reporting it, as most of the public do not save water service providers' phone numbers
Domestic water meter optimal replacement period to minimize water revenue loss	2019	Determine the optimal domestic water meter replacement period	Meters should be replaced from time to time by introducing meter replacement programs
Evaluating physical and fiscal water leakage in water distribution system	2019	Focused on real water loss in the water distribution system located in Ethiopia	Artificial Intelligence (AI) tools can predict the leakage before taking place
Increasing performance of water distribution network by using pressure management and database integration	2019	Improve the performance of the WDS in terms of water losses and leaks monitoring and management	District metering areas (DMA) enables monitoring the pressure and flows in the area to identify the most challenging zones
Reduction of water losses by rehabilitation of water distribution network	2017	Examine the effects of piping material management and network rehabilitation on the physical water losses and water losses management in a WDN	There are many benefits to the rehabilitation of WDN. For example, it reduces pipe leakage by reducing the failure rate

CHAPTER 3

METHODOLOGY

3.1 Introduction

In this research, the methodology adopted for data collection is the questionnaire survey, and then data analysis mean score analysis for analyzing the data. The following sections explain the steps of the data collection and data analysis. Many studies conducted this type of research that uses a questionnaire survey in the data collection and the cost-effective analysis in the data analysis within a similar search field of water, studies like: Islam et al (2010) and (Mogheir et al., 2005)

3.2 Research framework

Figure 3.1 shows the framework of the methodology and how to achieve each objective within the study. The first objective was achieved by identifying and analyzing variables conducted from the systematic review. The identification of the cost-effective enhancement approaches was concluded upon data analysis of the survey collected data. The final objective, which is the comparison between Egypt and Malaysia cost-effective enhancement approaches, was after the further investigation and analysis behind the reasons of each approach mechanism and finding solutions to make these enhancement approaches applicable within the developing counties

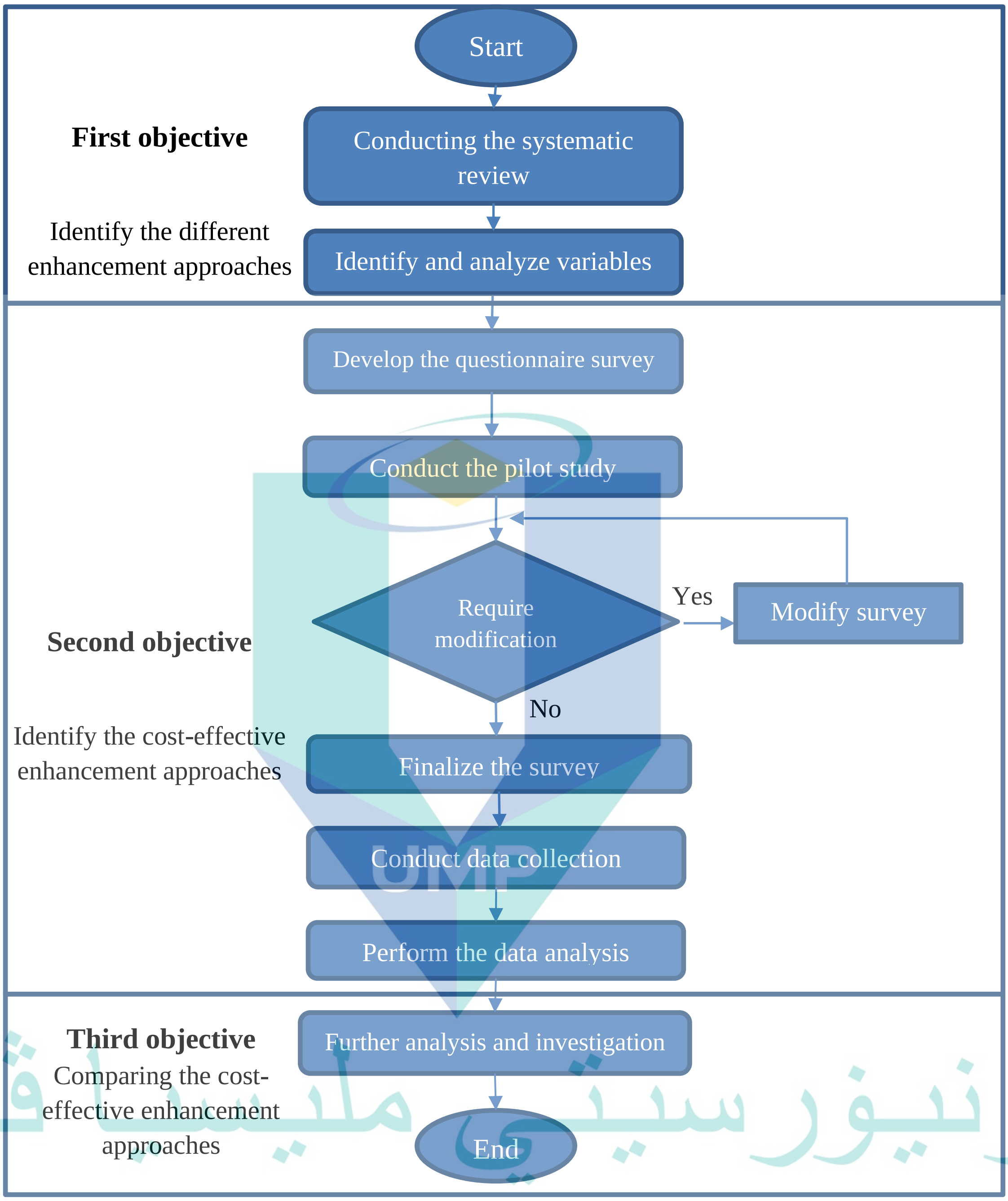

Figure 3.1 Methodology framework

3.3 Developing the questionnaire survey

First, to develop the questionnaire survey, the primary data was collected through a systematic review to identify WDN rehabilitation variables. Then a comprehensive review was conducted to identify the different rehabilitation enhancing approaches. Second, the questionnaire survey was developed, consisting of a 5-point Likert scale to measure the effectiveness and cost of the identified enhancement approaches of WDN rehabilitation. The questionnaire survey was adopted because it has many benefits: it accesses a wide range of participants, offers valid and reliable sources of information in a short time and limited resources, and it provides (Ameyaw et al., 2017; A. P. C. Chan & Owusu, 2017; Hoxley, 2008; Mathiyazhagan & Nandan, 2010). At the final stage, a pilot study was performed to ensure the validation of the questionnaires. This method of collecting the data is effective and adopted by others to collect data (Alaka et al., 2017; El-Gohary et al., 2013; Owusu et al., 2020).

3.3.1 Systematic review

A systematic review was used to collect the variables of the WDN rehabilitation enhancement approaches; a systematic review simply summarizes past research on a specific topic. The research aimed to identify the different rehabilitation enhancement approaches in the rehabilitation of WDN, consisting of three main stages. The first stage was the comprehensive search under "T/A/K (title/abstract/keyword)." This study uses Scopus as the search engine, as it has a wider database and covers more journals than other search engines, and it is well known in the field of systematic reviews (Falagas et al., 2008). The search involves the following keywords: (1) "water"; and (2) "pipeline" OR "pipe system" OR "water distribution" OR "water network" OR "water supply network" OR "distribution network" OR "supply system OR water main"; and (3) "rehabilitate" OR "renew" OR "repair" OR "reconstruction" OR "maintenance" OR "restoration" OR "replacement" OR "fix" OR "renovate" OR "re-establish." This study also limits the results to only articles and review papers in the final version and English. Then limited the search to the subject areas that are appropriate to the study, which consists of "engineering," "business, management, and accounting," and "decision sciences.". The journals selected must have more than two published articles related to the topic (Darko & Chan, 2016; Robert& Chan, 2015). The full search code is:

TITLE-ABS-KEY ((water) AND (pipeline OR pipesystem OR waterdistribution OR waternetwork OR watersupplynetwork OR distributionnetwork

OR supplysystem OR watermain) AND (rehabilitate OR renew OR repair OR reconstruction OR maintenance OR restoration OR replacement OR fix OR renovate OR reestablish)) AND (LIMIT-TO (SUBJAREA , "ENGI") OR LIMIT-TO (SUBJAREA , "BUSI") OR LIMIT-TO (SUBJAREA , "DECI")) AND (LIMIT-TO (PUBSTAGE , "final")) AND (LIMIT-TO (DOCTYPE , "ar") OR LIMIT-TO (DOCTYPE , "re")) AND (LIMIT-TO (LANGUAGE , "English")) AND (LIMIT-TO (SRCTYPE , "j"))

The search was on 5/11/2019, with 690 results. The results are then refined to journals with at least three papers in rehabilitation methods of WDN (Darko & Chan, 2016; Robert & Chan, 2015), resulting in 327 articles were concluded. Moving to the second stage, a visual examination is conducted on the title, abstract, and conclusion to choose suitable papers for the systematic review, which results in ten articles. Then, articles that are referenced in the collected papers are gathered. This method is adopted to identify articles outside of the designated databases but still relevant to the topic. Determining the articles involves going through the list of references of the collected papers. This process is repeated using the articles that have been selected to identify another set of articles until there are no new articles to be found. Some were not chosen as the papers would be duplicated or outdated as it is over 50 years old and unreachable. Finally, in the last stage, 17 articles are identified for further analysis. These articles are subjected to investigation to determine the rehabilitation enhancement approaches of WDN. A total of 17 approaches of WDN rehabilitation was defined as the key findings of the systematic review.

Choosing 16 articles that met the selection criteria will not affect the study. This study mainly deals with advanced rehabilitation methods of WDN, plus the excellent contribution of the pilot study made the survey suitable for collecting the data. Adapting these limited numbers is familiar, as many systematic reviews had a similar amount of papers, and the study was valid. Many studies are conducted on a similar number of results as 15 and 10 results only (Broadstock et al., 2000) and (Gil-Gouveia et al., 2015), respectively. Figure 3.2 shows the complete steps for conducting the questionnaire survey with the sequence of activities till identifying the enhancement approaches for WDN rehabilitation.

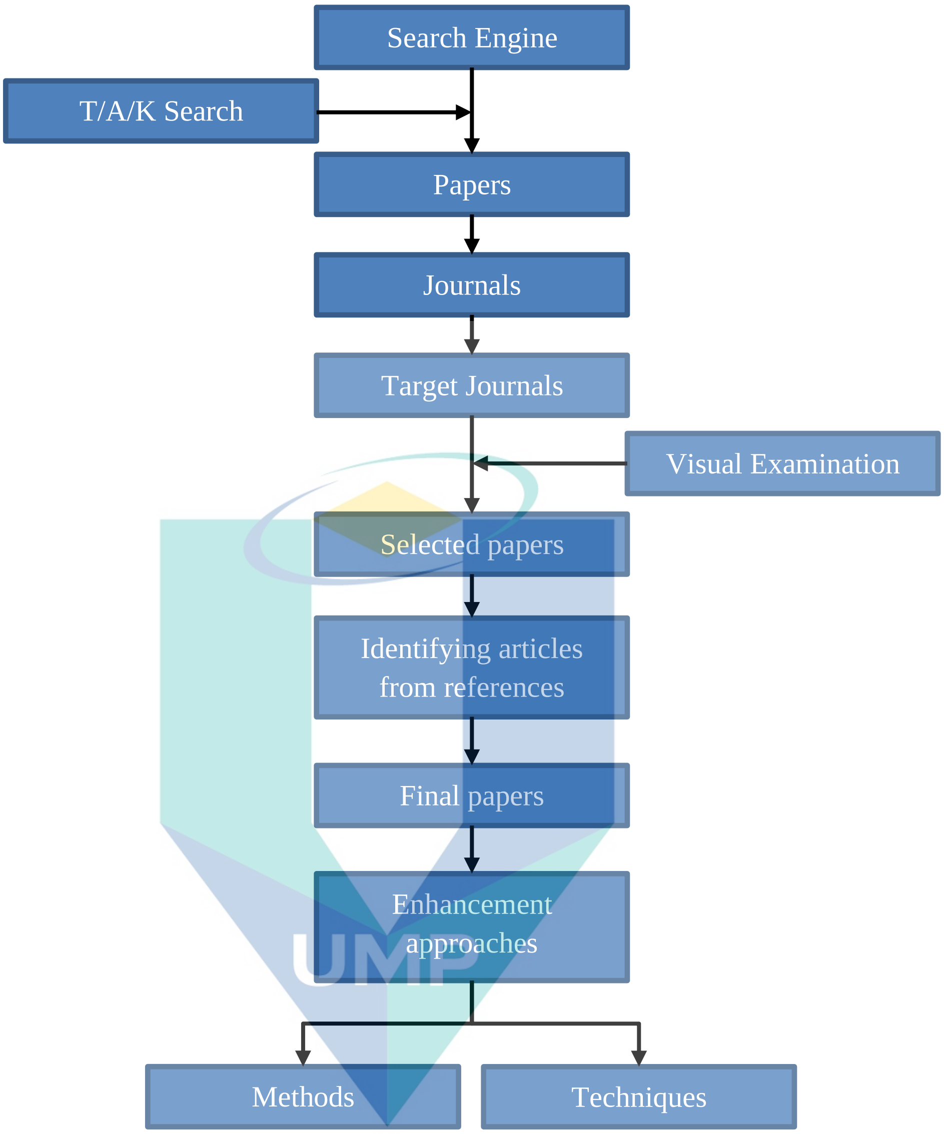

Figure 3.2 Systematic review framework

3.3.2 Survey design

After summarizing the data gathered from the systematic review and after the literature review, the data were compared to remove repeated data and to make sure to get the most outcome from the data. The questionnaire survey was then conducted so that every question is exact and forward, and duplicate or bias questions are avoided to make the data valid and suitable for further analysis. The survey consisted of four parts, as shown in Table 3.1

Table 3.1 Survey components

Part	Components
First	Respondent profile that ensures that all respondents are among the targeted population
Second	Acquire data on the effectiveness of each WDN rehabilitation approaches
Third	Acquire data on the cost of each WDN rehabilitation approaches
Fourth	Solicit additional WDN rehabilitation approaches to overcome any potential limitations

The questionnaire consisted of four parts. First, the respondent profile. Second, asking about the effectiveness. Third, asking about the cost and last asking about other factors to consider in the future studies and to make the questions less, a plan has been adopted to ask about the method itself before asking about its techniques. If the respondent does not use/know the method, asking about its techniques is skipped to reduce the total questions and decrease the respondent time.

3.3.3 Pilot study

After drafting the survey, this survey needs to be verified, so the next step after finalizing the survey was conducting the pilot study. A pilot study is testing the questionnaire on a small, targeted sample of people, and according to the words of De Vaus (1993:54), "Do not take the risk. Pilot test first.". A pilot study is such an essential step to highlight what can be done before finishing the survey. It has many strengths, including providing warning signs that the study is inappropriate, accessing the survey/study's feasibility, assisting in developing research questions, and identifying potential problems that may occur during the proposed methodology.

There are two types of targeted groups during the pilot study, university professors (academics) and industry practitioners (industrial). These individuals were targeted to identify the survey's limitations and suggest improvements to ensure validity. The combination of academic and industrial groups would be great as they have different work experiences and diverse background knowledge. The academic perspective forms the theoretical and the validity of the survey. On the other hand, the industrial would validate the survey's applicability in practice. The pilot study was sent to twenty people, with 14 returned responses. Their responses were analyzed, and four new approaches (one method and three techniques) were outlined. The new method is the Zoning network. Besides that new method, there are three: compact pipes, supervisory control and data acquisition (SCADA), and twin digital techniques. The compact pipe is under the trendless method, and SCADA is under the programming method, and lastly, the twin digital is listed under the models' method. After several revisions, the questionnaire survey was ready for data collection. The following Table 3.2 shows the approaches used in the survey with their respective codes.

Table 3.2 Questionnaire survey approaches

Code	Name of Approaches	Source
A01	RTM	Lee et al (2002)
A02	Trenchless method	Hastak & Gokhalev(2000)
A03	Algorithm method	(Arai et al., 2009; Cheung et al., 2003; Graeme C. Dandy & Engelhardt, 2004; G. C. Dandy and M. Engelhardt, 2001; Giustolisi & Berardi, 2009; Halhal et al., 1997; Tricarico et al., 2006)
A04	Programming method	Cheung et al (2003)
A05	Models method	(Cheung et al., 2003; Engelhardt et al., 2000; F. Li et al., 2016a)
A06	Significance Index	G. Prince Arulrajl & H. Suresh Rao (1995)
A07	Zoning network	pilot study
A08	Sliplining	Hastak & Gokhale (2000)
A09	CIPP	Hastak & Gokhale (2000)
A10	Pipe bursting	Hastak & Gokhale (2000)
A11	PR	Hastak & Gokhale (2000)
A12	Compact pipe	pilot study
A13	HGA	Arai et al (2009)
A14	NSGA	Tricarico et al (2006)
A15	GA	Dandy and M. Engelhardt (2001)
A16	MOGA	(Cheung et al., 2003; Graeme C. Dandy & Engelhardt, 2004; G. C. Dandy and M. Engelhardt, 2001; Giustolisi & Berardi, 2009)
A17	SMGA	Halhal et al (1997)
A18	SPEA	Cheung et al (2003)
A19	SCADA	pilot study
A20	Twin digital	pilot study
A21	RDOM-GS	F. Li et al (2016a)

3.4 Collecting the survey data

3.4.1 Target population

Before collecting the data in Malaysia and Egypt, the profiles were scanned to ensure it is related to WDN. The number of selected profiles in Malaysia was around 600 and 300 in Egypt. The population size was conducted to be 900. Moreover, the respondents must meet the two selecting criteria to get selected to participate in the survey: (1) having experience in the water industry, (2) having experience in WDN projects. The targeted population is across Malaysia and Egypt. They are engineers that are in the field of water distribution network. So, collecting data adopted here is sending the questionnaire survey via the internet faster and more comfortable access. The questionnaire survey is created using an online platform for creating online surveys called Survey Legend. Survey Legend allows creating the study to assist the respondent, and it is a handy platform in creating surveys. LinkedIn was used to send our questionnaire survey.

3.4.2 Sampling technique

The targeted population is based on the engineers working in water supply system companies or water supply system maintenance companies all over Malaysia and Egypt. Respondents are mainly site engineers or construction managers, as our questionnaire survey questions are based on the construction view rather than the designing phase. It is logical to have these targeted participants in that kind of survey questions as the survey questions deal with the construction. After determining the population, purposive sampling was adopted, that the profile was scanned and selected carefully. That emphasizes that all the respondents are related to the rehabilitation of the WDN and distributed all over the country. Snowballing sampling was adopted at some points in the survey. The respondents were requested to share the questionnaire with other WDN experts in their network. The data collection process was started from June 2020 to October 2020.

3.5 Analyzing the survey data

After collecting data, it must be checked to make sure it is valid for further analysis. First, the completeness of the survey as uncompleted surveys can cause bias. Second, making sure the respondent is from the targeted population. Finishing these steps leads to the next stage, which is checking the reliability of the data.

3.5.1 Cronbach's alpha

Cronbach's alpha coefficient was used to determine the questionnaire survey's reliability based on the systematic review. For the questionnaire survey to be reliable, a score of 0.7 Must be obtained (Taber, 2018). The scores for the Malaysian and Egyptian versions of the questionnaire survey were 0.91 and 0.879, respectively, which concludes that the data is reliable for further analysis.

3.5.2 Mean score ranking

The mean score ranking technique is used to rank the enhancement approaches of rehabilitating WDN. This method is widely used to analyze survey data Chan et al (2011) and Robert & Chan (2017). Scale ranking analysis is used to rank the 21 techniques and methods. A total of 109 and 67 survey answers were analyzed using SPSS 26.0 To generate mean, standard deviation, number. For ranking the approaches, items were ranked to their mean score values (Chen & Chen, 2007). If two items had the mean score values in the ranking process, then the highest rank is chosen based on the lower Standard deviation (SD). Then the choice of the items was based on the normalization value (NV); the score of the NV must be above 0.5 to be selected as the best in a specific category (cost or effectiveness)

3.5.3 Normalization technique

The min-max normalization method was tested; the dataset varies between 0 and 1. This method is chosen to choose the critical items in effectiveness and cost factors. The items with values more than 0.5 are selected as the vital factors in the effectiveness and cost factors. Only items with a normalized value ≥ 0.50 were considered most important (R. Osei-Kyei & Chan, 2017). This method is used before in many studies, such as drivers for risk management in construction companies Zhao & Zuo (2009) and determining the criticalities of the project's success (Adabre & Chan, 2019)

3.5.4 Agreement analysis

One-way ANOVA (α) is a suitable method for comparing the mean scores of more than two groups Misangyi et al (2006). It is used to check for any difference's levels in mean values between Malaysia and Egypt in both effectiveness and cost and to check if there is any significant difference between the Malaysian and Egyptian surveys. The check found three significant differences: the effectiveness factor (17 and 19) with values of 0.001 and 0.014, respectively. That may be explained as during the analysis process in SPSS, the results mentioned that the data is insufficient. The other factor (cost) has this only one item, number 15, with a value of 0.03; this can also be explained due to the same reason. That indicates that, in general, there are no significant differences. The results are displayed in tables 4.3 and 4.4. The tables are sorted depending on the NV values in descending order. The red font shows the items with specific problems as the number of respondents is less than 30, which is not a fair number for further analysis; therefore, it might have minor errors. The score of the one-way ANOVA (α) is less than 0.05.

3.6 Summary

The methodology chapter aimed to explain the path the study took to reach its objectives, the method used was the questionnaire survey, a research framework was included to highlight the main steps for fulfilling the research aims and objectives. The questionnaire survey was developed depending on a systematic review; after drafting the questionnaire survey, the pilot test was held to validate the questionnaire survey. The targeted population was chosen based on engineers, project managers, and owners of water authorities that are related to WDN rehabilitation. The primary sampling techniques used were purposive sampling and snowballing. After collecting the data and filtering the uncompleted surveys, a total of 176 valid survey responses were collected from Malaysia (109) and Egypt (67). The results went through Cronbach's alpha to measure the reliability of the respondents. The mean score value, normalization value, and agreement analysis were held to identify the cost-effective approaches for both countries; chapter 4 will highlight and discuss the findings from this chapter

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

Before data analysis, the characteristics of Malaysia and Egypt respondents' profiles were analyzed and compared. After the comparison, the analysis of both counties was conducted to compare Malaysia and Egypt's results. The comparison results resulted in the comparison of approaches in both countries and the overall ranking results. results are discussed in the following sections

4.2 Results

4.2.1 Enhancement approaches for WDN rehabilitation (Objective 1)

To identify the enhancement approaches for WDNT rehabilitation, a systematic review was carried, and it resulted in a total of 21 approaches that can be summed up to 7 methods and 14 techniques. The following Figure 4.1 summarizes the Enhancement approaches for WDN rehabilitation. The following sections would discuss the seven main enhancement methods for rehabilitating WDN.

4.2.1.1 Molding

In addition to causing traffic congestions and a large amount of waste, excavating during the process of repairing and replacing WDNs requires heavy machinery and longer operating time and cost. While there are trenchless technologies, most technologies involve high construction costs, inconvenience of operation, and limited application to circular conduits. To address those disadvantages, this technique - resin transfer molding (RTM) is a process for reinforcing retired or repairing damaged WDNs using fiber-reinforced composite materials (Lee et al., 2002). The technique also involves applying an appropriate and vacuum during the process of reinforcing the WDNs (Lee et al., 2002).

RTM requires shorter operational time, lower costs, and less operating equipment than conventional trenchless technologies that increase the compressive load capacity. Also, RTM can increase the pipes' reinforced strength up to 15% (Lee et al., 2002).

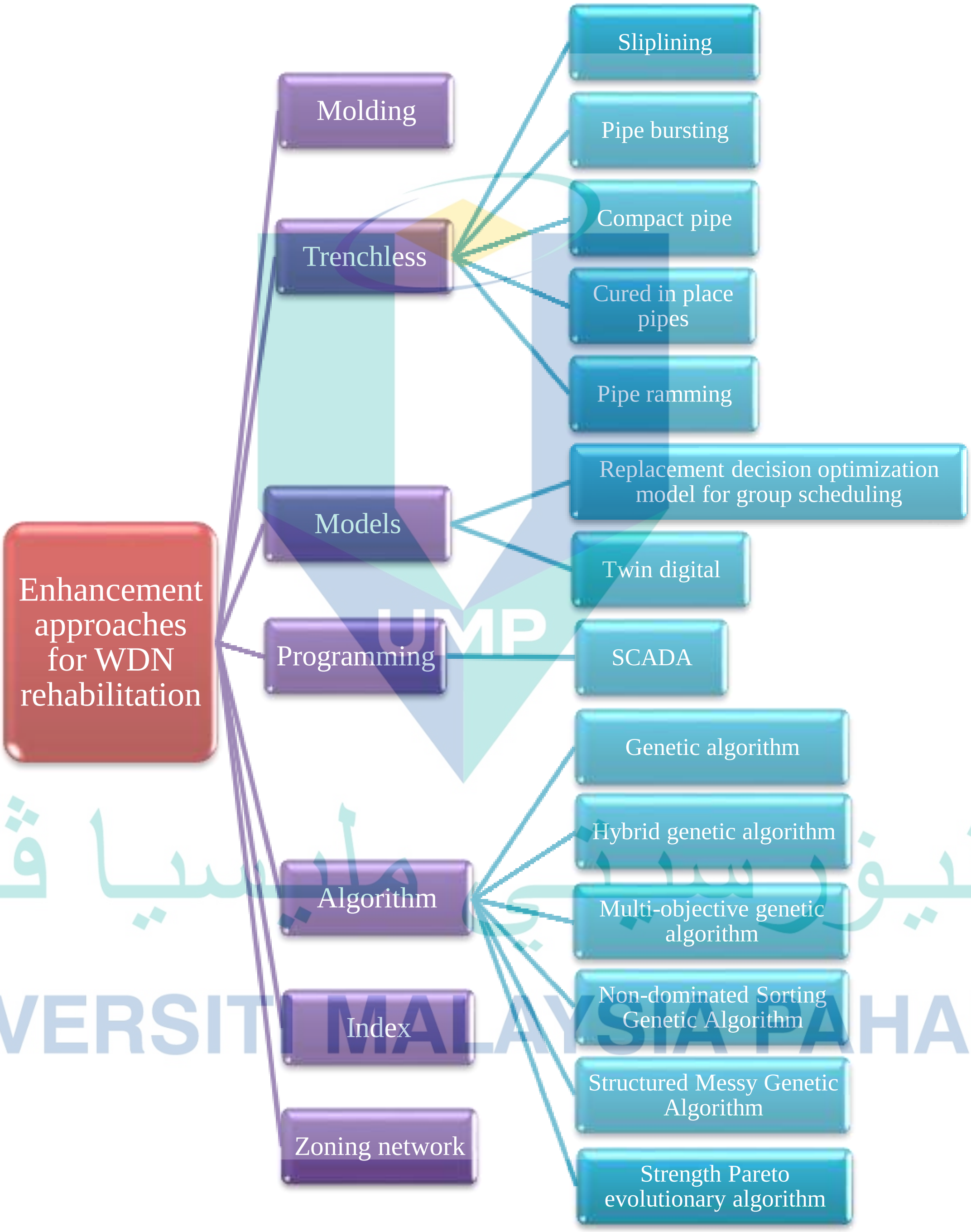

Figure 4.1 Enhancement approaches for WDN rehabilitation

4.2.1.2 Trenchless

There are several methods regarding trenchless techniques of WDN rehabilitation. First, slip lining is one of the oldest ways of water pipes rehabilitation. A slipping method consists of a small diameter pipe inserted in a deteriorated host pipe, and the annulus between the existing pipe and the new pipe is grouted. Second, cured in place pipes (CIPP) is the use of polyester or epoxy resin-impregnated fabric tubes. The tube is injected into the existing host pipe and inflated against the host's wall using a hydrostatic head or air pressure. Third, pipe bursting typically utilizes a percussive tool, static expansion cone, or a hydraulic expander to break out the existing pipe, while a new pipe is pulled in place. Forth, pipe ramming (PR) is a trenchless method that allows installing new pipes under roadways from a drive to a reception shaft utilizing the dynamic force and energy transmitted by a percussive hammer attached to the end of the pipe (like pile driving). PR permits installing a larger casing in a wide range of soil conditions (Hastak & Gokhale, 2000).

Every project is unique, so it is critical to evaluate the trenchless technique system on a project-to-project basis by considering each criterion and sub-criteria importance for the final decision task. The criteria are divided into five basic categories, need-based criteria, economic criteria, technological criteria, project-specific criteria, and safety/risk criteria. Furthermore, the sub-criteria includes labor intensity, the repetitiveness of work, critical to productivity achievement, quality, high production, labor savings, health hazards, and physical hazards. A support system would assist in the decision process by systematically evaluating five groups' criteria and sub-criteria to lead to optimal decision-making after comparing each technique. The system's strengths for the operation of selection are able to analyze quantifiable and intangible decision criteria and the determination of the most suitable option based on priority (Hastak & Gokhale, 2000).

4.2.1.3 Algorithm

The algorithm is a problem-solving operation that is used by computers. Genetic algorithms (GA) are a type of optimization algorithm, meaning they are used to find the maximum or minimum function (Mitchell, 2020). Most papers identified in this study are associated with GA. The main differences between GA and traditional search and optimization procedures are: (1) GA involves coding both conventional and new parameters while conventional methods only involve standard coding parameters; (2) GA analyzes multiple points while conventional methods analyze single points, (3) GA uses only payoff to achieve its objective function while traditional methods use both payoffs and derivatives; (4) GA consist of probabilistic models while conventional methods are fully deterministic models; and (5) GAs are inherently parallel that resulted in the main strength of GA on dealing with a large number of random points random (Lankhorst, 1996). This method's advantages are that it can identify and schedule pipe replacement in a deteriorating WDN, provide optimal scheduling of leakage detection and pipe replacement in WDN, improve the carting capacity of WDN, and minimize overall costs of the rehabilitation over a fixed time.

Arai et al (2009) aimed to optimize the selection of pipe diameter during pipe replacement planning for WDN. Through a hybrid genetic algorithm. El-Ghandour & Elansary (2018) sought to minimize the total rehabilitation cost by considering pipe size diameter and reducing the transient impacts by minimizing a surge damage potential factor (SDPF). A multi-objective ant colony optimization algorithm was developed to achieve that. The results indicated a decrease in cost as well as stability in water pipe flow. The hybrid genetic algorithm (HGA) was tested through a case study in two factors (economic efficiency and stability in velocity in pipes), and results were achieved. On the other hand, the HGA developed by Bakri et al (2015) simplified the network, which results in the reduction of labor, repair, operation, procurement, and maintenance cost. The results indicated that the optimum selection of pipe replacement directly affects cost-effectiveness and water pressure. The multi-objective genetic algorithm (MOGA) is another technique mentioned by Alvisi & Franchini (2009); this method provides an accurate picture of the structural and hydraulic conditions of WDN. It gives indications for each of

1. How to use the given budget in leakage detection and for pipe replacement
2. When and when to carry leakage detection
3. Which pipes to replace and when to be replaced

Applying these results in a narrowing range of solutions, which will create a balance between decreasing repairing costs and water losses. MOGA can be used in pipe failure detection. It also measures system reliability in terms of service interruption due to pipe failure. Although replacement schemes could not ensure the optimal solutions for optimization rehabilitation. (Giustolisi & Berardi, 2009)

Another algorithm method is the replacement decision optimization model for group scheduling (RDOM-GS) (F. Li et al., 2016b). This technique enables multi-group scheduling criteria that adapt the cost function and the service interruption model in the selection process. Significant cost savings and reduced service interruptions can be achieved. Its only limitation is that RDOM-GS can only accommodate two optimization objectives. The last genetic algorithm method adapted is the Structured messy genetic algorithm. Under a limited budget, this method can develop a set of possible network improvements. It finds the best way to invest in the rehabilitation process. The overall benefits of applying this method are:

1. Improving the carrying capacity
2. The physical integrity of its pipes
3. Improving water quality
4. Having more system flexibility (Berardi et al., 2009).

The algorithm method is a significant method that has been used among various papers. Future studies are recommended in this area. Due to its massive ability in the rehabilitation process

4.2.1.4 Models

Models are a popular method in the rehabilitation of pipes. It is a method of simulating what will happen for a specific rehabilitation situation Salehi, et al (2018) developed a comprehensive criterion based on 42 variables. The variables consist of technical and non-technical, which can affect the WDN rehabilitation. The Multi-Attribute Decision-Making model was developed that involves a TOPSIS/fuzzy logic. This logic was preferred due to its ability to model the uncertainty and imprecision, and Order Preferences by Similarity. Such that in the end, the ideal solution can be selected. Each pipe is considered for decision-making when rehabilitation. It can prioritize water pipes for rehabilitation. One of its advantages is its flexibility to adjust to governing conditions. Resulting in increasing the accuracy in WDN rehabilitation planning; it is suitable for group decision making. Experts can use this when studying the rehabilitation of a WDN. The model only prioritizes pipes and their zones. The study recommended developing a model that considers economic criteria helpful in planning as the main limitation of this study is ignoring the financial principles (Salehi, et al., 2018).

Another model for choosing and ranking suitable between different rehabilitation methods, Ammar et al (2012) proposed the decision support model included breakage rate and a lifetime of pipes when rehabilitation. The fuzzy-based Life cycle cost (LCC) analysis can be used as a decision support tool to compare and select the most cost-effective rehabilitation technique. There are many decisions for every scenario in the rehabilitation process. That can be used to help in decision-making.

There is a model called the replacement decision optimization model for group scheduling (RDOM-GS). It consists of three parts. First, the pre-analysis aims at divining the probability of failure for each pipe at each age using a hazard prediction model. Second, the group scheduling criteria analysis, which concentrates on decreasing the possible group scheduling options by considering multiple group-scheduling criteria. Third, the cost model and the service interruption model consider group scheduling of pipes by calculating cost savings and reducing service interruption results. This technique helps minimize both total cost and service interruption; besides that, it also has vital benefits that water utilities should consider by implementing RDOM-GS. The application can potentially be extended to other networks such as railway, road networks, and electricity distribution (F. Li et al., 2016a).

Prioritization models attempt to prioritize the mains requiring rehabilitation such that, for a given budget, the amount of the likely works can be identified. Optimization techniques consider the relation of each main with the system as a body. They allow cost and performance factors to have an essential role in formulating the rehabilitation program. In economic models, any rehabilitation decision should consider all costs that will be carried throughout the WDN lifetime. Reliability models consider the hydraulic reliability of the water distribution system. Hydraulic models evaluate the deterioration of the hydraulic performance and possible improvement in individual assets. Water quality models are considered the most intricate analysis included in the rehabilitation decision. This model could not be used to determine the rehabilitation actions due to this as the consideration of water quality is limited. Operational models considered the trenching and no dig options to rehabilitate water pipes based on many factors such as road surface, soil classification, and surge analysis. The rehabilitation strategy mentioned that a decision model must include many economic criteria upon selection, such as water, hydraulic, and quality (Engelhardt et al., 2000). These models minimize the expected annual cost during the planning period, generates gest solutions during the deteriorating stage. The model method helps in cost savings, decreased service interruption, functions representing the risk of pipe breaks, and product between the number of bursts and costs associated with future breaks.

The last prioritizing model developed by Marzouk et al (2015) aimed to rank the pipes according to their condition severity for rehabilitation activities and funding allocation. The model is friendly and can be integrated into GIS technology to improve the monitoring of WDN. Microsoft Excel is used in the applying of the model. The model schedules water rehabilitation activities and resource allocation, such as funds. A cost plan can be developed by using the bottom-up approach. The model helps in the WDN rehabilitation planning. That is why the optimization techniques for the rehabilitation process adapted models in rehabilitation

4.2.1.5 Programming

The mixed-integer nonlinear programming is a mixed-integer nonlinear programming problem that adapts a solution procedure that combines an implicit enumeration scheme using a branch and bound algorithm along with a generalized reduced gradient procedure to solve a nonlinear subproblem. This program will help determine the minimum cost and replace pipes in water distribution networks (Tricarico et al., 2006).

The second technique is the procedure for rehabilitation analysis of water distribution systems (P RAWDS), which is based on a dynamic programming approach combined with partial and (sometimes) implicit enumeration schemes (F. Li et al., 2016a). (P RAWDS) has a significant cost saving and reduced service interruption procedure for rehabilitation analysis F. Li et al (2016a), and minimizes the rehabilitation investment and maintenance costs over time (Yehuda et al., 1998). The advantages of (P RAWDS)are its ability to (1) explicitly consider the deterioration over time of both the structural integrity and the hydraulic capacity of the pipes in the WDN; (2) compare projected cost streams that are independent of the selected analysis period (by considering rehabilitation cycles to infinity); (3) evaluate the economics and performance of the entire network while regarding each pipe as a separate entity with its characteristics and parameters; and (4) determine each rehabilitation action not only by the current state of the system but by future rehabilitation actions as well. However, it is suitable for relatively small distribution systems with present computational techniques and equipment (Y. Kleiner et al., 2001). That technique has its strengths such as: differentiates between two kinds of rehabilitation measures, i.e., first measures that enhance both hydraulic capacity and structural integrity of pipes and second measures that improve only the hydraulic capacity of the pipe. It can find an optimal approach to identify a minimum cost solution in an ample combinatorial solution space and it is a methodology that takes the time dimension as a consideration to develop a rehabilitation action not only considering current state but also future optimal rehabilitation actions.

The last technique is a multilevel decomposition scheme; it is a multilevel decomposition scheme developed for water distribution systems, contributing to determining the best resource allocation among the main pipes to maximize the overall (D. Li & Haimes, 1992). This technique considers four kinds of costs, i.e., pipe replacement cost, pipe rehabilitation cost, pipe repair cost, and pumping cost. The solution methodology concept is different, where the strength relies on minimizing the overall cost and maximizing the system's availability.

4.2.1.6 Index

The significant index is a simple optimality criterion, which is a dimensional index defined as shown in Equation 1. Sf = LQ/(CD)

where L = length of the pipe (in m), Q = discharge in the pipe (in m^3/s), C = Hazen-Wil1iam coefficient, and D = diameter of the pipe (in m)

This index can be used in an effective way to rehabilitate an existing network as it pointed out that none of the other models managed to handle complex networks. This method is both for the design of new networks and for the rehabilitation of old ones. It is suggested to be applied to identify optimal designs of new networks after being modified slightly (Prince & H. Suresh , 1995)

4.2.1.7 Zoning network

The last method is the zoning network, which was added from the pilot study; the method is summarized in 4 steps. First, the area is divided into several zones based on the pipeline laid. The workforce is assigned to do a site survey for all the pipelines. That will cost the workforce to do the survey, workforce for data entry. The second step is after identifying the zone, data to be acquired for each location, and isolation for each area to be applied. To do this, engineers lead supervisors installing data loggers at each zone to identify isolation valves that need to be installed. (workforce + special tools cost required). The third step is after all zones have been set up, engineers to do the study on the pressure management for all the zones. By doing this, you can extend the pipe's life span by applying pressure for every particular of zones based on customers and types of pipe that laid; this step needs special tools purchasing. The last step is that several methods can do pressure management, either by installing a pressure reducing valve or flow control valve. Also, the final step requires special tools. The zoning network's main strengths are that it can identify the leaks fast, and the team can solve them in a short period, resulting in the reduction of NRW in the area. However, there is a minor limitation in that method, which is that small leaks do need to be found by the team manually because only significant leakage is visible by this method. so, groups are required for performing leak detection

4.2.2 Respondent profile

Table 4.1 and Table 4.2 displays the characteristics of survey results for Malaysia and Egypt, respectively. The study surveyed a total of 176 questionnaires, 109 from Malaysia and 67 from Egypt. The number of respondents is suitable in Malaysia as many studies in Malaysia in the same field had similar respondents (Abas et al., 2018; Kadir et al., 2006; Pong, 2020). In Egypt, there are similar studies with the same respondents' size in the same field: (Abd El Razek et al., 2014; Ghallab & Hosain, 2020; Gupta et al., 2013). In Table 4.1, more than 55% of the respondents are owners of organizations. 45% of the respondents had more than nine years' experience in the water industry, and around 54% had more than six years' experience in WDN. Moving to Table 4.2, in Egypt, owners of organizations and consultants have the primary respondents with 43% and 31%, respectively. Around 70% of the respondents had more than nine experience in WDN; this ensures the high confidential data collected from the respondents. The same scenario happened regarding company grades. Most respondents' company grades were not applicable because they are not related directly to construction. Still, the majority of the company grades are from the seventh category, with around 33%. The higher the grade, means more substantial evidence of works and financial capability provided by the contractor. The rehabilitation is usually adapted from high companies because the cost of rehabilitation is high therefore it is expected that the most respondents are from large companies with high experience in the WDN rehabilitation.

Table 4.1 Malaysia respondents' profiles

Malaysia		
Respondent's Organisation	Number	Percentage
Owners	61	55.96
Contractors	23	21.1
Consultants	20	18.35
Other	5	4.59
Respondent's Water Industry Experience		
less than 2 years	9	8.26
2-5 years	22	20.18
6-9 years	29	26.61
More than 9	49	44.95
Respondent's WDN Experience		
less than 2 years	21	19.27
2-5 years	29	26.61
6-9 years	28	25.69
More than 9	31	28.44
Respondent's Location		
Central Region	27	24.77
East Coast Region	21	19.27
Northern Region	21	19.27
East Malaysia	20	18.35
Southern Region	20	18.35
Company's Grade		
Not applicable	60	55.05
Grade 1	0	0
Grade 2	1	0.92
Grade 3	2	1.83
Grade 4	4	3.67
Grade 5	4	3.67
Grade 6	2	1.83
Grade 7	36	33.03

Table 4.2 Egypt respondents' profiles

Egypt		
Respondent's Organisation	Number	Percentage
Owners	29	43.3
Contractors	21	31.3
Consultants	11	16.4
Other	6	9
Respondent's Water Industry Experience		
less than 2 years	2	3
2-5 years	6	9
6-9 years	13	19.4
More than 9	46	68.7
Respondent's WDN Experience		
less than 2 years	2	3
2-5 years	19	28.4
6-9 years	21	31.3
More than 9	25	37.3
Respondent's Location		
Greater Cairo Regional Unit	12	17.9
Asyut Regional Unit	11	16.4
Alexandria Regional Unit	10	14.9
Delta Regional Unit	10	14.9
South Upper Egypt Regional Unit	9	13.4
Suez Canal Regional Unit	9	13.4
North Upper Egypt Regional Unit	6	9
Company's Category		
Not applicable	26	38.8
Category 1	5	7.5
Category 2	6	9
Category 3	5	7.5
Category 4	0	0
Category 5	0	0
Category 6	3	4.5
Category 7	22	32.8

Table 4.3 Effectiveness results

Item	Name	Malaysia n	Malaysia mean	Malaysia SD	Malaysia NV	Malaysia Rank	Egypt n	Egypt mean	Egypt SD	Egypt NV	Egypt Rank	N	ANOVA
A19	SCADA	48	4.13	0.64	1	1	45	4.04	1.02	0.83	2	93	0.014
A09	CIPP	75	4.08	0.87	0.95	2	38	3.24	1.22	0.2	19	113	0.068
A12	Compact pipe	78	4.06	0.84	0.93	3	43	3.3	1.06	0.25	16	121	0.43
A11	PR	68	4.03	0.73	0.9	4	42	3.26	0.89	0.22	18	110	0.457
A07	Zoning network	80	4	0.77	0.86	5	20	4	1.19	0.8	3	100	0.956
A10	Pipe bursting	81	3.9	0.86	0.76	6	41	3.54	0.87	0.44	10	122	0.139
A20	Twin digital	46	3.89	0.88	0.74	7	43	3.74	1.09	0.6	5	89	0.288
A02	Trenchless method	100	3.86	1.03	0.71	8	46	3.65	0.85	0.53	7	146	0.9
A08	Sliplining	72	3.85	0.91	0.7	9	40	2.98	1.12	0	21	112	0.708
A05	Models method	64	3.81	0.96	0.66	10	54	4.26	0.87	1	1	118	0.587
A04	Programming method	51	3.8	0.85	0.65	11	51	3.8	0.92	0.65	4	102	0.689
A15	GA	38	3.74	0.95	0.58	12	32	3.31	1.09	0.26	15	70	0.171
A13	HGA	27	3.7	0.78	0.54	13	33	3.27	0.94	0.23	17	60	0.561
A17	SMGA	49	3.65	0.98	0.48	14	31	3.35	1.02	0.3	12	54	0.001
A03	Algorithm method	22	3.55	0.94	0.37	15	38	3.58	0.72	0.47	9	87	0.444
A21	RDOM-GS	42	3.55	1.01	0.37	16	42	3.62	1.1	0.5	8	64	0.716
A06	Significance Index	26	3.5	0.77	0.32	17	43	3.53	0.98	0.44	11	85	0.239
A14	NSGA	26	3.46	0.86	0.27	18	29	3.34	0.94	0.29	13	55	0.577
A16	MOGA	23	3.35	0.93	0.15	19	34	3.71	1.12	0.57	6	57	0.255
A18	SPEA	29	3.34	0.86	0.15	20	33	3.33	1.27	0.28	14	62	0.212
A01	RTM	38	3.21	1.14	0	21	35	3.11	0.93	0.11	20	73	0.433

Table 4.4 Cost results

Item	Name	Malaysia n	Malaysia mean	Malaysia SD	Malaysia NV	Malaysia Rank	Egypt n	Egypt mean	Egypt SD	Egypt NV	Egypt Rank	N	ANOVA
A06	Significance Index	48	4.13	0.6	1	1	45	4.04	1	0.8	2	93	0.014
A05	Models method	75	4.08	0.9	1	2	38	3.24	1.2	0.2	19	113	0.068
A14	NSGA	78	4.06	0.8	0.9	3	43	3.3	1.1	0.3	16	121	0.43
A20	Twin digital	68	4.03	0.7	0.9	4	42	3.26	0.9	0.2	18	110	0.457
A4	Programming method	80	4	0.8	0.9	5	20	4	1.2	0.8	3	100	0.956
A17	SMGA	81	3.9	0.9	0.8	6	41	3.54	0.9	0.4	10	122	0.139
A13	HGA	46	3.89	0.9	0.7	7	43	3.74	1.1	0.6	5	89	0.288
A15	GA	100	3.86	1	0.7	8	46	3.65	0.9	0.5	7	146	0.9
A18	SPEA	72	3.85	0.9	0.7	9	40	2.98	1.1	0	21	112	0.708
A21	RDOM-GS	64	3.81	1	0.7	10	54	4.26	0.9	1	1	118	0.587
A03	Algorithm method	51	3.8	0.9	0.7	11	51	3.8	0.9	0.7	4	102	0.689
A19	SCADA	38	3.74	1	0.6	12	32	3.31	1.1	0.3	15	70	0.171
A07	Zoning network	27	3.7	0.8	0.5	13	33	3.27	0.9	0.2	17	60	0.561
A16	MOGA	49	3.65	1	0.5	14	31	3.35	1	0.3	12	54	0.001
A08	Sliplining	22	3.55	0.9	0.4	15	38	3.58	0.7	0.5	9	87	0.444
A09	CIPP	42	3.55	1	0.4	16	42	3.62	1.1	0.5	8	64	0.716
A01	RTM	26	3.5	0.8	0.3	17	43	3.53	1	0.4	11	85	0.239
A11	PR	26	3.46	0.9	0.3	18	29	3.34	0.9	0.3	13	55	0.577
A02	Trenchless method	23	3.35	0.9	0.2	19	34	3.71	1.1	0.6	6	57	0.255
A12	Compact pipe	29	3.34	0.9	0.2	20	33	3.33	1.3	0.3	14	62	0.212
A10	Pipe bursting	38	3.21	1.1	0	21	35	3.11	0.9	0.1	20	73	0.433

4.2.3 Cost-effective approaches – all data (objective 2)

After collecting the data through the questionnaire survey, Table 4.2 and Table 4.3 display the overall results of the survey in the effectiveness and cost for both countries, respectively. The first column is the item code starting with the letter A which means the approach; then the second column is the approach name. Then there are two parts Malaysia and Egypt. the table part for each country consists of the descriptive statistics (number, mean, and standard deviation), the normalization value, and the ranking. The items were ranked according to Malaysia normalization value for a better comparison between items, and then in the last two columns is the total number of respondents of both countries and then the results of the one-way ANOVA. After calculating the normalization value, the items with a value more than 0.5 were selected as the cost-effective items in each table according to the category, Table 4.3 for effectiveness, and Table 4.4 for cost. In Malaysia, the effective items are 12, while in Egypt, they are only 7. Moving to the cost table, in Malaysia, there are 8 and 5 in Egypt. in conclusion, the cost-effective items in Malaysia are SCADA, Zoning network, Twin digital, Models, Programming, and GA, and in Egypt, the cost-effective items are Models, SCADA, Programming, and Twin digital. Graphs 4.1 and 4.2 summarizes the results for the effectiveness and cost, respectively. The y- axis represents the mean and the x-axis is the approach name. The items included in the graph are with normalization values of more than 0.5.

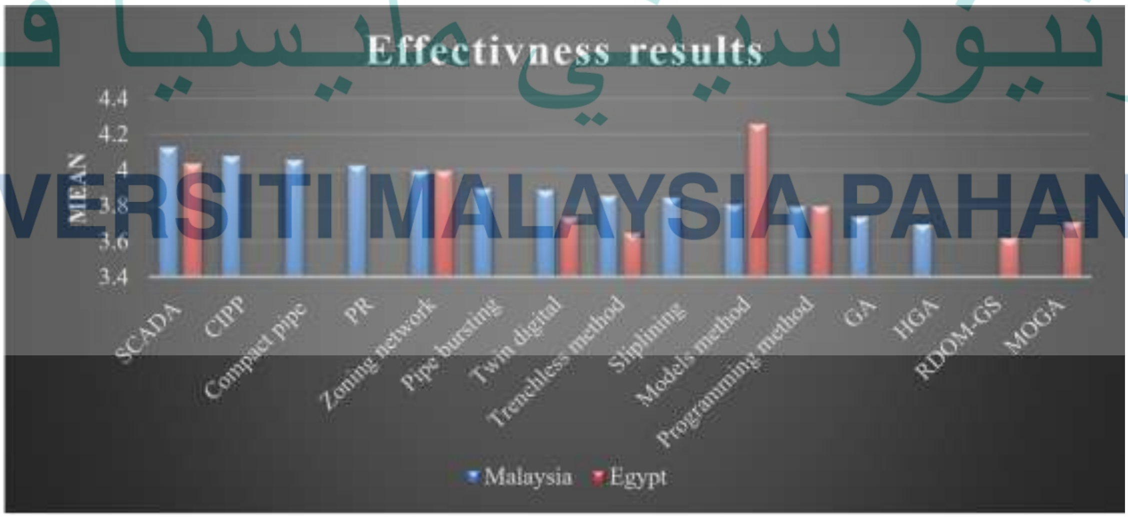

Figure 4.2 Effectviness results

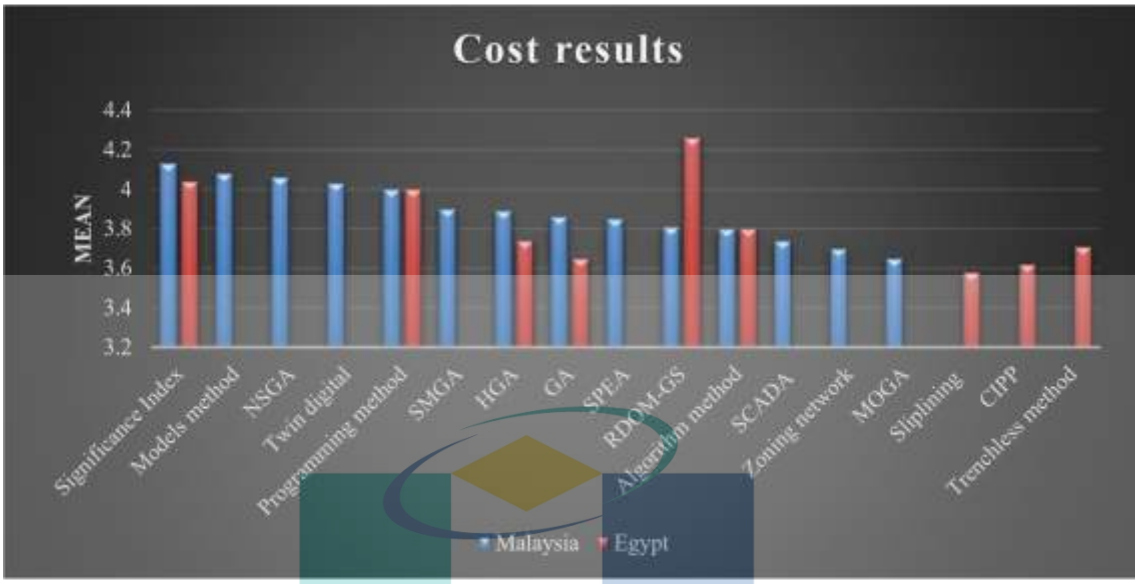

Figure 4.3 Cost results

4.2.4 Results of comparison analysis between countries (objective 3)

Figure 4.4 and Figure 4.5 show the summary of effectiveness and cost between Egypt and Malaysia. For the first figure, the effectiveness of the Supervisory control and data acquisition (SCADA), Twin digital, Trenchless, Models, and Programming are the most effective in both Malaysia and Egypt with normalization values of (1 and 0.83), (0.74 and 0.6), (0.71 and 0.53), (0.66 and 1) and (0.65 and 0.65) respectively. On the other hand, the Models, Twin digital, Programming, and SCADA cost the least in Malaysia and Egypt with normalization values of (0.92 and 0.66), (0.84 and 0.63), (0.8 and 0.55), and (0.66 and 1) respectively. The following figures would have the results of each country separately and then a figure with both countries

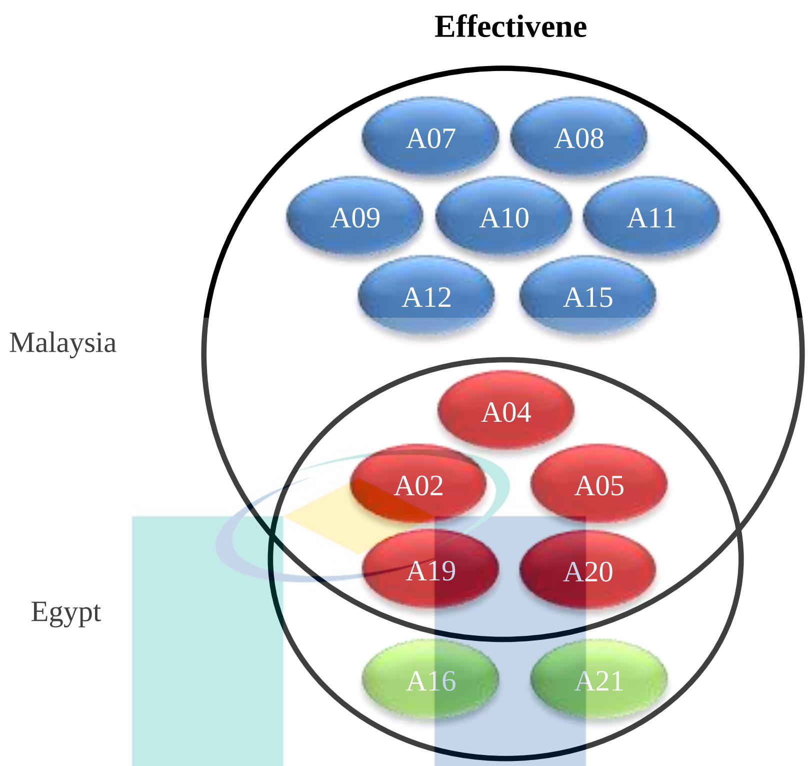

Figure 4.4 Comparison of the WDN rehabilitation approaches' effectiveness between Malaysia and Egypt

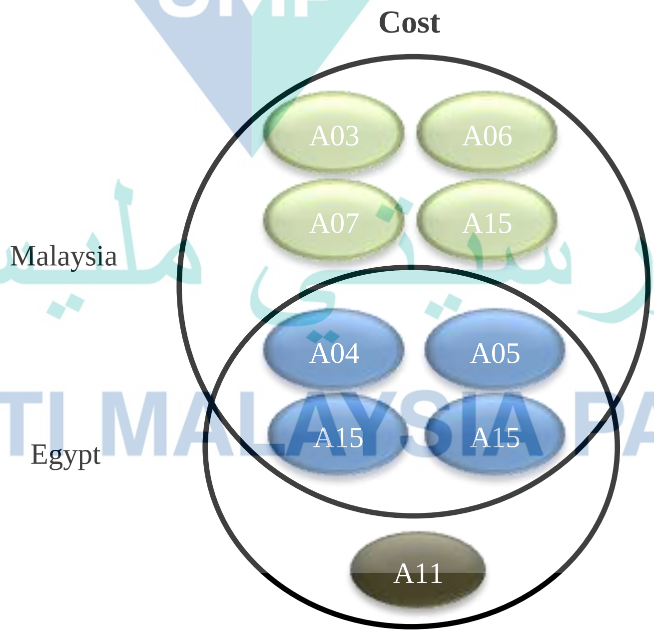

Figure 4.5 Comparison of the WDN rehabilitation approaches' cost between Malaysia and Egypt

Figure 4.6 shows the results of Malaysia, SCADA, Zoning network, Twin digital, Models, Programming, and GA are on top with NV of (1, 0.86, 0.74, 0.66, 0.65, and 0.58) respectively. Figure 4.7 shows the results of Egypt, Models, SCADA, Programming, and Twin digital are the best with NV of (1, 0.83, 0.65, and 0.6) respectively.

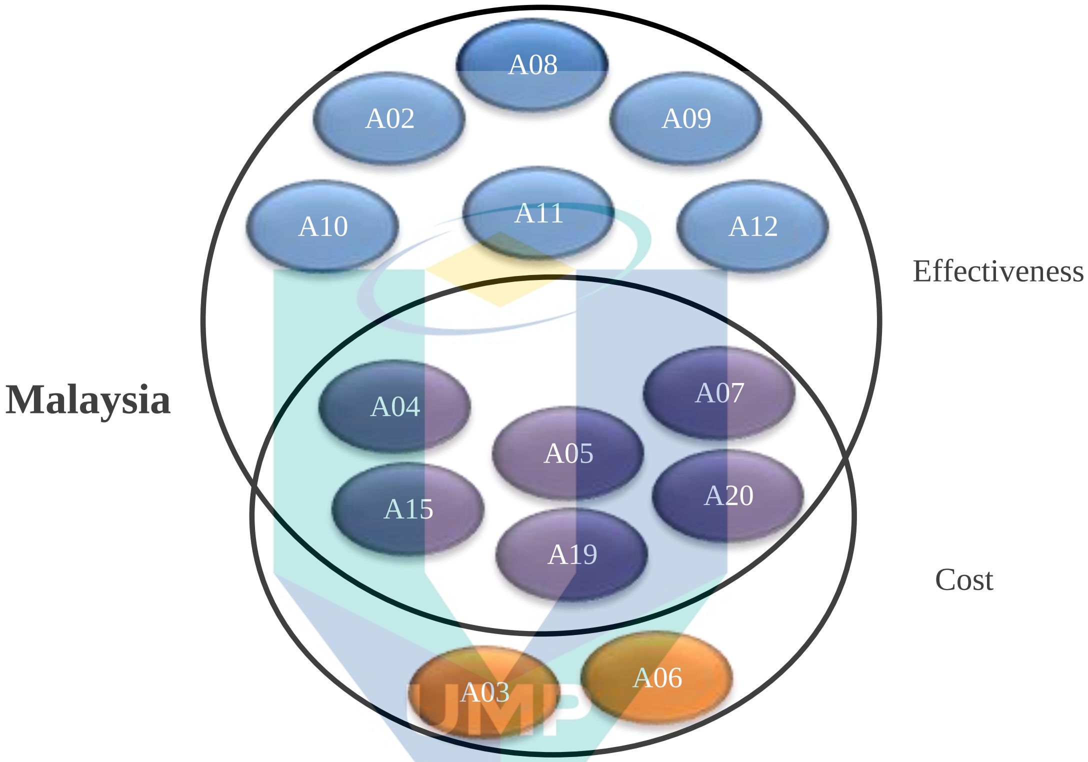

Figure 4.6 Identification of the cost-effective WDN rehabilitation approaches in Malaysia

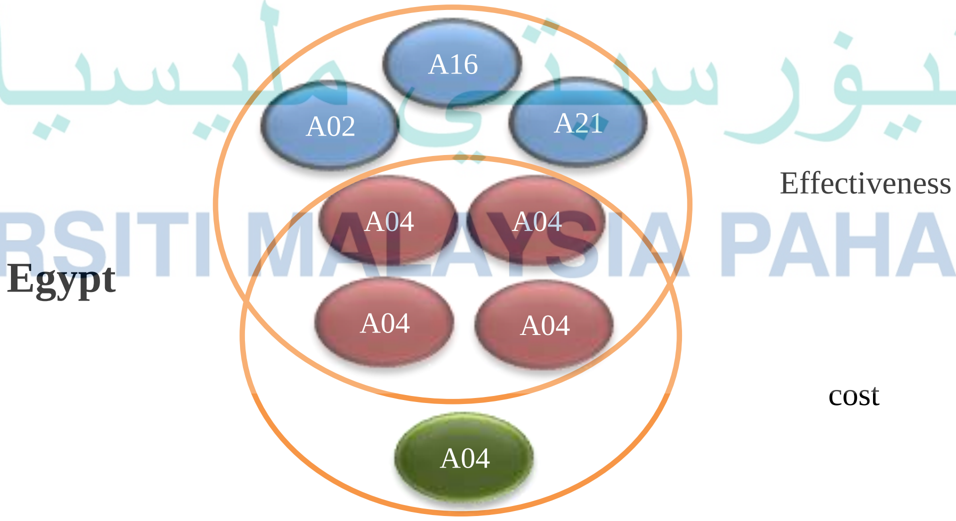

Figure 4.7 Identification of the cost-effective WDN rehabilitation approaches in Egypt

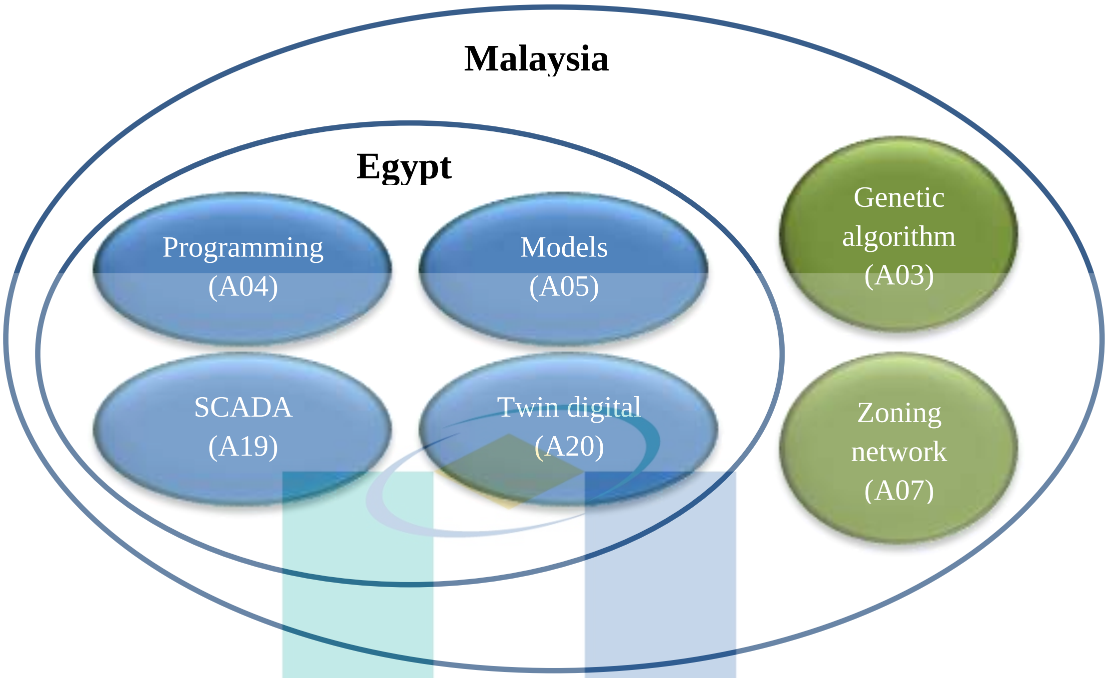

Figure 4.8 Comparison of the cost-effective WDN rehabilitation approaches between Malaysia and Egypt

Figure 4.8 includes the top items in both countries. Egypt and Malaysia have four overlapping cost-effective enhancement approaches: Programming method, Models method, SCADA, and Twin digital. At the same time, Malaysia has two other cost-effective enhancement approaches: The zoning network and GA. The Zoning network is effective in Egypt, but it is not wieldy, explaining why it is not as cheap as Malaysia. More research should be done on this method as the problems are 1- not being widely known 2- not being expensive. Overcoming these problems can make this method valid for use. The other method is the Genetic algorithm, which is considered the costliest method in Egypt because it is an advanced technology in rehabilitation and still not completely available in Egypt. It can be concluded from these two figures that rehabilitation in Egypt is not considered as critical as in Malaysia. The following section discusses the top items between Malaysia and Egypt.

4.3 Discussion

4.3.1 Cost-effective approaches

From the previous sections 4.2.2 and 4.2.3, it was concluded that both counties' top methods are the Programming method, Models method, SCADA, and Twin digital. In the following sections, more discussion on the items that can be considered in the rehabilitation of WDN

4.3.1.1 Programming (A04)

The programming method is the use of programs and software in the rehabilitation process. This method has been used in WDN optimization for a long time (Cheung et al., 2003). This method is regarded to be on top of approaches towards WDN rehabilitation in Malaysia and Egypt, and it is considered effective and relatively cheaper than other methods. Computer programs are much easier to obtain and learn, and it seems to be effective in both countries. The assessment of water pipes can be costly and challenging. Computer programs that are used in the evaluation of pipes would save money. The programs are faster and more efficient in making optimal decisions, which maximizes effectiveness. That opens the option for other developing countries to consider while choosing the best rehabilitation approach. More research is required in this field as computer programs grow fast every year.

4.3.1.2 Models (A05)

Models are computer simulations that run according to specific programs to produce results according to mathematical analysis. The review in Engelhardt et al (2000) has concluded the requirements for a successful rehabilitation approach. A model should have economic, hydraulic, reliability, and water quality criteria to produce a successful rehabilitation approach. This method is concluded to be effective and cheap in Malaysia and Egypt. Therefore, these models do not require special equipment, which affects the cost. Models are used to identify and prioritize pipe replacement, which effectively reduces costs while securing the system's reliability. It can calculate future costs and prioritize pipes according to their risk level (Large et al., 2014). The expenses of pipe rehabilitation can be included in many models, which helps decision-makers decide to rehabilitate the existing pipes now or later. Models have been adopted from (2000-2016), which can explain its availability, and thus, this method is recommended for future rehabilitation techniques in developing counties

4.3.1.3 SCADA (A09)

As agreed before, that programming method is from the top approaches towards WDN rehabilitation. One of the suggested techniques during the pilot study is the SCADA program, which means Supervisory control and data acquisition. The primary function of SCADA is to monitor flow and pressure within the WDN. SCADA is used to control and manage various industries (Wu et al., 2011). A SCADA system includes signal hardware, controllers, networks, user interface, communications equipment, and software. SCADA benefits the overall WDN system. However, SCADA's main strength is in monitoring data in real-time to detect leaks and failures faster. Another benefit is that it reduces power consumption and no need for many workforces; thus, it is economical for the WDN (*Water Distribution System Operation*, n.d.). This program is recommended to help in the rehabilitation and be a part of the WDN rehabilitation strategy for developing countries

4.3.1.4 Twin digital (A20)

A digital twin, also called a digital twin, is a dynamic physical plant/system model (hydraulic model + machine learning) that pairs a live feed for continuous calibration from the whole system to the digital twin. Today, digital twin technology is used in all sectors, from manufacturing and pharmacy to transport and services, and now the water sector. This technology to be adapted from other developing countries. Much research and study should be done in this area. Twin digitals are less costly in the long term because the approach requires less labor than traditional practices. Also, having a digital version of infrastructure provides an accurate view of the system. This feature allows decision-makers to make more accurate decisions, resulting in a more effective rehabilitation process. Therefore, this technique is promising and worth using for WDN rehabilitation (Staff, 2019)

4.3.1.5 Zoning network (A07)

Zoning network is one of Malaysia's methods is considered to be from the top in rehabilitation. Nevertheless, it is not the same in Egypt. first of all, this method was suggested by the pilot study, which may cause this method to be only applicable in Malaysia. Another explanation can be derived from the zoning method's mechanism as this method divides the area into small areas where the leaks and replacement of pipes are identified and done. During the rehabilitation process, there are three stages, and each step has its unique requirements. So, in the first stage, where the district is being divided, it requires a workforce with qualified knowledge. In the second stage in the data collection stage, the workforce is still needed with other special equipment. In the last stage, the pressure management stage, special tools need to be applied. Also, the software is required to monitor the NRW, such as (NRWmanager), and the use of a system that monitors the pressure and flows in the network in the whole 24 hours is required. In conclusion, this method requires additional workforces and special tools to make this method applicable to Egypt. That will decrease the overall cost of this method and make it suitable for adaptation.

4.3.1.6 Genetic algorithm (A15)

The second item is the Genetic algorithm; this is a computer process used to identify pipes that need rehabilitation. In Malaysia, it is considered one of the top methods in the rehabilitation of WDN, although the algorithm method is not regarded as effective in Malaysia. However, in Egypt, it is deemed to be costly besides being considered least effective. In this section reasons behind that will be discussed. First of all, this approach is related to the computer; it is an advanced program that indicates the pipes that need replacement. This technique already has a significant disadvantage of the lengthy time taken in the physical system simulation. Advanced computers are required to carry this kind of simulation. Besides that, there are many programs, tests, and software used in the rehabilitation process. To make this method adaptable, all of the previous must be available together with the staff qualified to deal with it

4.3.2 Effective approaches

4.3.2.1 Trenchless (02)

One method is agreed to be considered effective in Malaysia and Egypt but expensive at the same time. This method is the trenchless method; it includes many techniques such as Sliplining, CIPP, Pipe bursting, Pipe ramming, Compact pipe. The trenchless method is the construction activities, which require little or no trench activity; it is well-known in the construction industry. The method has many different techniques, but they have some common factors contributing to its high cost. Some of the reasons are 1- it requires special machines which costs a lot of as in many cases these machines are rented per day. 2- Besides that, it takes much time, which will cause an increase in the duration of water interruption and the period of roadblocks, making it even more costly. 3- Lastly, some are not valid for all kinds of pipes. To solve these problems the machines and equipment should be available, which can lead to a decrease in the total cost of applying this method

4.3.2.2 Other effective approaches (Malaysia)

This section and the following section will discuss the items that are considered effective in only one country. First, Malaysia's effective approaches are (Sliplining, CIPP, Pipe bursting, pipe ramming, and Compact pipe). These techniques are considered effective but expensive in Malaysia only but not Egypt. Although its main method (trenchless is agreed to be effective). There are many reasons why these methods are not used in Egypt, and there are other trenchless techniques used. Second, the absence of suitable equipment and technology can cause errors in the application process, which decreases its effectiveness. Third, the lack of equipment, technology, and qualified staff can cause searching for alternative equipment, which can sometimes negatively impact the rehabilitation process. The last possible reason is that maybe these methods are not applied correctly because the staff does not have experience or are not qualified enough to do these rehabilitation techniques.

4.3.2.3 Other effective approaches (Egypt)

Moving to Egypt, the two items: MOGA and RDOM-GS, are considered effective in Egypt only, but in Malaysia, it is not considered highly effective. MOGA is from the algorithm method. The algorithm method is not considered also effective in Malaysia. The algorithm method was proposed in 2001. The method may be expired or not applicable, and many methods took their place. In Egypt, maybe the research in WDN rehabilitation is considered, which explains using these methods, although it can be outdated. The second technique is the RDOM-GS; this technique is under the model's method, considered the best in the rehabilitation process. RDOM-GS is a newly proposed technique proposed by F. Li et al (2016a) in 2016. The only reasonable explanation for this is that the number of respondents who filled the whole technique is only 25% of the respondents who filled the model's method. And around 15% of the total respondents. That demonstrates that this technique is not quietly known. More research on this technique is required as it has the potential to be effective in the rehabilitation process in Malaysia

4.4 Summary

This chapter can be summarized in the following section; the survey had 21 enhancement rehabilitation approaches from the systematic review. The survey's main aims were to identify the cost-effective enhancement approaches and compare the cost-effective enhancement approaches between Malaysia and Egypt. Not all the items are considered to be cost-effective; the cost-effective items are only 6. After comparing both countries, additional seven items were concluded to be promising for the developing countries.

CHAPTER 5

CONCLUSION

5.1 Introduction

In the thesis, the NRW problem was introduced, and how the rehabilitation of WDN was suggested to solve the NRW. The first chapter aimed to give an outline of the background of the thesis variables, the motivation, and the problem statement of the research was defined and explained. The research questions are raised from the problem statement and to answer them, the research aim and objectives were developed. The research significant showed the potential impact of the research. The literature review chapter summarized the past work on the following topics: NRW reduction methods, NRW status in Egypt and Malaysia, NRW and rehabilitation of WDN, and last, the cost-effectiveness analysis. The research gap was clearly stated as no study compared the rehabilitation of WDN rehabilitation approaches according to their cost and effectiveness. To fill the gap, a systematic review was conducted to identify the variables of WDN. The results of the systematic review summarized the techniques and methods of the rehabilitation of WDN. After identifying the approaches, data analysis was carried, mean score ranking, normalization value, and the agreement analysis to compare the approaches according to their cost and effectiveness. After the discussion, the cost-effective approaches were discussed and then followed by the effective but costly approaches. Finally going to the final chapter, the conclusion, this chapter will show the research contribution.

5.2 Significant findings

Objective 1: After conducting the systematic review, the variables of WDN rehabilitation were concluded. Therefore, the methods and techniques of WDN rehabilitation were determined, which satisfy the research's first objective.

Objective 2: To identify the cost-effective items after conducting the questionnaire survey (the second objective), data analysis was carried. Mean score ranking and normalization values were calculated, resulted in six approaches that are regarded to be cost-effective. The cost-effective items in both countries are: Programming, Models, SCADA, Twin digital. At the same time, Malaysia exceeds by two cost-effective items: Zoning network, Genetic algorithm.

Objective 3: Agreement analysis was carried to highlight the main differences and similarities between Egypt and Malaysia, the compassion between Malaysia and Egypt WDN rehabilitation approaches was conducted, and the approaches were critically discussed, which fulfill the third and final objective.

5.3 Research contribution

5.3.1 Theoretical contribution (research)

The list of 21 approaches can be found in Table 3.2. the list was used in the questionnaire survey. The list can be used in the research industry to identify and compare more approaches that can adapt and update these approaches in the future. Overcoming the limitations of some approaches is a crucial step in adapting these approaches in the future from developing countries. A list of cost-effective strategies was a part of the research outcome, which can aid in future research to make more comparisons of different factors other than the effectiveness and cost. The findings are considered a valuable reference for researchers in the WDN rehabilitation field.

5.3.2 Practical contribution (industry)

A systematic review was conducted to identify the enhancement approaches to WDN rehabilitation, which was the first objective of the research. After analyzing the variables, 17 enhancement approaches of WDN rehabilitation were identified, which are considered the systematic review's critical findings. The list of enhancement approaches can be helpful as a database for future studies after drafting the data gathered from the systematic review. In order to reach the second objective of the research, a questionnaire survey was conducted. The questionnaire survey aimed to compare the different WDN rehabilitation enhancement approaches according to their cost and effectiveness to identify the cost-effective enhancement approaches. The survey was collected from 176 respondents, 109 from Malaysia and 67 from Egypt. Data analysis found that cost-effective enhancement approaches are programming, modeling, SCADA, and Twin digital. That completes the second objective of the research. So, these enhancement approaches are suggested to be adapted in the rehabilitation of WDN in developing countries. There were two cost-effective enhancement approaches represented in the zoning network and genetic algorithm suggested by Malaysia's data. These two techniques can have great potential in the rehabilitation of WDN. More research is required on both techniques to make them adaptable in different economic countries within the developing countries.

Further analysis was conducted to discuss the reasons and potential solutions of each approach between Malaysia and Egypt, which was the third objective. The comparison results showed that the trenchless method was mostly answered by 146 out of 176 (87%), which is the most known method. This method is considered effective but expensive. The reasons behind that can be summarized into some factors like special equipment, tools, workforce, and time. If these factors were considered accordingly, then it can be a great opportunity in the rehabilitation process. On the other hand, there are techniques considered effective in one country but not the other one. Starting with Malaysia, techniques like, Sliplining, CIPP, Pipe bursting, pipe ramming, and Compact pipe are from the trenchless method, which is already considered in Egypt to be effective. Solutions must be taken to reduce the cost of these techniques to be as effective as in Malaysia. In Egypt's case, two techniques are considered effective Egypt: MOGA and RDOM-GS. After discussing the reasons, it was found that RDOM-GS can be an excellent choice in Malaysia or other countries, and it can be promising in the rehabilitation field, that fulfill the third objective of the research

Different economic levels affect the adaptation of the WDN rehabilitation enhancement approaches. Choosing the proper technique in the rehabilitation process can save a lot of money and maximize WDN rehabilitation benefits. That can consider by industry partitioners to help them optimize the rehabilitation process. That decreases NRW and is regarded as an essential step towards sustainable water management.

Decreasing NRW in the developing counties would be considered a substantial economic leap. WDN rehabilitation is considered to be one of the best solutions towards developing counties' NRW problem.

5.4 Research limitation

This research, like many studies, has some limitations to be considered; these limitations, however, will not affect the results of the study, as the research objectives were achieved, but the limitations are worth mentioning. The first limitation in the study is that some of the enhancement approaches in the following survey conducted from the systematic review can be more theoretical rather than practical. The theoretical approaches mean that some approaches are not used in the field of rehabilitation, so more research is required to verify these approaches to generalize them and to ensure their validity. To overcome this limitation, part of the pilot study was to ask if there are any approaches that needed to be deleted. The pilot study concluded that (respondents) experts advised it to keep those approaches that can give insights on how much a specific approach is adapted.

Another limitation is that the study only involves managers of decision-makers at the top management and not including the people who work at the lower level, as the rehabilitation of WDN requires high cost and equipment; therefore, the rehabilitation of WDN is often adopted from high companies, and the mangers are regarded as the highest position in the companies, and they are directly involved in the WDN rehabilitation process. The last limitation to the study is that the systematic review may not cover all the WDN rehabilitation enhancement approaches. Some of the WDN rehabilitation enhancement approaches are not found in the systematic review. To overcome that issue, the pilot study aimed to ask for enhancement approaches in WDN rehabilitation. The pilot study resulted in 4 new approaches, which were agreed on.

5.5 Research recommendation

The findings of this research recommend that other factors can be considered other than effectiveness and cost for future studies. One of the suggestions of the questionnaire survey is the external factors other than cost and effectiveness that can be adopted in future surveys. A future survey can consider other factors like time, as some approaches need more time to be applied than others. The environment is another factor to be considered, as some approaches depend on the local environment, rural or urban. One of the suggestions of the questionnaire survey is that there are external factors that can affect the selection criteria, which are the general requirements of the particular water projects from Water Authorities and political influence. These factors are agreed not to be avoided worldwide. Authorities can have an impact on the rehabilitation process by considering these factors. The same survey idea can be done on the developing counties, with the same or other factors, which can compare the WDN rehabilitation between developed and developing counties in the future. That comparison can help counties in developing and adapting more suitable WDN rehabilitation enhancement approaches in the future for both developed and developing counties and would help in overcoming the overall difficulties that the WDN rehabilitation face. Lastly, a software or decision support system can be developed to assist engineers and decision-makers in prioritizing WDN rehabilitation approaches.

5.6 Summary

This chapter highlighted the findings of the thesis. The methodology used in the thesis fulfilled the research objectives and aims; therefore, this chapter aimed to prove that. The purpose of this chapter was to highlight the research findings ensuring achieving the research objective and overcoming the problem statement. The significant findings were introduced in this chapter to relate the findings with the objectives of the thesis. The research contribution (theoretical and practical) was highlighted. The theoretical contribution would help the researchers; it shows how the research findings could help the research field. On the other hand, the practical research contribution highlights how the industry could benefit from the research findings. Research limitations were mentioned, the research limitations are vital to be included to show the major weakness and limits that were in the research. Finally, the research recommendation was developed which will help future studies and help in further benefits that the research could potentially give.

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APPENDICES

Appendix A: Malaysia's questionnaire survey

Dear Sir/Madam,

This research project is part of the requirements to complete a master's degree in civil engineering at the faculty of civil engineering and earth resources Universiti Malaysia Pahang (UMP). This research aims to identify the optimal rehabilitation techniques for water distribution networks (WDN).

The following questionnaire will require approximately 7 to 10 minutes to complete there is no known risk to participate. Please be assured that all information provided will be used only for this study and your answers will be kept confidential, and no firm, organization or individual will be identified in this Thesis or any report published based on this research. Participation is completely voluntary, and you may refuse to participate at any time; if you agree to participate in this research, please answer the questions on the questionnaire as best you can.

Thank you for taking the time to assist me in my educational purposes composition of this questionnaire will indicate your willingness to participate in this study; if you require additional information or have questions, please contact me through the email address below:

Student information
name: Abdel Rahman Mohamed Farouk Rady
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Survey Questionnaire: effectiveness and easiness to apply factors in the rehabilitation of (WDN)

Section A: Respondent's Profile

Instruction: Please provide the following information.

1)Your type of organization:

a. Owners (e.g., government, developers)
b. Consultants
c. Contractors
d. Others: _____________

2)Please state your title/position: __________________

3)Your years of experience in the water industry:

a. Less than 2 years
b. 2-5 years
c. 6-9 years
d. More than 10 years

4)Your years of experience related to water distribution networks projects:

a. Less than 2 years
b. 2-5 years
c. 6-9 years
d. More than 10 years

5)Please select the location of most of your WDN projects :

a. Northern Region (Perlis, Kedah, Pulau Pinang & Perak)
b. Central Region (Selangor & WP Kuala Lumpur)
c. Southern Region (Negeri Sembilan, Melaka & Johor)
d. East Region (Pahang, Terengganu & Kelantan)
e. East Malaysia (Sabah & Sarawak)

For CIDB registration, there are 7 specified registration grades Gl to G7

6)What is your company CIDS grade according to the tendering capacity:

a. Not applicable
b. Gl - Not exceeding RM 200,000
c. G2 - Not exceeding RM 500,000
d. G3 - Not exceeding RM 1 Million
e. G4 - Not exceeding RM 3 Million
f. G5 - Not exceeding RM 5 Million
g. G6 - Not exceeding RM 10 Million
h. G7 - No Limit

Part 1: Please rate the effectiveness of the following methods and techniques in the rehabilitation of WDN in Malaysia.

Methods (**Numbers**) Techniques (**Letters**)

Approaches	Not effective	Slightly effective	Moderately effective	Effective	Extremely effective	Don't use
[1]Resin transfer molding (RTM)	1	2	3	4	5	6
[2]Trenchless Method	1	2	3	4	5	6
a)Sliplining	1	2	3	4	5	6
b)Cured-in-place lining	1	2	3	4	5	6
c)Pipe bursting	1	2	3	4	5	6
d)Pipe ramming (PR).	1	2	3	4	5	6
e)Compact pipe	1	2	3	4	5	6
[3]Algorithm Method	1	2	3	4	5	6
A. Hybrid Genetic Algorithm model (HGA model)	1	2	3	4	5	6
B. Non-Dominated Sorting Genetic Algorithm (NSGA)	1	2	3	4	5	6
C. Genetic Algorithms (GA)	1	2	3	4	5	6
D. Multi-Objective Genetic Algorithm (MOGA)	1	2	3	4	5	6
E. Structured Messy Genetic Algorithm (SMGA)	1	2	3	4	5	6
F. Strength Pareto Evolutionary Algorithm (SPEA)	1	2	3	4	5	6
[4]Programming	1	2	3	4	5	6
A. Online Scada combine	1	2	3	4	5	6

[5]Models	1	2	3	4	5	6
a. Twin digital	1	2	3	4	5	6
b. Replacement Decision Optimization Model for Group Scheduling (RDOM-GS).	1	2	3	4	5	6
[6] Significance Index (SI)	1	2	3	4	5	6
[7] Zoning network	1	2	3	4	5	6

Part2: Please rate the cost of the following methods and techniques in the rehabilitation of WDN in Malaysia.

Methods (**Numbers**) Techniques (**Letters**)

Methods and techniques	Extremely expensive	Expensive	Average	Cheap	Extremely cheap	Not applicable
[1]Resin transfer molding (RTM)	1	2	3	4	5	6
[2]Trenchless Method	1	2	3	4	5	6
a)Sliplining	1	2	3	4	5	6
b)Cured-in-place lining	1	2	3	4	5	6
c)Pipe bursting	1	2	3	4	5	6
d)Pipe ramming (PR).	1	2	3	4	5	6
e)Compact pipe	1	2	3	4	5	6
[3]Algorithm Method	1	2	3	4	5	6
A. Hybrid Genetic Algorithm model (HGA model)	1	2	3	4	5	6
B. Non-Dominated Sorting Genetic Algorithm (NSGA)	1	2	3	4	5	6

C. Genetic Algorithms (GA)	1	2	3	4	5	6
D. Multi-Objective Genetic Algorithm (MOGA)	1	2	3	4	5	6
E. Structured Messy Genetic Algorithm (SMGA)	1	2	3	4	5	6
F. Strength Pareto Evolutionary Algorithm (SPEA)	1	2	3	4	5	6
[4]Programming	1	2	3	4	5	6
A. Online Scada combine	1	2	3	4	5	6
[5]Models	1	2	3	4	5	6
a. Twin digital	1	2	3	4	5	6
b. Replacement Decision Optimization Model for Group Scheduling (RDOM-GS).	1	2	3	4	5	6
[6] Significance Index (SI)	1	2	3	4	5	6
[7] Zoning network	1	2	3	4	5	6

Part3: IF you think there are other important factors to consider when rehabilitating WDN, please suggest:

1-
2-
3-
4-
5-

If you would like more updates on this research, please provide the following information.

Name:
Phone number:
E-mail address:

THANK YOU

Appendix B: Egypt’s questionnaire survey

UMP
Universiti
Malaysia
PAHANG
Engineering • Technology • Creativity

Dear Sir/Madam,

This research project is part of the requirements to complete a master’s degree in civil engineering at the faculty of civil engineering and earth resources Universiti Malaysia Pahang (UMP). This research aims to identify the optimal rehabilitation techniques for water distribution networks (WDN) in Egypt.

The following questionnaire will require approximately 7 to 10 minutes to complete; there is no known risk to participate. Please be assured that all information provided will be used only for this study and your answers will be kept confidential and no firm, organization or individual will be identified in this Thesis or any report published based on this research. Participation is completely voluntary, and you may refuse to participate at any time; if you agree to participate in this research, please answer the questions on the questionnaire as best you can.

Thank you for taking the time to assist me in my educational purposes composition of this questionnaire will indicate your willingness to participate in this study; if you require additional information or have questions, please contact me through the email address below:

Student information
name: Abdel Rahman Mohamed Farouk Rady
email: abdelrahman.mfarouk@gmail.com
phone no:0175132987

Survey Questionnaire: effectiveness and easiness to apply factors in the rehabilitation of (WDN)

Section A: Respondent's Profile

Instruction: Please provide the following information.

1)Your type of organization:

a. Owners (e.g., government, developers)
b. Consultants
c. Contractors
d. Others: _____________

2)Please state your title/position: __________________

3)Your years of experience in the water industry:

e. Less than 2 years
f. 2-5 years
g. 6-9 years
h. More than 10 years

4)Your years of experience related to water distribution networks projects:

e. Less than 2 years
f. 2-5 years
g. 6-9 years
h. More than 10 years

5)Please select the location of most of your WDN projects :

a. Greater Cairo Regional Unit (Cairo Governorate - Giza Governorate - Qalyubia Governorate)
b. Alexandria Regional Unit (Alexandria Governorate - Beheira Governorate - Matruh Governorate)
c. Delta Regional Unit (Damietta Governorate - Monufia Governorate - Gharbia Governorate - Kafr El Sheikh Governorate - Dakahlia Governorate)
d. Suez Canal Regional Unit(Sharqia Governorate - Port Said Governorate - Ismailia Governorate - Suez Governorate - North Sinai Governorate - South Sinai Governorate)
e. North Upper Egypt Regional Unit (Minya Governorate - Beni Suef Governorate - Faiyum Governorate)
f. Asyut Regional Unit (Asyut Governorate - New Valley Governorate)
g. South Upper Egypt Regional Unit (Sohag Governorate - Qena Governorate - Luxor Governorate - Aswan Governorate - Red Sea Governorate)

6)What is your company CIDS grade according to the tendering capacity:

a. Not applicable
b. First grade
c. Second grade
d. Third grade
e. Fourth grade
f. Fifth grade
g. Seventh grade

Part 1: Please rate the effectiveness of the following methods and techniques in the rehabilitation of WDN in Egypt

Methods (**Numbers**) Techniques (**Letters**)

Approaches	Not effective	Slightly effective	Moderately effective	Effective	Extremely effective	Didn't use before
[1]Resin transfer molding (RTM)	1	2	3	4	5	6
[2]Trenchless Method	1	2	3	4	5	6
a)Sliplining	1	2	3	4	5	6
b)Cured-in-place lining	1	2	3	4	5	6
c)Pipe bursting	1	2	3	4	5	6
d)Pipe ramming (PR).	1	2	3	4	5	6
e)Compact pipe	1	2	3	4	5	6
[3]Algorithm Method	1	2	3	4	5	6
A. Hybrid Genetic Algorithm model (HGA model)	1	2	3	4	5	6
B. Non-Dominated Sorting Genetic Algorithm (NSGA)	1	2	3	4	5	6
C. Genetic Algorithms (GA)	1	2	3	4	5	6
D. Multi-Objective Genetic Algorithm (MOGA)	1	2	3	4	5	6
E. Structured Messy Genetic Algorithm (SMGA)	1	2	3	4	5	6
F. Strength Pareto Evolutionary Algorithm (SPEA)	1	2	3	4	5	6
[4]Programming	1	2	3	4	5	6
A. Online Scada combine	1	2	3	4	5	6

[5]Models	1	2	3	4	5	6
a. Twin digital	1	2	3	4	5	6
b. Replacement Decision Optimization Model for Group Scheduling (RDOM-GS).	1	2	3	4	5	6
[6] Significance Index (SI)	1	2	3	4	5	6
[7] Zoning network	1	2	3	4	5	6

Part2: Please rate the cost of the following methods and techniques in the rehabilitation of WDN in Egypt

Methods (**Numbers**) Techniques (**Letters**)

Methods and techniques	Extremely expensive	Expensive	Average	Cheap	Extremely cheap	Not applicable
[1]Resin transfer molding (RTM)	1	2	3	4	5	6
[2]Trenchless Method	1	2	3	4	5	6
a)Sliplining	1	2	3	4	5	6
b)Cured-in-place lining	1	2	3	4	5	6
c)Pipe bursting	1	2	3	4	5	6
d)Pipe ramming (PR).	1	2	3	4	5	6
e)Compact pipe	1	2	3	4	5	6
[3]Algorithm Method	1	2	3	4	5	6
A. Hybrid Genetic Algorithm model (HGA model)	1	2	3	4	5	6
B. Non-Dominated Sorting Genetic Algorithm (NSGA)	1	2	3	4	5	6

C. Genetic Algorithms (GA)	1	2	3	4	5	6
D. Multi-Objective Genetic Algorithm (MOGA)	1	2	3	4	5	6
E. Structured Messy Genetic Algorithm (SMGA)	1	2	3	4	5	6
F. Strength Pareto Evolutionary Algorithm (SPEA)	1	2	3	4	5	6
[4]Programming	1	2	3	4	5	6
A. Online Scada combine	1	2	3	4	5	6
[5]Models	1	2	3	4	5	6
a. Twin digital	1	2	3	4	5	6
b. Replacement Decision Optimization Model for Group Scheduling (RDOM-GS).	1	2	3	4	5	6
[6] Significance Index (SI)	1	2	3	4	5	6
[7] Zoning network	1	2	3	4	5	6

Part3:IF you think there are other important factors to consider when rehabilitating WDN, please suggest:
1-
2-
3-
4-
5-

If you would like more updates on this research, please provide the following information.
Name:
Phone number:
E-mail address:

THANK YOU