Johannes Gutenberg - University Mainz
Institute of Geosciences

Sustainable Improvement of Water Networks

‘To achieve best decisions for rehabilitation plans using advanced GIS and statistical techniques’

Dissertation
zur Erlangung des Grades
„Doktor der Naturwissenschaften“
im Promotionsfach Geowissenschaften

am Fachbereich Chemie , Pharmazie und Geowissenschaften
der Johannes Gutenberg-Universität Mainz

vorgelegt von **Basheer Obaid**
geboren in Libya

Mainz, 2013

DEDICATION

To my country, ***Palestine****……*

To my ***Father and Mother*** *for their endless love……*

To my wife, ***Shahrazad****, who has dedicated tremendous patience, encouragement and support during my doctoral study……..*

To my children, ***Ahmed , Haifaa, Zaina and Mohammad*** *who have given me so much happiness in my daily life……..*

and to my brothers and sisters for their continuous support……

DECLARATION AND COPYRIGHT

ABSTRACT

Many of developing countries are facing crisis in water management due to increasing of population, water scarcity, water contaminations and effects of world economic crisis. Water distribution systems in developing countries are facing many challenges of efficient repair and rehabilitation since the information of water network is very limited, which makes the rehabilitation assessment plans very difficult. Sufficient information with high technology in developed countries makes the assessment for rehabilitation easy. Developing countries have many difficulties to assess the water network causing system failure, deterioration of mains and bad water quality in the network due to pipe corrosion and deterioration. The limited information in developing countries brought into focus the urgent need to develop economical assessment for rehabilitation of water distribution systems adapted to such countries.

Several models have been developed in the last years to assess the condition of water networks. Most of these model based on database with high quality, which are not applicable in many countries even in developed countries.

Gaza Strip is subject to a first case study, suffering from severe shortage in the water supply and environmental problems and contamination of underground water resources. This research focuses on improvement of water supply network to reduce the water losses in water network based on limited database using techniques of ArcGIS and commercial water network software (WaterCAD) . A new approach for rehabilitation water pipes has been presented in Gaza city case study. Integrated rehabilitation assessment model has been developed for rehabilitation water pipes including three components; hydraulic assessment model, Physical assessment model and Structural assessment model. WaterCAD model has been developed with integrated in ArcGIS to produce the hydraulic assessment model for water network. The model have been designed based on pipe condition assessment with 100 score points as a maximum points for pipe condition.

As results from this model, we can indicate that 40% of water pipeline have score points less than 50 points and about 10% of total pipes length have less than 30 score points. By using this model, the rehabilitation plans for each region in Gaza city can be achieved based on available budget and condition of pipes.

The second case study is Kuala Lumpur Case from semi-developed countries, which has been used to develop an approach to improve the water network under crucial conditions using, advanced statistical and GIS techniques. Kuala Lumpur (KL) has water losses about 40% and high failure rate, which make severe problem. This case can represent cases in South Asia countries. Kuala Lumpur faced big challenges to reduce the water losses in water network during last 5 years. One of these challenges is high deterioration of asbestos cement (AC) pipes. They need to replace more than 6500 km of AC pipes, which need a huge budget to be achieved. Asbestos cement is subject to deterioration due to various chemical processes that either leach out the cement material or penetrate the concrete to form products that weaken the cement matrix. This case presents an approach for geo-statistical model for modelling pipe failures in a water distribution network. Database of Syabas Company (Kuala Lumpur water company) has been used in developing the model. The statistical models have been calibrated, verified and used to predict failures for both networks and individual pipes. The mathematical formulation developed for failure frequency in Kuala Lumpur was based on different pipeline characteristics, reflecting several factors such as pipe diameter, length, Pressure and failure history. Covariates that have a significant influence on the rate of occurrence of failures are documented.

Methodology is developed for analysing pipe condition based on the data resulting from the probability of mechanical failure analysis incorporating pipe failure history.

Generalized linear model have been applied to predict pipe failures based on District Meter Zone (DMZ) and individual pipe levels.

Based on Kuala Lumpur case study, several outputs and implications have been achieved.

Relations between covariates and pipe failures have been developed based on GLM model.

Correlations between spatial and temporal intervals of Pipe failures also have been done using ArcGIS software.

In addition, Water Pipe Assessment Model (WPAM) has been developed using the analysis of historical pipe failure in Kuala Lumpur which prioritizing the pipe rehabilitation candidates based on ranking system.

Frankfurt Water Network in Germany is the third main case study. This case makes an overview for Survival analysis and neural network methods used in water network.

Rehabilitation strategies of water pipes have been developed for Frankfurt water network in cooperation with Mainova (Frankfurt Water Company).

This thesis also presents a methodology of technical condition assessment of plastic pipes based on simple analysis.

This thesis aims to make contribution to improve the prediction of pipe failures in water networks using Geographic Information System (GIS) and Decision Support System (DSS).

The output from the technical condition assessment model can be used for a variety of purposes in water network management. In the long term, the models can be used to estimate future budget needs for rehabilitation in addition to define pipes with high priority for replacement based on poor condition.

This thesis has in parts been published and presented in the following researches, conferences and seminars.

<u>Publications</u>

Obaid. B, Sorge.C and Wilken. R, (2012) ‘Räumliche und zeitliche Clusteranalyse von Rohrschäden im Trinkwassernetz von Kuala Lumpur-Malaysia‘ 3R international Journal (**Published**).

Obaid. B, Sorge.C and Wilken. R (2012) ‘ Spatial and temporal clustering analysis of drinking water network pipe failures in Kuala Lumpur – Malaysia 3R international Journal (**Accepted**).

Obaid. B and Wilken. R (2012) ‘A New Approach for Technical Condition Assessment of AC Pipes - Kuala Lumpur as Case Study’. (**Submitted**)

Obaid. B and Wilken. R (2012) Developing a rehabilitation framework model based on Integration between Hydraulic and Geospatial techniques. Gaza Strip - Palestine as Case. (**Submitted**)

Obaid. B and Wilken. R (2012) ‘Water Pipe Failure prediction using Generalized linear Model Kuala Lumpur as Case Study’. (**Submitted**)

<u>Conferences</u>

Obaid. B and Wilken. R (2011) New Application Model for sustainable Improvement of Urban Water under Crucial Conditions -The Gaza Strip Case, Palestine. **Oral Presentation** in World Water Week 2011 Stockholm International Water Institute, SIWI Stockholm.

Obaid, B (2010) ‘Advanced Application for Water Information System based on GIS in Palestinian Water Authority’ **Poster Presentation** in World Water Week 2010 Stockholm International Water Institute, SIWI Stockholm.

Obaid. B, Sorge.C and Wilken. R (2011) ‘A New Approach for Technical Condition Assessment of AC Pipes Using Geostatistical Techniques - Kuala Lumpur as Case Study’ **Poster presentation** in LESAM 2011, The fourth IWA Leading-Edge (LE) conference on Strategic Asset Management (SAM) of water and wastewater infrastructures. Mülheim an der Ruhr-Germany.

TABLE OF CONTENT

LIST OF TABLES

LIST OF FIGURES

LIST OF ABREVIATIONS

AC	Asbestos Cement
AG	Age of water mains
AHP	Analytic Hierarchy Process
AL	Connection pipelines
ANNs	Artificial Neural Networks
ASCE	American Society of Civil Engineers
At	Total area of pipe wall thickness
Aw	White color area of the pipe wall thickness
AWWA	American Water Works Association
AWWARF	American Water Works Association Research Foundation
B	Concrete (Beton in German)
CAD	computer aided design
CAT	condition assessment technologies
CI	Cast Iron
CV	Censored Value
CWWA	Canadian Water and Wastewater Association
DI	Ductile Iron
DMZ	District Meter Zone
DP	Depth of water mains
DR	Diameter of water mains

DSS	Decision support System
DVGW	German Technical and Scientific Association for Gas and Water (Deutscher Verein des Gas- und Wasserfaches e.V)
EE	Expert Opinion Elicitation method
Et	Asbestos pipe
FR	Failure Rate
GG	Cast iron (Grauguss in German)
GGG	Ductile cast iron (duktiles Gusseisen in German)
GIS	Geographic Information System
GLM	Generalized Linear Models
GPS	Global positioning system
HN	Hidden Node
ID	Identification Number
IDW	Inverse Distance weight
KL	Kuala Lumpur (city in Malaysia)
KM	Kaplan Meier (Analysis Statistical method)
Lg	Leaching degree
MAT	material types
MCM	Million cubic meter
NPF	Number of Pervious Failure
P	Water Pressure
Pb	Polybutene
PE	Polyethylene
PHM	Proportional Hazards Models

PVC	Polyvinyl Chloride
PWA	Palestinian Water Authority
RM	Ringgit Malaysia
ROCOF	Rate of occurrence of failures
RSL	residual service life
SL	Stand Pipes
Spb	Prestressed concrete (Spannbetonrohre in German)
St	Steel
StBit	Steel with bitumen
StZm	Steel with Cement mortar lining for interior protection
Syabas	Kuala Lumpur Water Company
TPs	Thiessen Polygons
VL	Distribution lines,
WDS	Water distribution system
WPAM	Water Pipe Assessment Model

Chapter 1

1 Introduction and overview

1.1 Introduction

Water sector in the world face several challenges with problems of quality and quantity of water. The population growth is high while the water sources become scarce. Water utilities in the world tried to develop an effective plan to save water and decrease the water losses through effective and efficient operational management of Water supply Systems.

The effective operation management needs to develop condition assessment techniques of available assets. Such condition assessment techniques are related to water quality and quantity. The assessment of water quantity is evaluated by the water flow, water pressure in the water distribution system. However, the water quality is evaluated by assessment of water flavour, odour, and appearance delivered to consumers, which are necessary to be established according the international regulations and standards.

Water distribution system (WDS) is an important section in the water sector. There should be an effective plan for sustainability of WDS. This plan should include the repair, maintenance and renovation of WDS to prevent the failures, reducing water losses (Quantity) and to prevent water contamination (Quality) delivered to customers (Dehghan, 2009).

Water supply systems are subjected to several environmental and operational effects. These effects can cause in several cases failure in the system. This causes increasing in the water losses and reduction of water quality. This increases the pressure on the water utilities to develop condition assessment models to estimate the maintenance requirement according to the financial constraints (Dehghan, 2009).

Database for pipe failure are very limited in many cases even in developed countries with required information related to condition assessment.

Pipe maintenance includes three options; pipe replacement, repairing, and replacement. Pipe maintenance decisions should consider many parameters as lifetime of the pipe and economic issue.

Many researchers developed models taking on the consideration pipe age as the main factor for pipe deterioration. However, in many cases old pipes appear high resistance for failure and still satisfactorily functioning.

Many researchers have been trying to develop tools that help as decision support model used for pipe condition assessment. Decision support models are required by most of water utilities to prioritize the water pipes based on numbers of available criteria. Prediction models are one of the attractive models to predict pipe failures. These models help to schedule the pipe maintenance before the failure as proactive tools.

Skipworth et al (2002) mentioned that the best long-term solution can be identified by assessment and analyse the life of water pipes based on avoidance of level of disruption and continued operational and maintenance costs versus rehabilitation and replacement costs.

The difficulty of applied long-term rehabilitation strategy is that the water pipes are underground. Most of these strategy required data to understand the real condition of the pipes. Database used in condition assessment can be found using several techniques. Pipe failure history one of the most suitable and economic techniques used in condition assessment. Although there are many new investigation techniques like ‘Pigs’ (Inspection tool that measure pipe thickness and location of leaks inside the pipe) but they are applicable in few cases sine using of Pigs are not economic in cities where there are many of cross sections.

The main approach for this thesis is to build a framework for failure analysis model taking into consideration the relationship between previous pipe failures. Prediction model have been developed for Kuala Lumpur case study using generalized linear model. Developing new criteria for pipe failure predictions using the relationship between failures based on time and distance.

In this research, several water distribution cases have been studied from several countries. First case study is Gaza water distribution system in Palestine, which is representing developing countries. Second case study is Kuala Lumpur water distribution system in Malaysia, which is representing semi-developed countries. Third case study is Frankfurt am Main water distribution system in Germany representing developed countries. Figure (1-1) shows research structure.

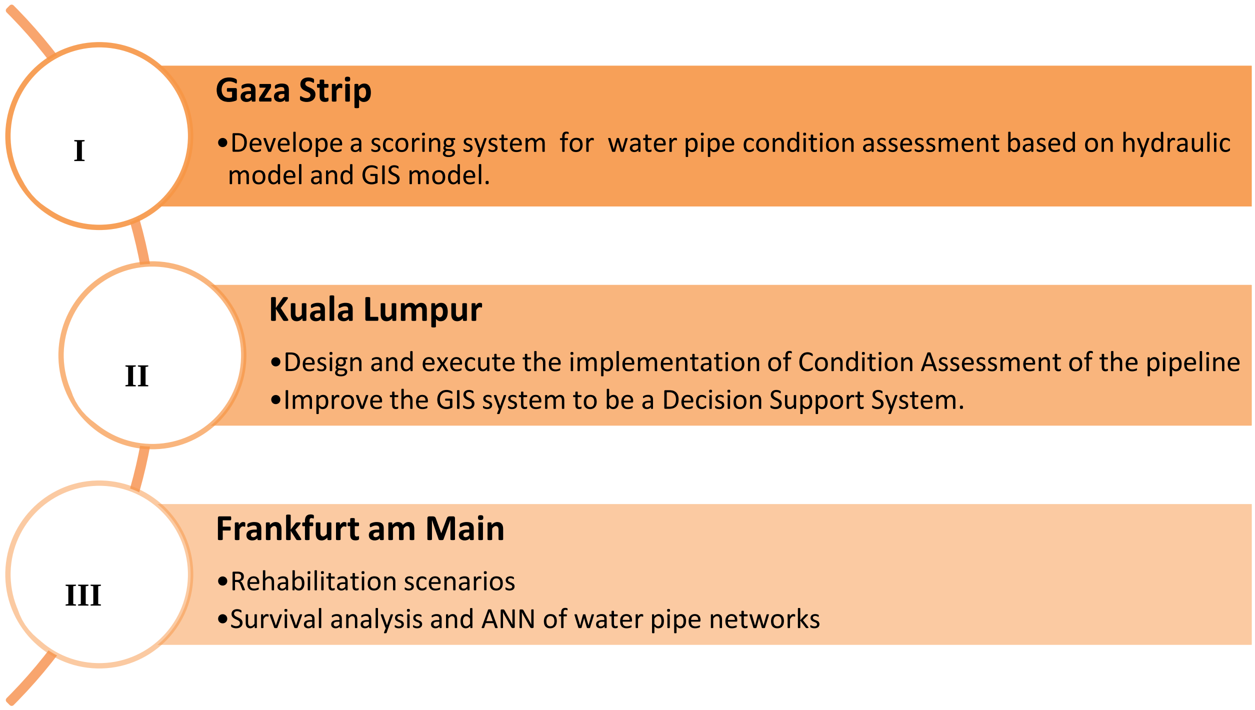


Figure (1-1): Research Structure

1.2 Research Objectives

Main objectives

The main objective of this research is to improve the sustainability of water network used in pipe conditions assessment. The techniques developed should be applicable to existing data collected by utilities, and build upon on-going developments in the field of pipe deterioration modelling. Table (1-1) shows promoting sustainable improvement of water networks including the tasks and outputs.

Specific objectives

In summary, the objective of this thesis can mainly be articulated as follows:

- Predicting future performance of water network.
- Investigating the important factors affecting the deterioration of the water pipes.
- Analysis of a pipe failure using GIS applications
- Develop a condition assessment model, which can be implemented in evaluation of water pipeline.
- Develop a framework to incorporate existing failure modelling techniques into condition scoring technique.

1.3 Research Questions

Research questions that will be addressed in this thesis are the following:

1. How we can develop condition assessment model using limited available data?
2. What are the important factors affecting the water pipe condition?
3. How may the water pipes condition improved using statistical techniques?
4. How may pipe failures be able to be estimated using the relationship between spatial and temporal intervals?
5. How we can use hydraulic models to estimate pipe condition?
6. How we can use Geographic Information System (GIS) as a decision support system (DSS) in water network rehabilitation plans?
7. How we can use the failure history to develop future rehabilitation scenarios for water pipes?

Table (1-1) Promoting Sustainable Improvement of Water Networks

Outputs	**Tasks**
Outcome 1: Sustainable Improvement of Water Pipe Network	
Output 1: Design and execute the implementation of water pipe condition assessment model.	▪ Analysis of contributing factors for pipes deterioration ▪ Building full condition assessment for pilot area ▪ Lifetime prediction of water assets for asset management
Output 2: Improve and enhance Rehabilitation System	▪ Implement rehabilitation scenarios ▪ facilitate strategic planning and cost-effective inspection ▪ Long-term plan that forecasts the remaining life of various types pipe.
Outcome 2: Enhancing the development of Geospatial Decision Support System	
Output 4: Developing the GIS system to be a Decision Support System.	▪ Building the foundation of condition inventory system ▪ Building Geospatial Decision Support System bases
Output 5: Improving the decision making	▪ Short and Long plan actions for maintenance and rehabilitation ▪ Plan & implement orderly replacement of deteriorating pipeline assets.

1.4 Summary:

This chapter has introduced the research objectives, structure of thesis and the main research equations that designed to increase our understanding in sustainable improvement of water network. The main contribution of this research is developing framework models used to understand the actual condition of water pipes and planning for future rehabilitation decisions.

Chapter 2

2 Literature Review.

2.1 Introduction

Condition assessment models of water network are used by several water utilities to find the optimum way to know the current and predicted condition of water networks. The quality of models depends on available data into water utilities. (Misiunas, 2005) define condition assessment as “a process or processes that establish records of the state of the critical aspects of an object at a given time”. Condition assessment is an important tool to prioritize the rehabilitation needs in water sector based on available budget and water improvement requirements. (Misiunas, 2005) has classified failure management cycle as proactive management where rehabilitation decisions are made prior to the pipe failure event, and reactive management, which performed the decisions of rehabilitation only after the pipe failure.

2.2 Causes of pipe failures

Deterioration of pipe networks can be classified according to (Røstum et al., 1997) into four groups. First group is structural factors such as pipe diameter, length and material. Second group is environmental factors includes soil types, bedding condition and temperature. Third group is hydraulic factors such as water velocity and pressure. Fourth group is maintenance factors include failure modes, failure date and previous pipe failure history. Based on pipe material there are different factors leading to pipe deterioration or failure (WSTB, 2006). In plastic pipes (PVC and PE) cases, the excessive deflection, leaking connection and longitudinal cracks are the common problems lead to plastic pipe failures. In iron pipes such as cast and ductile pipes and steel pipes, the internal and external corrosion are common factors for pipe failures. Asbestos cement pipes, mortar leaching can lead to pipe failure, in addition to joint misalignment and connection leaking (WSTB, 2006),(AWWA, 1986). Factors of pipe deterioration have been studied by several researches. Figure (2-1) shows factors cause the pipeline deterioration adapted from (Preston et al., 1999).These factors will be described in detail through next chapters.

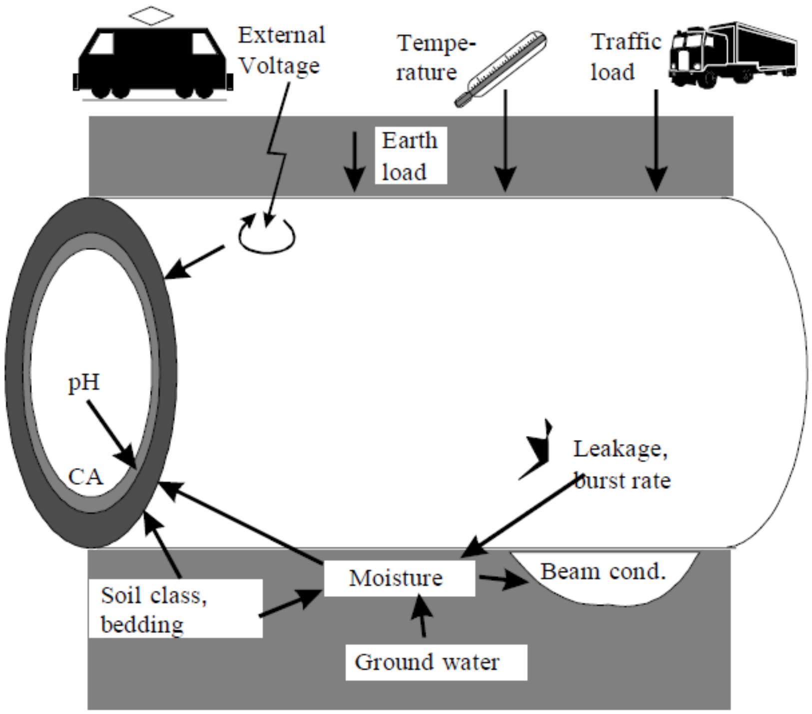


Figure (2-1) Factors cause the pipeline deterioration (Preston et al., 1999).

2.3 Pipe deterioration process

Pipe failures have a several process starts from pipe installation until complete failure, the common failure steps for brittles pipe materials are as following (Misiunas, 2005):

1. *Installation*: The new pipe is installed with good condition based on pipe manufacturing.
2. *Initiation of corrosion or deterioration*: After the pipe has been in operation for some time, the corrosion start on the internal or external surface of the pipe.
3. *Crack before leak*: cracks can be initiated by increasing mechanical stress.
4. *Partial failure*: increasing of corrosion pits and cracks which leading to reduce the strength of the pipe causing pipe failure.
5. Complete failure: The complete failure of the pipe can be caused by a crack, corrosion pit causing water leakage and change in the hydraulic balance. Figure (2-2) shows pipe failure development valid for brittle materials (Misiunas, 2005).

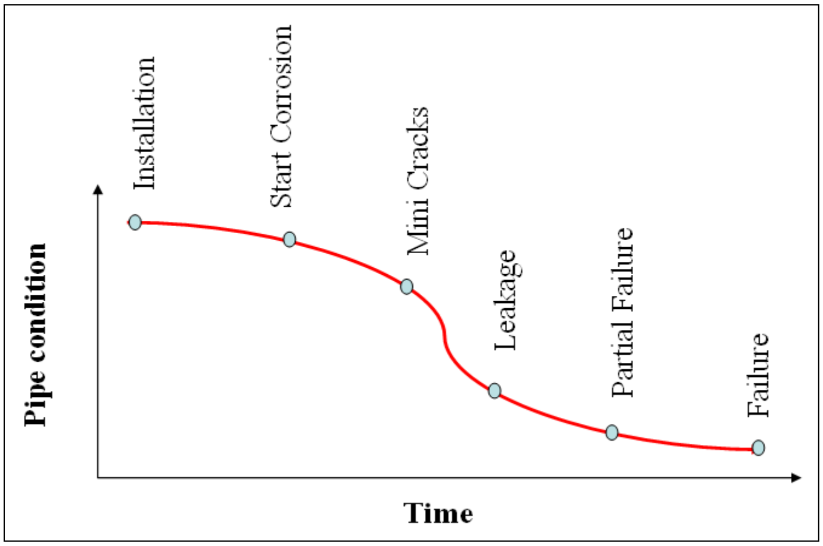


Figure (2-2) Pipe failure development valid for brittle materials

2.4 Consequences of a pipe failure

Makar and Kleiner (2000) divided pipe failure consequences into three main groups; direct costs including repair costs, cost of water losses and surrounding damages of infrastructure and bad water quality. Indirect costs including interruption costs due water leakage and affected surrounding infrastructure. Social costs including cost of water quality degradation due to contaminant intrusion caused by traffic disruption and water supply corruption to important locations like hospitals.

2.5 Short and long Term actions for pipe Condition Assessment

Improvement of Pipe sustainability can be divided for two terms; short term planning and long term planning. Short term planning will depend on little information about the pipeline such as pipe material and soil type. Short-term plan will be important in case of failure occurs. The failure mode will be the best indicator to select rehabilitation methods; repair, renovate or replacement (EPA, 2009).

Long-term plan will depend on more investigated data such as failure analysis, pipe inspection using pigs (the inspection tool that measure pipe thickness and location of leaks inside the pipe), Condition assessment etc. Long-term plan also is an important to predict lifetime of pipes and to sort the pipeline from highest priority to lowest priority. Flowchart for improvement of pipe sustainability is shown in figure (2-3). Within the short-term, the use of existing information for condition assessment could offer the best opportunity to improve the asset management performance of the water industry. There is a wealth of environmental, historical, and operational information that are into an asset database. Operational records provide information on failures and repairs (EPA, 2009). The knowledge and understanding of the network of the management, engineers, and operators should be harnessed, because they are in the best position to understand local conditions, defects, and failures (EPA, 2009). Many water utilities used short term planning for condition assessment of water network depending on simple available data. The decision of rehabilitation methods may depend on failure modes.

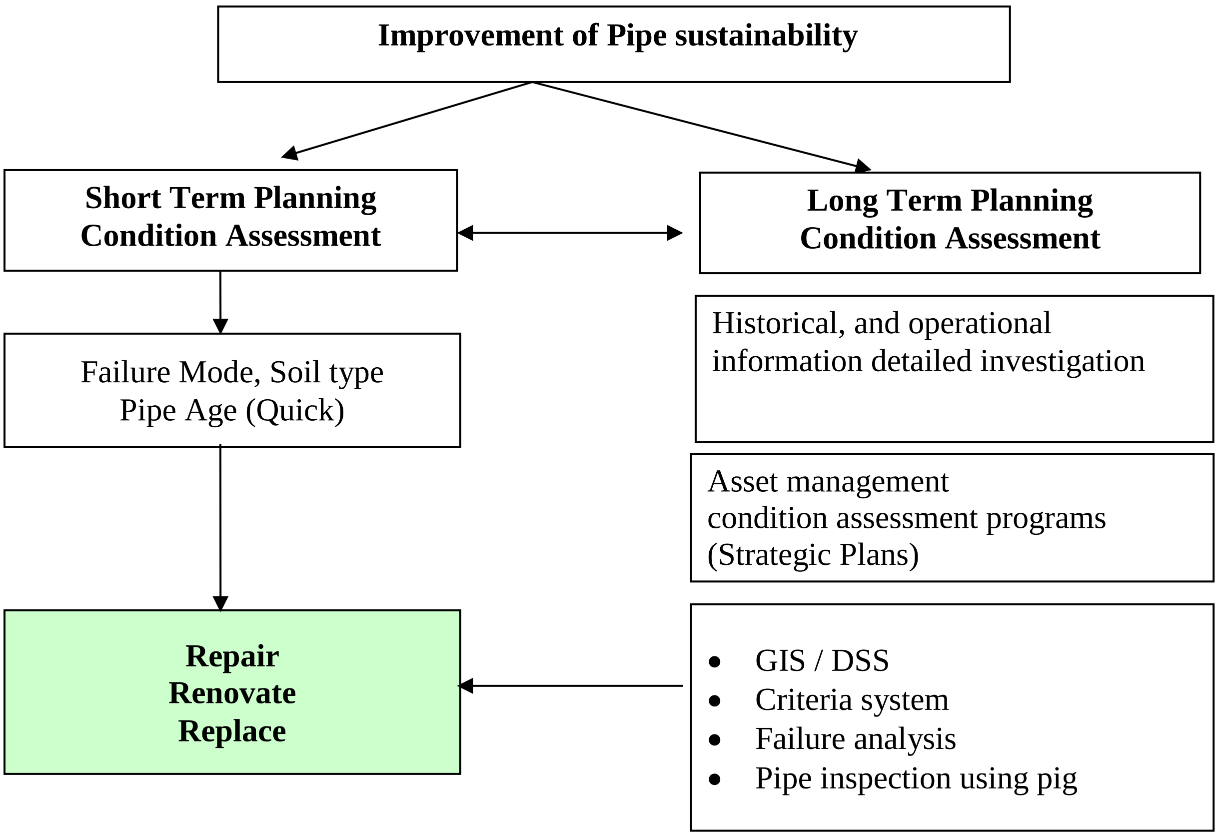
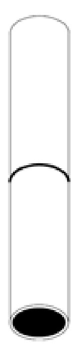
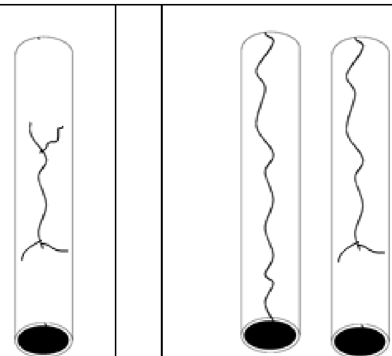
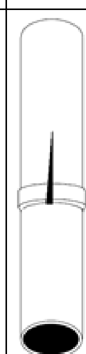
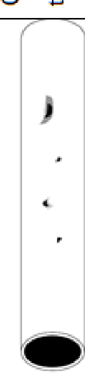


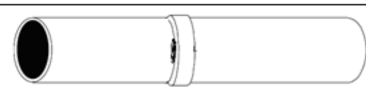
Figure (2-3) Improvement of Pipe Sustainability

Failure modes:

A failure mode is an important indication factor for actual pipe conditions. There are several failure modes in water networks such as; *Circumferential Cracking* which is common in small diameter caused by increasing of bending forces by soil movements. *Longitudinal cracking* which is common in large pipes diameter caused due to internal water pressure. *Blowout holes are* caused by corrosion pitting which can be also a good indication about the high deterioration of pipes. *Bell Splitting* is common in small diameter pipe in metallic pipes. *Bell Shearing* caused due to compressive forces pushing the spigot of a pipe into the bell of the next pipe in the pipeline. Spiral cracking is produced by a combination of bending forces and internal pressure Table (2-1) shows pipe failure modes and sample of decisions adapted from (Misiunas, 2005).

Table (2-1) Pipe failure mechanisms and sample of decisions adapted from (Misiunas, 2005)

No	Failure mechanisms	Figure	Reasons	Notes	Decisions
1	**Circumferential cracking**		bending forces applied to the pipe	small diameter pipes	Repair
2	**Longitudinal cracking**		internal water pressure and ring stress created by the soil cover load, external load or thermal changes	large diameter pipes	Replace / Repair
3	**Bell splitting**		sealing of the joints	small diameter cast iron pipes	Repair
4	**Corrosion pitting**		Corrosion: reduces the thickness and mechanical resistance of the pipe wall		Replace

No	Failure mechanisms	Figure	Reasons	Notes	Decisions
5	**Blow-out hole**	I  II 	When the wall is thinned to a certain point, the internal pressure blows out a hole	The size of the hole depends on the distribution of corrosion and the pressure in the pipe	Replace
6	**Bell shearing**		Bending, compressive loading		Repair
7	**Spiral cracking**		pressure surges, bending force and internal pressure	occurs in medium diameter pipes	Repair
8	**Joint deterioration**		Corrosion		Repair

Long-Term Planning

Long term planning requires deep information about the current condition of water network (EPA, 2009). Many of wealth information used in several models and programs have limited applicability and contradictions (EPA, 2009). Also based on (EPA, 2009) report the information should be synthesized into practical guidelines for operators and it would be possible to develop a range of more specific life expectancy curves and models that relate not just to a pipe material but to various periods in the pipe manufacture that have different failure expectancies. In addition, curves and models need to be changed to be suitable with local conditions such as soil parameters (EPA, 2009).

Detailed investigation for long-term decision support system is classified based on failure patterns, spatial analysis of failures using GIS, failure rate and pipe sampling for examining the success of rehabilitation methods life cycle cost is an important approach in long term planning to decide on alternative rehabilitation strategies for infrastructure systems. The “Bathtub Curve” is a widely accepted conceptual representation of a pipeline life cycle by (Wayman,. 2003). Figure (2-4) shows the life cycle of typical pipeline.

Also Figure (2-5) shows flow chart for iron pipe rehabilitation system as a sample for optimal rehabilitation technology adapted from recent researches .

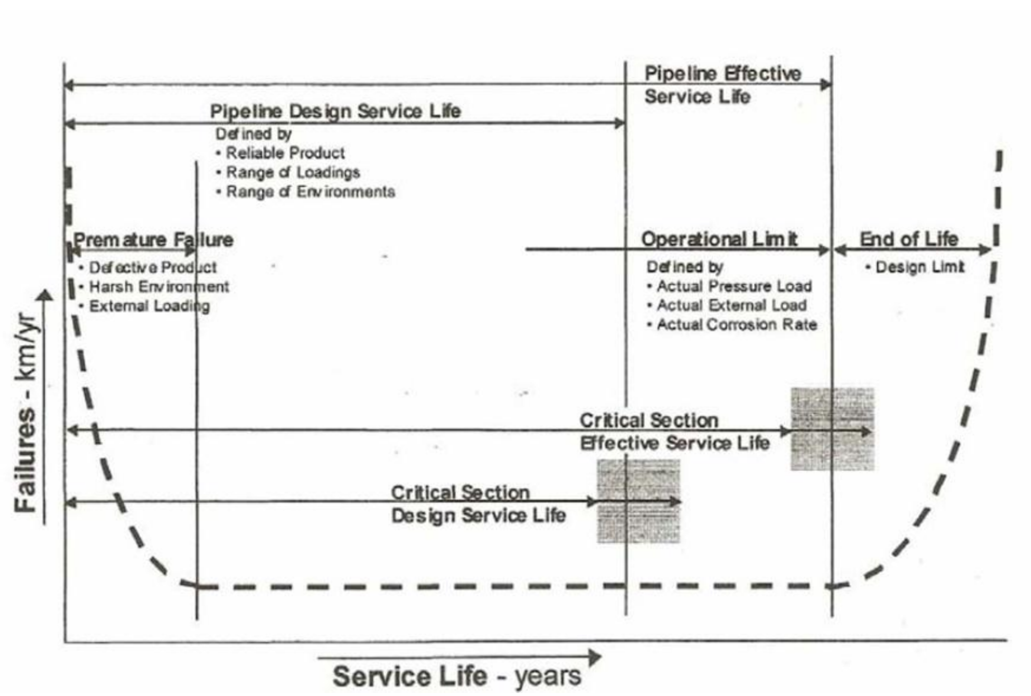


Figure (2-4) Life cycle of typical pipeline, (Wayman, 2003).

2.6 Modelling of water pipe failures

The ability to predict failure probability is important for investment planning and scheduling maintenance (Boxall, 2007). Boxall, (2007) classified the pipe failures models for three groups; Load models, Statistical models and Regression model. Load models are very difficult to predict since the load is varying in magnitude. Hadzilacos et al (2001) has attempted to determine the probability of pipe failure by determining the exposing load on the pipe but the data for model to determine pipe loadings are mostly not available in most water companies. Statistical models can be different based on the level of information available in water companies. These types of models need a more detail about the historical pipe failures for different types of material and diameters. Several researchers attempt to build models for pipe failures. Herz (1996) and Saegrov (1998) developed probability model to predict the useful life for water pipes. However, these models need detailed information, which are mostly not available in water companies (Boxall, 2007). Regression model used the failure rate of pipe in groups as a function such as diameter and installation years and material types. As an example Shamir and Howard (1979) developed relationships between failure rate and pipe age based on pipe groups of diameter and material. They found that the number of pipe failures is predicted to be an exponentially increasing function of age.

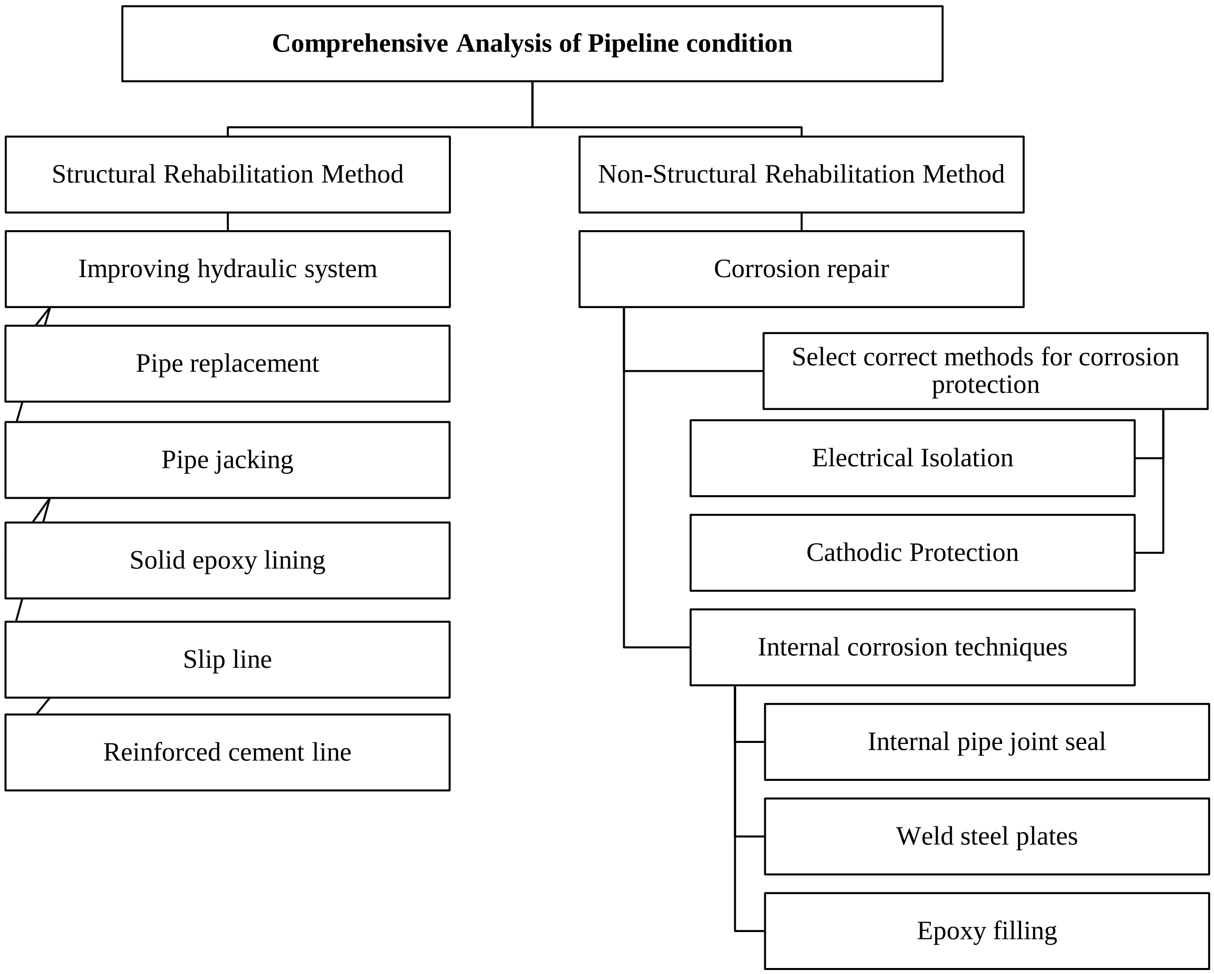


Figure (2-5) flow chart for iron pipe rehabilitation system

2.7 Inspection Methods

Pipeline inspection techniques have been used by water utilities for condition assessment of water network. These techniques range from simple and low cost such as using pipe failure history to expensive direct methods such as pipe wall thickness measurements. Condition assessment approaches and inspection techniques are illustrated in figure (2-6) adapted from (Vickridge and Lau, 2010). Asset planning and prioritization models of water networks required condition assessment techniques based on several factors such as , location of water network, pipe material, diameter and available budget. Using of advanced inspection techniques such as internal inspection device (pigs) can be not proper and expensive to use it in high pipe cross connection density. Table (2-3) shows inspection techniques adapted from (istt, 2005).

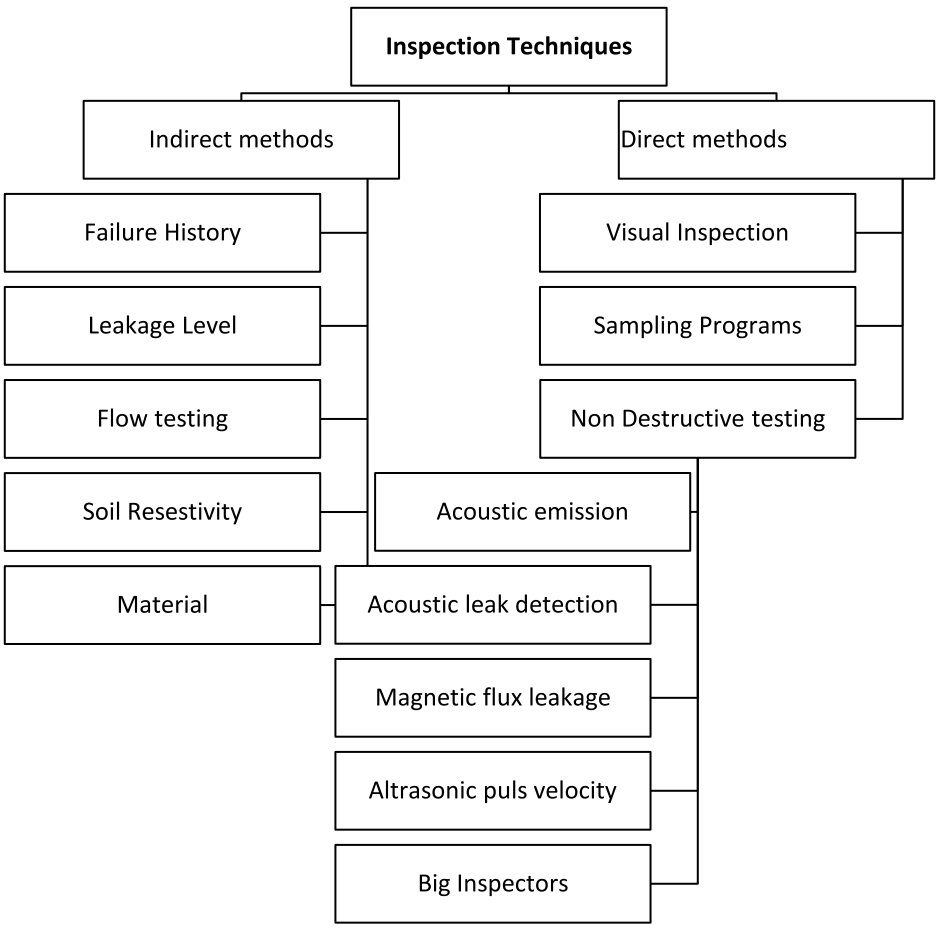


Figure (2-6) Categories of Condition Assessment Techniques

Table (2-3) Inspection Techniques

Inspection Techniques	
Visual Inspection	This method checks for signs of corrosion and any damage to external protection.
Pit depth measurements	Used to measure the extent of external corrosion in pipes by assessing the depth and distribution of corrosion.
Ultrasonic	Ultrasonic equipment can be used in metallic pipelines to measure the remaining wall thickness.
Coupon Removal	In AC pipe cases, the coupon can be tested to determine the strength of the pipe.
Pipe sample removal	This is an accurate method to determine the actual condition of the pipe and extent of corrosion. However, this method needs to close down the section of pipe.

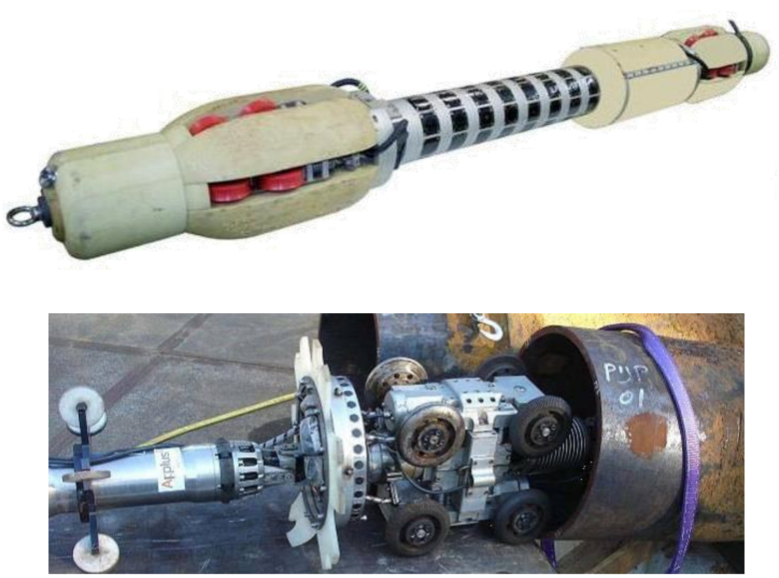


Figure (2-7) Intelligent Inspection – (Applus, 2011)

Pigs Technology (pipe inspection tool)

Pigs are inspection tools that measure pipe thickness and location of leaks inside the pipe. Many water utilities have no drawings maps for water network underground. Pigs (inspection tool inside the pipe) can be used without drawing maps for pipeline inspection. The Pre-requirements for pipeline inspection are just pipe diameter, pipe types and valve location. Pigs also are important tool to locate underground pipes using combination between Gyroscope and GPS (Global positioning system). The minimum pipe diameter to use pig is 200mm. Pigs can be used in 90degree bend. Cost of using pigs for plastic pipes is about 80,000 Euro and the cost for one job day for pipeline inspection using pigs is about 6000-8000 Euro. Smart Pigs can be in special cases practical solution and cost effective rather than using physical Inspection in special cases. (Applus, 2011). Figure (2-7) shows intelligent inspection tools.

SmartBall

SmartBall is a leak detection technology. It is a free ball swimming inside the pipe with capable of detecting and locating very small leaks in pipelines. SmartBall is inserted in a pipeline under normal operation and retrieved at pipe end. The ball moves with the water flow inside the pipe for up to 15 hours, detecting leak locations. This technique is suitable for pipeline sizes of 4 inches (100mm) and greater diameter. The cost of service is 2-4 Euros per meter depending on the pipe length and work progress per day and depending on water pressure. About 18 km-35 km pipeline length inspection can be achieved using SmartBall. Figure (2-8) shows SmartBall Technology (SmartBall, 2012).

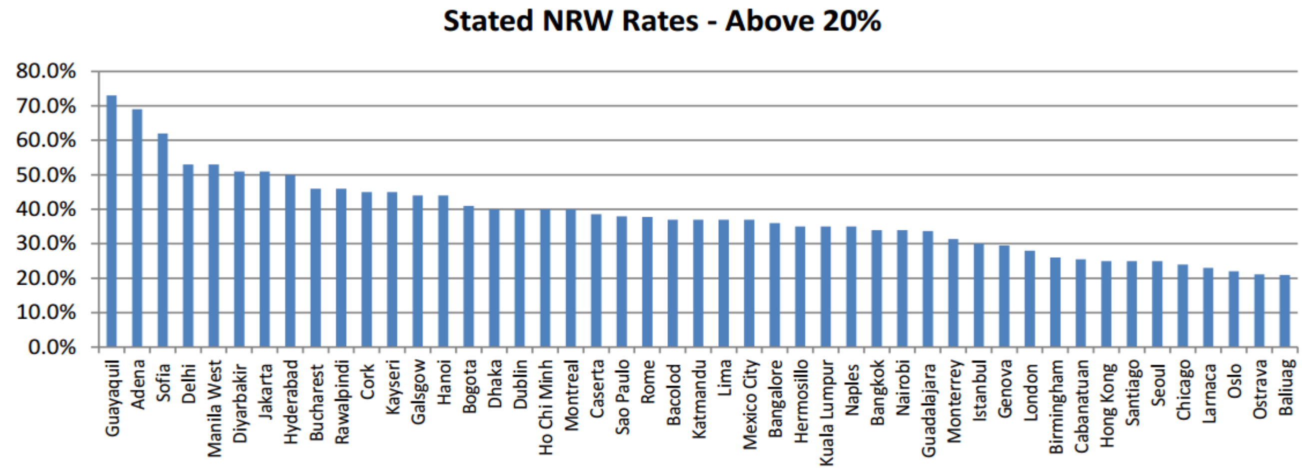
Figure (2-8) SmartBall Technology (SmartBall, 2012)

IMQS (Infrastructure Management Query Station)

IMQS is a system used for spatial display of attribute data related to lines and polygons based on GIS querying (IMQS, 2010).

2.8 Non-Revenue water NRW

Non-revenue water (NRW) is one of the most important problems in the water utilities. NRW as defined by (Kingdom et al. 2006) is “the difference between the volume of water put into a water distribution system and the volume that is billed to customers". NRW comprises three components: physical (or real) losses which include leakage from water networks and storage tank overflows. The second is commercial (or apparent) losses which caused by illegal water connection and data handling errors. unbilled authorized consumption is third component incldes water used in utility operation such as firefighting (Kingdom et al. 2006) . Figure (2-9) shows IWA water balance (IWA, 2006). NRW is different from country to another based on condition of water networks. Figure (2-10) shows and stated NRW rates (SWAN, 2011). We can identify that NRW ranged from about 70% to 4%.



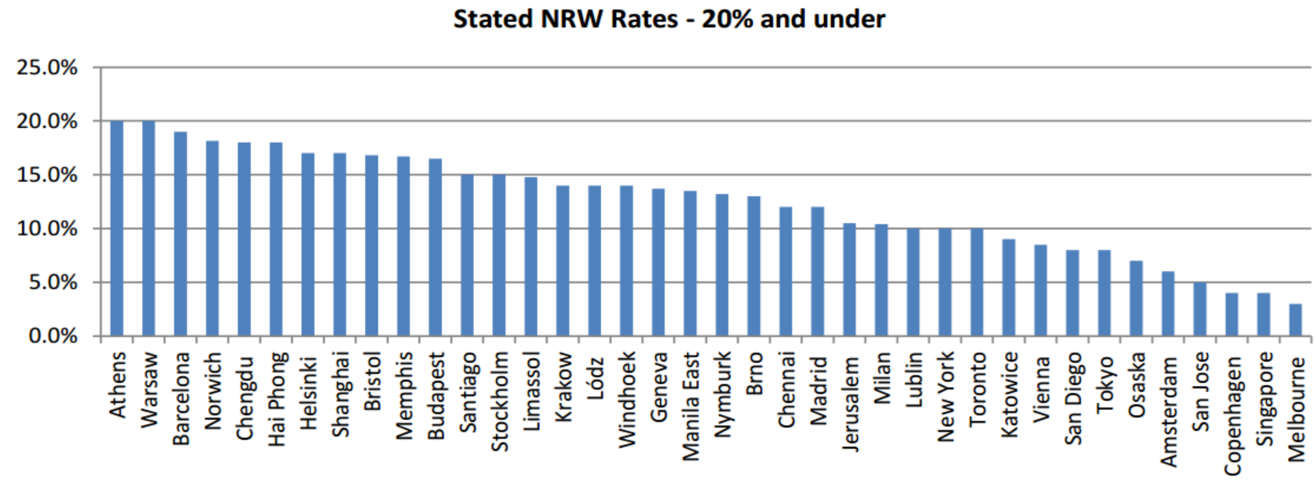


Figure (2-9) Stated NRW Rates (SWAN, 2011)

System Input Volume	Autorized consumption	Billed authorized consumption	Billed metered consumption (including water exported)	Revenue Water (or billed volumes)
			Billed unmetered consumption	
		Unbilled authorized consumption	Unbilled metered consumption	Non Revenue Water or (unbilled volumes)
			Unbilled unmetered consumption	
	Water losses	Apparent losses	Metering inaccuracies	
			Unauthorized consumption	
		Real losses	Transmission and distribution mains	
			Overflow or leakage of storage tanks	
			Service connections to meter	

Figure (2-10): IWA Water Balance

2.9 Conclusion

Numbers of studies and researches presented in this chapter have been described. This chapter summarised the technical condition assessment of existing models and describing pipe failures and analysis, which required different types of database.

Existing Condition assessment models and pipe failure reasons have been described based on several studies and researches. In addition, this chapter shows the short and long-term actions for pipe condition assessment. In addition, recent inspection technologies for pipe inspection system have been described. Some of inspection techniques such as pipe inspectors (Pigs) are just used in specific locations with long pipe distance and low cross connections. Also as an example, using of advanced inspection techniques in Gaza Strip case is too expensive due to limited budget and material restrictions.

Some models in recent researches have been developed without taking into consideration the actual dada available in water utilities, which can be an obstacle in applying the model.

This research considered the limited data available in water utilities. Three main cases of water network have been studied. These cases described different water network conditions. The Kuala Lumpur (KL) case described semi developed countries with high deterioration rate of failures. The NRW is about 40% in Kuala Lumpur. The NRW in Frankfurt water network is about 9%. However the water network in Frankfurt is over 120 years of age and there are more than 100 km of water pipeline are under service with zero remaining life. This research gives several rehabilitation scenarios taking into consideration failure rates. Gaza water network has NRW about 40% and ranking system for pipe condition has been developed in this research to improve the sustainability of pipe network.

Chapter 3

3 Developing a rehabilitation framework model based on integration between hydraulic and geospatial techniques. Gaza Strip, Palestine as Case

3.1 Abstract

This research presents a new tool for sustainable improvements model for water network using the most necessary basic information to increase the water network efficiency. Gaza Strip is used as a case study. The limited information in Gaza Strip as one of developing countries brought into focus the urgent need to develop economical assessment for rehabilitation of water distribution systems adapted to such countries.

This research present a new approach for condition scoring of water pipes used in risk management models.

The research presented in this research deal with problem of water pipe renewal and the condition assessment required by decision maker under crucial conditions. The results obtained show that the model performance is efficient depends on limited data; pipe material, diameter, number of previous failures and water pressure. The model is used to improve the sustainability of water network. The output from the condition assessment model can be used for to estimate future money budget needs for rehabilitation. In the short term, the models can be used to define the important candidates' pipes for replacement based total pipe condition. The model is innovative compared to the previous models in this field. This model combined between statistical models within GIS techniques based on simple database, which is available in water utilities in developing countries. This approach model will be an important tool to improve the sustainability of water network in developing countries with limited data available

Keywords: Water pipes, bursts, waterCAD, GIS

3.2 Introduction

Rehabilitation of pipeline systems is facing challenge for water utilities in Gaza Strip. These challenges include budgetary constraints, demand for quality service, and the need to preserve existing pipeline infrastructure. Aging of water pipeline can result in the dramatic failures in critical pipes within critical locations. Assessment and predicting of failures in pipes can increase the effectiveness of decision for maintenance planning. Most of water utilities in the world have just limited data about the water network. This research presents simple approach for determining the critical pipes based on limited data available in most of water utilities. Water network are one of the most important underground infrastructure. High importance is given for water supply from all levels in governments. The operation water pipelines have the priorities in water utilities. Many water utilities are using Geographic information systems (GIS) as archiving system or as database system. GIS can be more effective to be used in water supply as decision support system using limited data available.

Hydraulic models are required to analyze the water pipe system to analyze the hydraulic parameters such as water pressure and water velocity in the pipe.

Several researches worked on rehabilitation of pipes using hydraulic modes and GIS.

UtilNets model have been developed by Hadzilacos et al. (2001). UtilNets is a decision-support system for rehabilitation planning and optimization of the maintenance of underground pipe networks of water utilities.

Watson et al. (2004) used a Hierarchical Bayesian Model for the pipe failure rate based on length, diameter, type and age of pipes besides hydraulic pressure. Tabesh et al. (2010) introduced a GIS based tool for the rehabilitation and replacement of pipes in WDNs. They developed combined EPANET and ArcView software in which several sub models were incorporated such as unaccounted for water, pipe breakage rate, hydraulic and quality performance indices.

This research presents an integrated model combined between hydraulic and physical parameters. This model takes in consideration important parameters; pressure and velocity in addition of several physical parameters, which available in most of water utilities like pipe diameter, pipe material etc.

Framework model is developed to prioritize the critical pipes in water distribution networks using WaterCAD as hydraulic model and GIS as decision support model.

3.3 Material and Methods

The condition assessment model developed in this study considers physical, hydraulic, and structural factors for different types of mains including cast iron, ductile iron, asbestos and plastic pipes. A condition-rating model is developed to assess and set up rehabilitation priority for water mains using the integration between hydraulic model and GIS technique. Figure (3-1) shows description of the model.

Data are collected from water utility in Gaza Strip – Palestine. The basic hydraulic model has been based on Master plan of Gaza city.

The data in this case study were available at the pipe level, contain both asset information, and recorded bursts. The water pipes considered in this study consisted of 4,500 individual pipes, 1,260 km in total length and installed since 1970.

The approach is tested and verified from data available for a real PWA water system.

The selection of pipe candidates for replacement or repaired was based on condition index of pipes and predicted failures. According to model outputs, scenarios have been illustrated for pipe replacement and renovation based on expected demand requirements in the future. Demand management has become a necessity for PWA, as well as many other countries in order to sustain its development and satisfy population needs (PWA, 2006).

Geographic Information System (GIS) has been used as database and decision support system (DSS). ArcGIS10 software and Water Modeling software (WaterCAD) have been used to build the optimizing tool. The WaterCAD software was chosen due to its popular usage by engineers and municipalities. The model was applied to water supply network in Gaza City. The Gaza network supplies a population about 500,000 inhabitants within the municipality of Gaza. The supply is provided by 30 wells located in Gaza city and water is pumping directly into the distribution system by the borehole pumps (PWA, 2006).

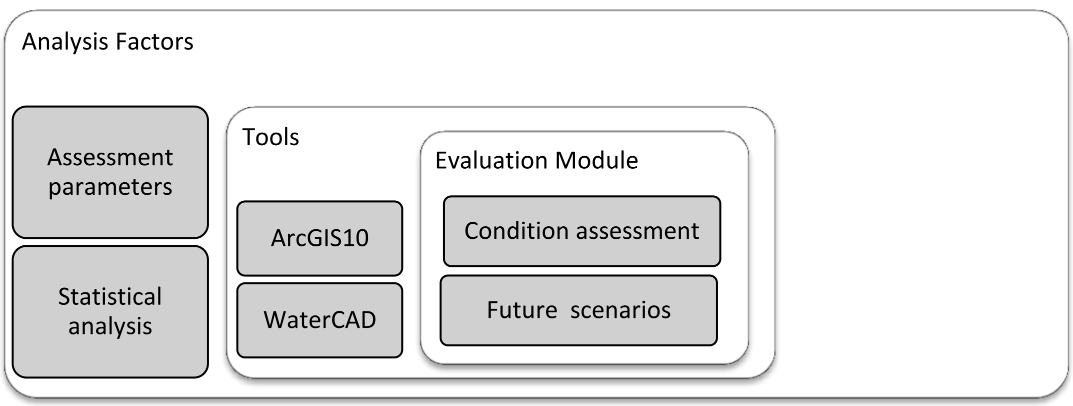


Figure (3-1) Description of the model

3.4 Case Study

3.4.1 Description of the study area

Gaza Strip is a part southwest of Palestine. Its area is 365 km^2 and its length is approximately 45km (Abu Shaaban ,1999)

The Gaza City faces severe problems in water supply and distribution system. The existing water resources are inadequate and limited to ground water wells. Additional problems are available includes poor pressure during the supply times and the very complicated intermittent supply which are mainly due to limitations in the network infrastructure and water resources. The rapidly growing population and expanding urbanization in the Gaza Strip during the past few decades have increased pressure on the aquifer, contributing to its overexploitation and the formation of deep hydrological depressions. The estimated water demand for the domestic sector in the Gaza Strip is expected to double during the next decade and triple within two decades (Population growth rate in Gaza Strip is 3.45%) (PCBS ,2011). Thus, further increases in the size of population and consequent exploitation will diminish the aquifer's quality, as long as it serves as the primary source of water. The major environmental problem in the Gaza Strip is deteriorating water quality through salinization and pollution resulting from a deficit in the water balance (PWA, 2006).

This problem covers the fresh groundwater in the shallow aquifer underlying the Gaza Strip. The major indicators for deterioration are increase in salinity (chloride) and nitrate concentration. Other pollutants like hydrocarbons, heavy metals, pesticide may also cause serious problems but a little data are available on these. Gaza City divided into 11-Zones shown in Table (3-1), the current estimated populations for (2009) are 450.000 inhabitation and the total area is 45 Km^2 PCBS (2011).

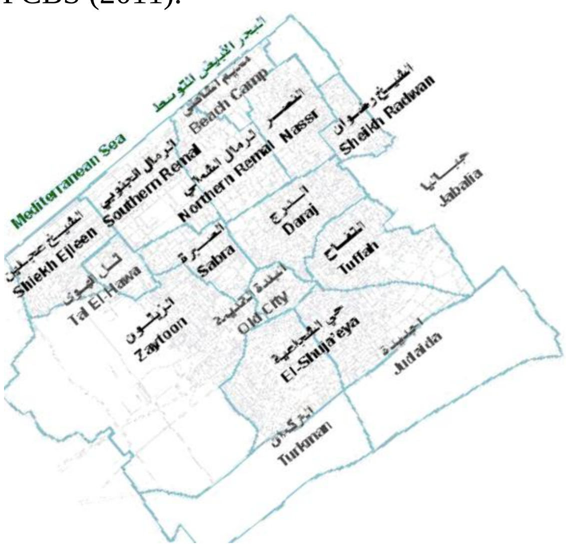


Table (3-1) zones, area and population (PWA, 2006)

Number	Zone	Area $1000m^2$	Population
1	AL-EJdaida	2761	25500
2	AL-Torekman	2664	36000
3	AL-Zaitun	7423	46000
4	AL-Tofah	2912	29000
5	AL-Daraj	2838	37000
6	AL-Sabra	585	23500
7a	South Remal (1)	2761	90000
7b	South Remal (2)	890	30000
7c	South Remal (3)	6537	30000
8a	North Remal (1)	2415	43000
8b	North Remal (2)	1978	43000
9	Beach Camp	989	72031
10	Blakhia	748	53462
11	AL-Shigh Radwan	1009	22000

3.4.2 Water Quality:

While there is no surface water (lakes or rivers) available in the Gaza Strip, the only fresh water resources is ground water. At present about 5000 wells tap this water supply (PWA, 2006). Many years of over-pumping have resulted in seawater intrusion and upcoming of brine groundwater. Further human activities, like agriculture and industries have increased the pollution levels in the groundwater. The major environmental problem in the Gaza Strip is deteriorating water quality through salinization and pollution resulting from a deficit in the water balance. The major indicators for deterioration are increase in salinity (chloride) and nitrate concentration. Other pollutants also are available like hydrocarbons, heavy metals and pesticide, which may also cause serious problems. Figure (3-2) shows spatial distribution of water quality and quantity in Gaza Strip (PWA, 2006).

According to the assessment report of World Bank (2009), Water quality in Gaza Strip is very poor and small scale desalination has emerged as a stop-gap solution. High concentrations of salts and nitrates are difficult and costly to remove from drinking water supplies. Just 5% and 10% of water supplied meets potable standards. The main reasons for water quality problems are due to aquifer overdraft, and wastewater seepage pollution and infiltration of agricultural fertilizers (PWA, 2006).

3.4.3 Water supply situation

Based on World Bank (2009) report, water supply coverage has high rate of connection, 98% of the population are covered. Per capita supply is 152 liters per capita per day (L/c/d), in 2005. Average consumption is 60% of supply levels, due to network losses. Total municipal and industry supply increased from 52 MCM in 2000 to about 76 MCM in 2005. Actual water availability after losses increased from 35 MCM to 45 MCM. Water supply comes from Palestinian controlled sources, with dependency on Mekorot (The main water pipe line) for just 4%. Recently, problems in Gaza water supply have reached crisis levels, due to the deteriorating economic, political and security situation (World Bank, 2009).

3.4.4 Water Demand

Over the next 20 years, several policies and trends will increase the demand for water in the Gaza Strip. Municipal and industrial demand will rise due to factors such as population crease, and an increase in per capita consumption. Agricultural demand is expected to decrease, due to loss of land to urbanization, changes in cropping patterns, and increased irrigation efficiency. Figure (3-3) shows water demand prediction in Gaza Strip (CAMP, 2000).

3.4.5 Per capita consumption

The estimated average per capita consumption (the amount of water actually provided to individuals, after system losses) is now 77 L/c/d, well below the World Health Organization's recommended standard of 150 L/c/d, also recommended by the PWA (CAMP, 2000).

3.4.6 Water supply mode

Gaza water supply system comprises water wells, distribution water network and tanks. Water is abstracted from wells and discharged directly into water network. Water supply in Gaza city is intermittent due to the limitation of infrastructure and water resources. The network operation mode depends on two-day cycle managed by opening and closing valves. The network is operated by using manual valves located on the main pipe feeders. Each well has a specific operation time in summer and winter based on zone demands (PWA, 2006).

3.5 Overview for prioritization criteria used in PWA

Prioritization of rehabilitation projects in PWA is based on the Expert Opinion Elicitation (EE) method. The EE method used to identify the criteria assigned for this method. Weights are assigned to each criterion based on the beneficiaries' feedback and the experts' elicitation opinions.

Prioritization Criteria used in PWA are based mainly on six factors; Project Importance (36%), Finance Suitability, Execution suitability, Operation suitability, Reliability and Consequence of failures Table (3-2) shows the prioritization process Criteria for water network rehabilitation used in PWA.

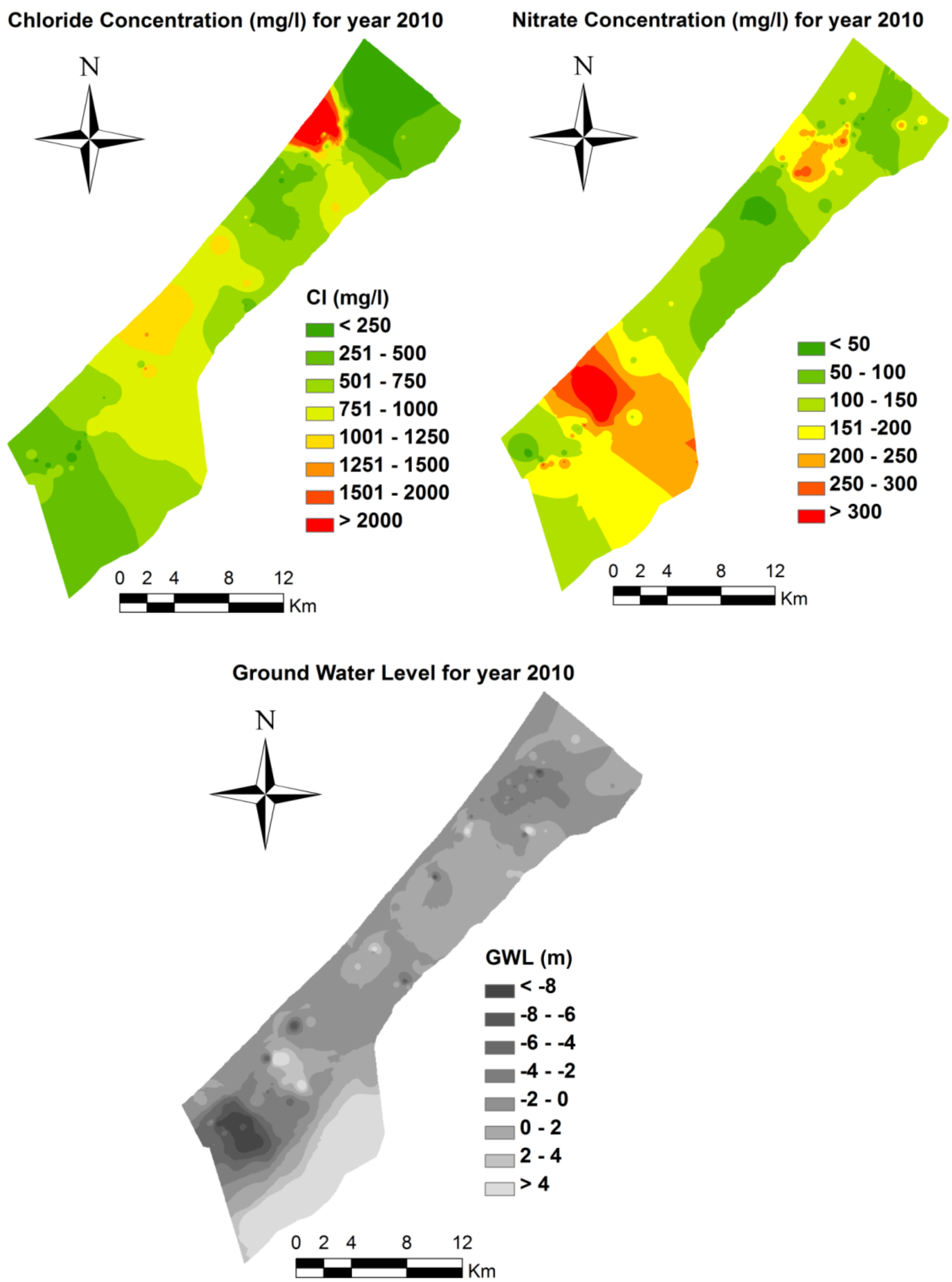


Figure (3-2) spatial distribution of water quality and quantity in Gaza Strip

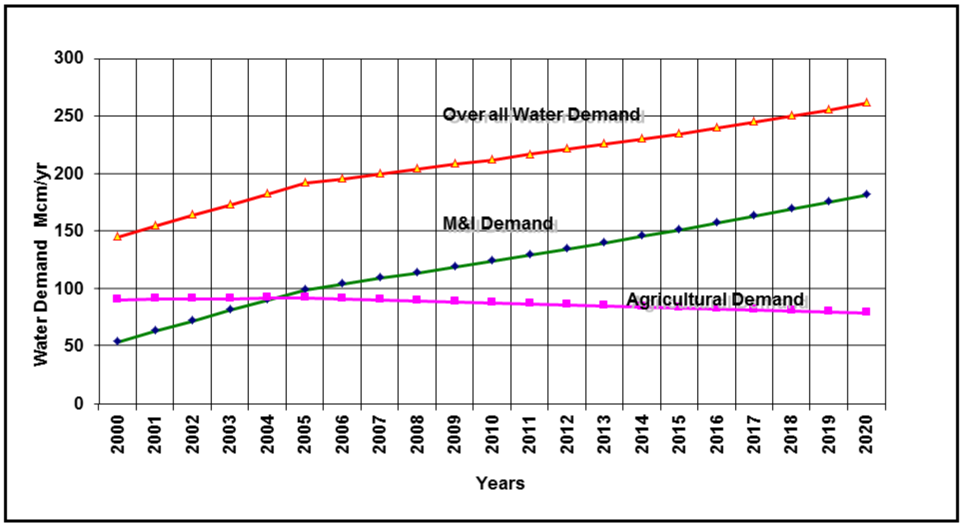


Figure (3-3): Water demand prediction in Gaza Strip

Table (3-2) prioritization process Criteria for water network rehabilitation used in PWA (PWA, 2006).

Criteria	**Weight**	**Sub- Criteria**
Project Importance	0,36	• Percentage of direct and indirect beneficiaries to the total population (efficiency of the project) • Increase the percentage of the network coverage • Improving the water quality • Water distributing equality to the whole zones (quantity and quality) • Continuous supply • Achieve the planning consumption figures • Minimize the UFW
Finance Suitability	0,13	• Fund availability • Donors willing to fund similar projects • Fund restrictions • Project value
Execution suitability	0.18	• Labour and Technicians availability • Equipment availability • ability for Construction • Land Availability
Operation suitability	0.10	• Need of a continuous supply of raw materials • Sophisticated technical experience and or a large operation budget • Lack of maintenance • Environmental impact
Reliability	0.13	• Includes the introduction and identification of involved uncertainties, experience of people, human factors and defining interrelationship of parameters.
Consequence of failures	0.10	• Includes the adverse effects of failure such as the consequence of deviating from planned targets and / or stopping before completion
	1.0	

3.6 Development of WaterCAD Model

Analysis of the water distribution system is performed using the WaterCAD version 8.0. WaterCAD is modeling, analysis and design software developed by Heastead. WaterCAD software provides a computer aided design (CAD) interface for building and editing model facilities, together with hydraulic analysis to perform model scenarios. Figure (3-4) shows a view for WaterCAD model. The developed WaterCAD model consists of the following components:

- Flow Control Valve
- Junction
- Pipe
- Pressure Reducing Valve
- Pump
- Tank

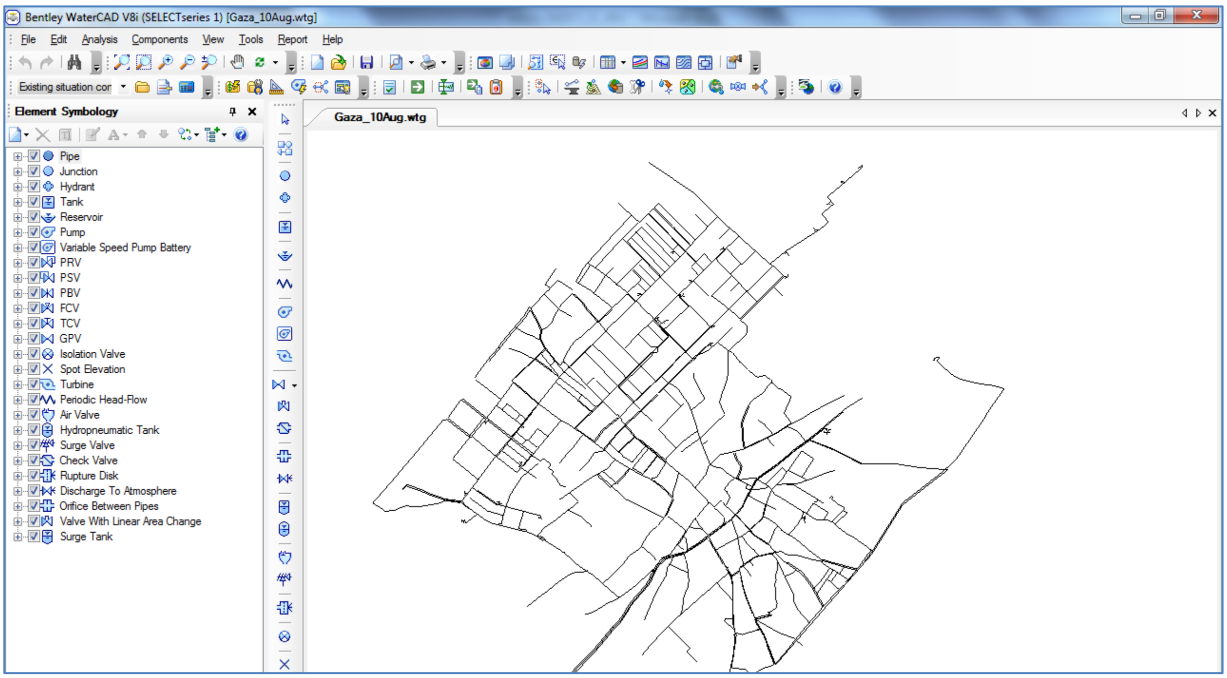


Figure (3-4) WaterCAD model setup

This WaterCAD model is developed based on database of master plan for Gaza city PWA (2006). Table (3-3) Water network inventory (produced from WaterCAD Model) and Table (3-4) shows characteristics of pipes within the WaterCAD Model.

Table (3-3) Water network inventory produced from WaterCAD Model

Scenario Summary

Network Inventory

Pipes	991	-Constant Speed - No Pump Curve	37
Junctions	721	-Constant Speed - Pump Curve	0
Hydrants	0	-Shut Down After Time Delay	0
Tanks	26	-Variable Speed/Torque	0
-Circular	26	-Pump Start - Variable Speed/Torque	0
-Non-Circular	0	Variable Speed Pump Batteries	0
-Variable Area	0	PRV's	0
Reservoirs	30	PSV's	0
Pumps	37	PBV's	0
-Constant Power	0	FCV's	0
-Design Point (1 Point)	8	TCV's	0
-Standard (3 Point)	0	GPV's	26
-Standard Extended	0	Isolation Valves	0
-Custom Extended	5	Spot Elevations	1
-Multiple Point	24		

Table (3-4): Characteristics of Pipe sample within the WaterCAD Model

Label	Length (m)	Start Node	Stop Node	Diameter (mm)	Material	Flow (L/s)	Velocity (m/s)
P-359	667,09	J22-14	J22-20	69	Steel	1,43	0,38
P-292	340,5	J17-007	J17-013	101,6	PVC	4,24	0,52
P-448	1.218,40	J21-10	J30-06	69	Steel	4,32	1,16
P-151	81,95	J26-034	J9-13	147,6	Steel	2,59	0,15
P-39	503,76	J28-14	J28-16	101,6	PVC	0,25	0,03
P-1608	22,39	J18-092	J19-04	101,6	Steel	5,23	0,64
P-1611	165,87	J7-20	J7-14	292	Asbestos Cement	0,49	0,01
P-1637	217,35	J10-90	J10-07	101,6	PVC	3,17	0,39
P-1650	80,24	J8-91	J8-08	144	Asbestos Cement	6,9	0,42
P-1653	289,58	J11-08	J11-90	147,6	Steel	0,58	0,03

3.7 Integrated Gaza Rehabilitation Model

Condition assessment model is based on three modules; hydraulic module and physical module and structural module. The hydraulic module has been developed using WaterCAD software. Two criteria have been determined using hydraulic module; water pressure and water velocity. Physical module includes three criteria; pipe diameter, material and pipe length. Third module is structural module, which includes three criteria; pipe age, number of previous failure (NOPF) and number of leakage per Km.

Table (3-6) summarized the factors influencing the criticality of water pipes. The factors were determined based on failure analysis of water pipes in Gaza Strip In addition of expert opinion from a panel of professionals in different functions. Total scores were assigned based on scale between 0 and 100 and then added up to measure the overall score using a GIS model. Low pipes scores indicating that these pipes need to high consideration and important. On the other hand, high pipe scores means that these pipes have a good condition and need for low consideration in short term rehabilitation projects.

The model was calibrated and the contributing factors scores relative weight of importance was adjusted using WaterCAD software. Figure (3-5) shows the flow chart for water pipe condition model using Modelbuilder in ArcGIS 10.

3.7.1 Physical assessment Analysis

Physical assessment of water pipes based on three criteria: Pipe material, Pipe diameter and pipe length. Ranking system of physical criteria is based on statistical effects of each factor on pipe deterioration. SPSS software has been used in pipe condition analysis.

Table (3-5) factors influencing the criticality of water pipes

	Criteria		Points Matrix*				
	Physical Criteria	Max score					
1	Pipe diameter		100	150	200	250	300
	Points	10	3	5	7	9	10
2	Material		AC	Steel	UPVC	HDPE	
	Points	10	2	10	8	6	
3	Pipe Length		<100m	100-200	>200		
	Points	10	10	5	0		
	Hydraulic Criteria						
4	Pressure (bar)		0 bar	1-2 bar	2-4bar	4-7bar	>7bar
	Points	15	0	5	10	15	5
5	Velocity (m/s)		0	0,1 -0.8	0.8-1	1-2.5	>2.5
	Points	10	0	5	7	10	2
	Structural Criteria						
6	Pipe age		0-5 years	5-10 years	10-20 years	20-30 years	>30 years
	Points	20	20	15	10	5	2
7	NOPF /km		0	1-2	3	>3	
	Points	15	15	10	5	0	
8	Leakage /Zone/km		0	1-3	4-6	>6	
	Points	10	10	7	5	0	

* Points Matrix have been allocated based on effect of each factor on pipe condition and based on expert opinion. Description of each factor is in section 3.7. Score weight is distributed from low pipe condition (0) which need high importance in rehabilitation projects to high pipe condition scores which low consideration in rehabilitation projects based on assigned max score.

Pipe material

Gaza water network depends mainly on four material types; 1% AC pipes, 26% Steel pipes, 53% UPVC pipes and 20 % HDPE pipes. UPVC pipes has highest rate of leakage in joints in Gaza water networks. Steel pipes have been installed since 25- 35 years. Wight scores for pipe material has been allocated based on pipe failure analysis for Gaza city. AC pipes has highest rate of pipe failures and high deterioration. AC pipes has high importance for rehabilitation projects. Pipe material scores for AC =0, which has the lowest condition scores. Steel pipes have the highest material score which is 10.

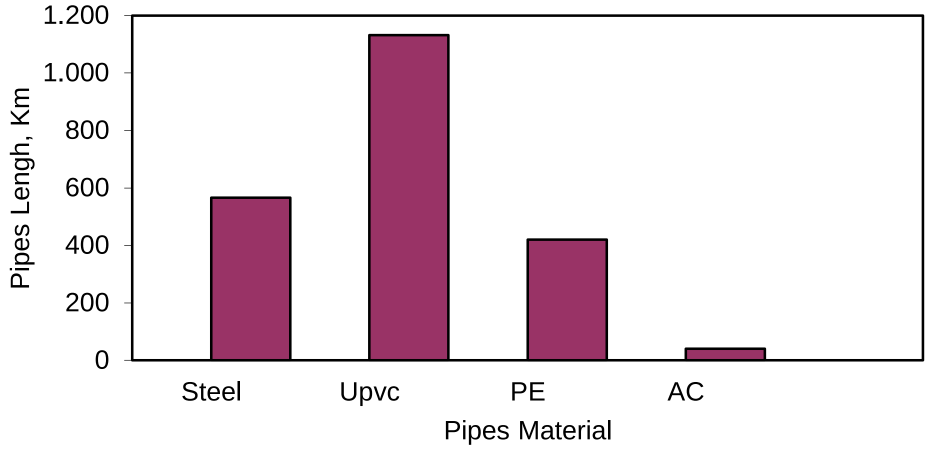


Figure (3-5) pipe material types in Gaza Strip

Pipe length

The mean average of pipe length in Gaza water network is about 200 m. For long pipes (e.g. >1000 m) external conditions like soil conditions and traffic might vary along the pipe Røstum et al. (1997). Røstum et al. (1997) also recommended pipe lengths about 100m in order to avoid different conditions for the same pipe. Andreou (1986) found the hazard function to be approximately proportional to the square root of length.

The longer pipe section has higher tendency to suffer breaks. For Gaza case study, the variable of length has been categorized according to the following classification: pipes with less than 100 m of length, between 100-200 and pipe length > 200m.

Pipe diameter

According to failure analysis of main pipes, pipes with diameter 110mm have particularly large number of failures. The high frequency of failures for small pipe dimensions is explained by reduced pipe strength, reduced wall thickness, different construction standards and less reliable joints for smaller pipes (Wengström, 1993b). In addition, there are high failure rate in the connection pipes in diameter ranged from 15mm - 50 mm. these pipe failure in small diameter are resulting from bad material of pipes, settlements of material inside the pipes and illegal pipe connections.

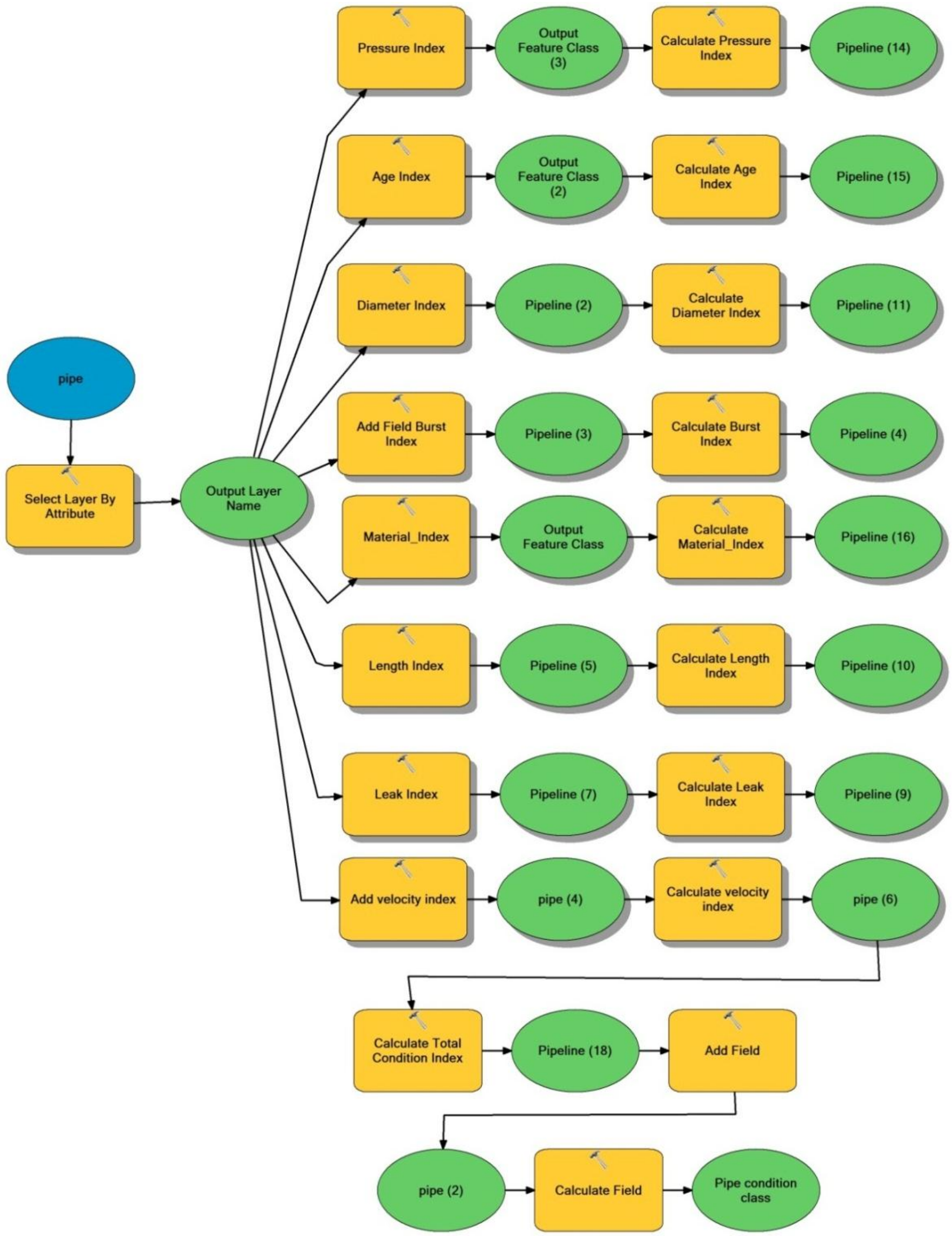


Figure (3-6) flow chart for water pipe condition model using Modelbuilder in ArcGIS 10

3.7.2 Hydraulic assessment Analysis

Rehabilitation system of water networks could faces several problem without real understand the actual requirements of the system. Expected rehabilitation needs are one of the main important factors required to build a sustainable improvement of water network. Figure (3-7) shows hourly hydraulic pattern in 24 hours. Evaluation of hydraulic performance has been carried based on two criteria velocity and pressure analysis.

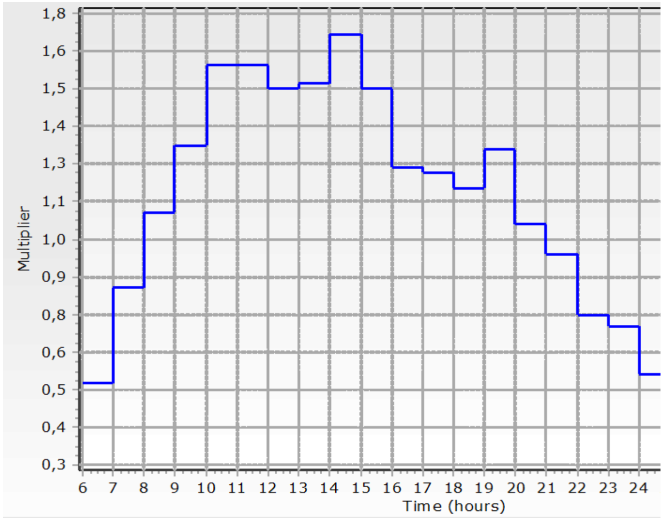


Figure (3-7) Hourly hydraulic pattern in 24 hours

Pressure

Pressure analysis has been performed based on hydraulic simulation using WaterCAD software. Adequate pressure has been maintained in the water distribution network based on PWA standards. Maximum pressure limits is 7 bars and minimum pressure is 2 bars.

According to the analysis of water network there are some points have water pressure higher than acceptance limits. Point matrix has been allocated based on pipe pressure condition in water networks. For example, if water pressure more than 7 bar, the pipe has low point score which need high consideration in future rehabilitation projects.

Velocity:

Water pipe velocity has been determined based on WaterCAD simulation. The recommended water velocities based on PWA standards are as following:

Maximum velocity is 2 m/s to prevent erosion and high head losses

Minimum velocity is 0.6 m/s to prevent water sedimentation

3.7.3 Structural assessment analysis

Pipe Age

Pipe age is a factor for determining condition assessment of pipes.

Many of previous researches indicated that the failure rates increase with pipe age. However Boxall et al. (2007) have found that age alone is a poor indicator of the necessity for pipe replacement or rehabilitation. O’Day et al. (1982) presented that expected failure rate is not strongly correlated with pipe age. Hu and Hubble (2007) found general trend that the older the pipe age, the higher the pipe failure rate.

Also different installation periods show different failure characteristics Røstum (2000). Andreou et al., (1987b) found that some construction periods have a higher break rate than others. In some cases, older pipes are more resistant to failure than younger pipes. Table (3-6) shows pipes age based on pipe diameter (PWA, 2006). The age index is shown is table (3-5).

Table (3-6) Pipes age based on pipe diameter (PWA, 2006)

Diameter mm	Pipes age (years)		
	AC	Steel	UPVC
500	25	35	-
400	25	35	-
355	25	35	-
300	25	32	15
250	22	30	30
200	20	30	30
150	20	30	25
100	18	27	25
75	15	25	20
50	-	25	15

Number of previous failures NOPF

Number of previous failures are important factor which used by most of available model in rehabilitation and replacement of water pipes. In this research, simple index of number of bursts in pipe network has been considered for determining break rates. Simple index has been used due to limited information about pipe failures in Gaza Strip. Figure (3-8) shows monthly burst counts per in Gaza Strip from May 2008 to Nov 2009. Figure (3-9) shows total pipe bursts for each pipe diameter and figure (3-10) shows burst rate per km per year. We can identify that pipe burst rate is higher in pipe diameter less than 80mm.

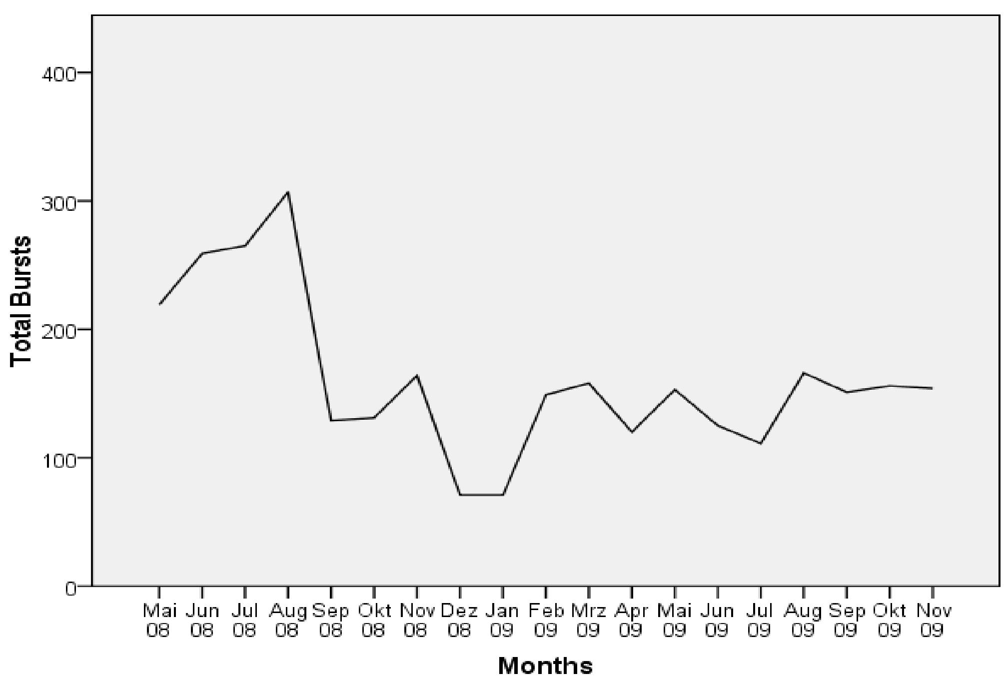


Figure (3-8) Monthly bursts counts in Gaza City

Leakage rate

Leakage management is one of the most important issues in water-pressurized networks; it has several potential benefits. Leakage level is strongly correlated to the structural condition and intensity of failures of the network. Leakage level is reduced by carrying out leakage control programs. Leakage control programs are costly, and from an exclusively economic perspective, it is well known every water network has an optimum leakage level (Røstum, 2000). (Sterling and Bargiela ,1984) and (Germanopoulos and Jowitt, 1989) found that real losses are directly related to pressure and pressure management may lead to high leakage reduction (Nicolini, et al, 2011). In Gaza Strip, water losses reach to 40 % (PWA, 2006). Based on our model, score points of pipe condition is zero if leak are more than 7 leaks per km.

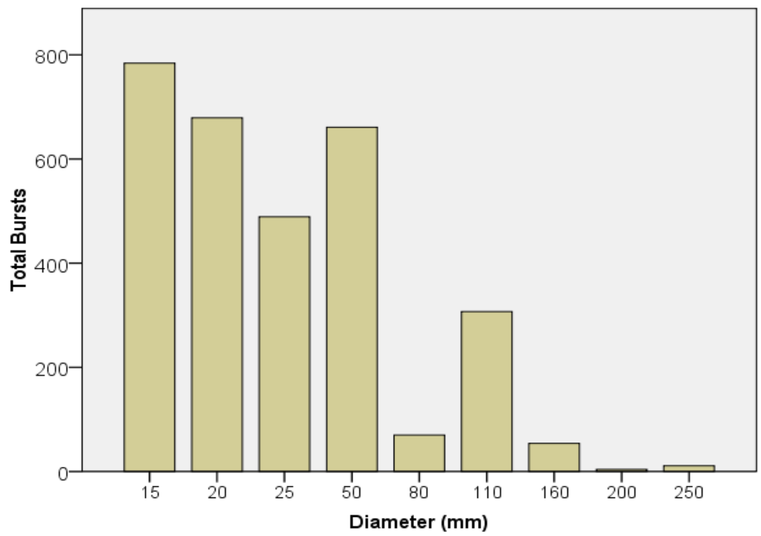


Figure (3-9) Total pipe bursts for each pipe diameter

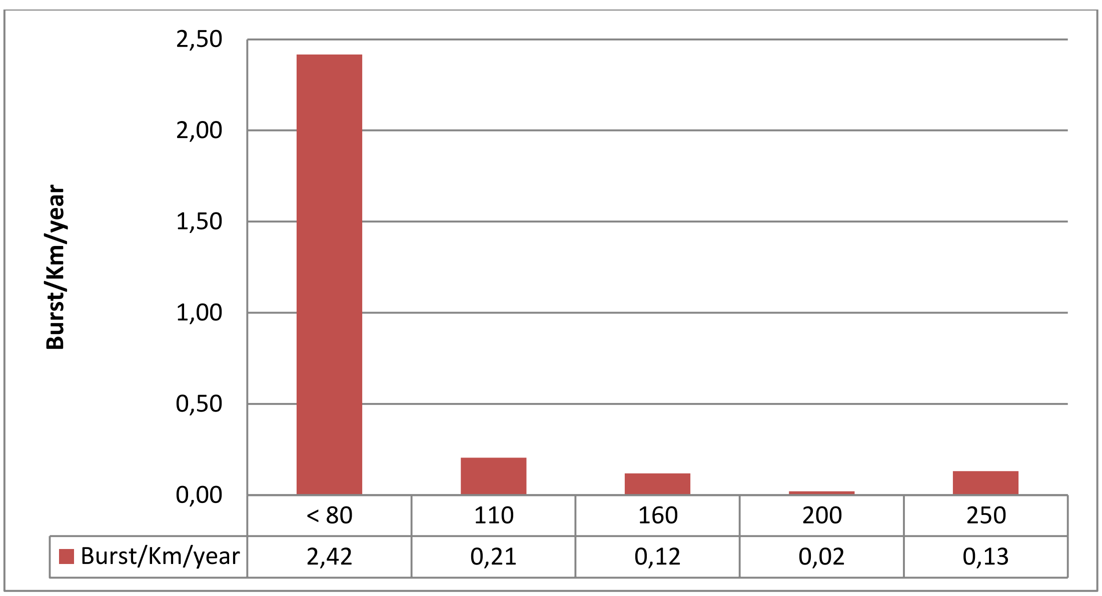


Figure (3-10) Average pipe burst rate per Km per year

3.8 Results and Discussion:

Based on the criteria and the scoring matrix, a GIS model was constructed in ArcMap to evaluate and assess the water pipes. The GIS model, contained several functions, calculated the scoring for the pipe networks. In the initial stages, maps were produced and the weighting factors were modified to reflect actual conditions. GIS module has been developed based on criteria. ArcGIS 10 has been used to make assessment for each pipeline. The model contains weighting factor for primary and secondary contributing factors.

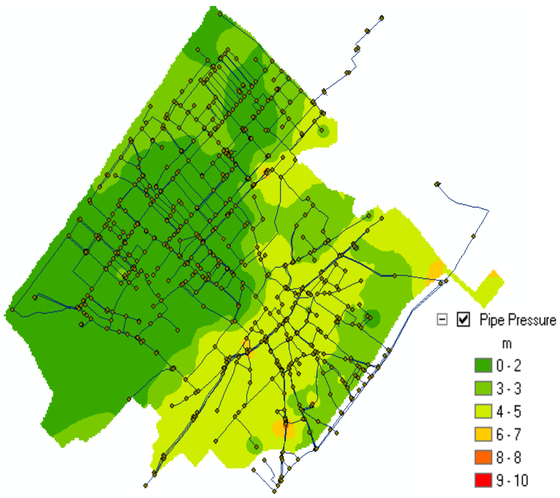


Figure (3-11) spatial distribution for water pressure in Gaza network

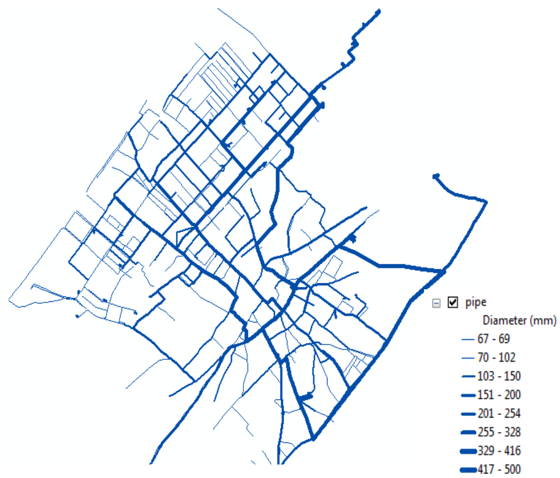


Figure (3-12) Pipe classifications based on diameter

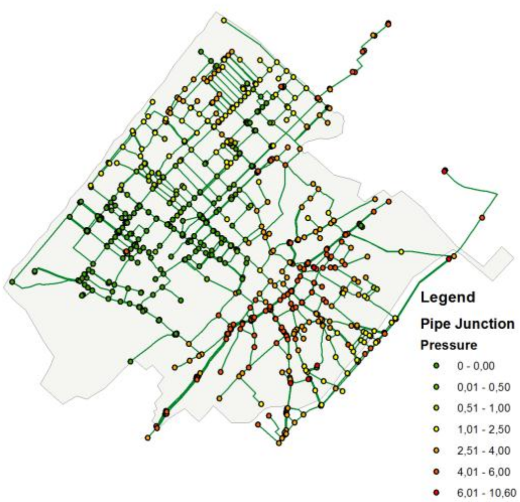


Figure (3-13) Water pressure for each junction

Figure (3-14) water pipe lines with water velocity higher than recommended limit by PWA

Several mathematical equations have been used inside the model to calculate the condition index of pipes.

The model identified the pipes with high risk and required for replacement. Based on the results of GIS model the percentage of pipes needed for replacement is 7%. High critical areas have been identified in Beach Camp zone. This area contains old pipe material with high water pressure. Also GIS map shows the critical pipe condition in the center of Gaza city due to frequent rehabilitation of roads in this zone.

According to the model output, there are some pipes with high velocity. The highest velocity is 6.4 m/s at pipe no. P-2045 this value is higher than the recommended values of velocities (1.2 m/s –2.0 m/s), that have to be avoided in order to avoid stagnation and water quality problems in the water systems. These high velocities will affect adversely causing pipes deterioration. Figure (3-13) shows water pressure for each junction and figure (3-14) shows water pipe lines with water velocity higher than recommended limit by PWA.

The normal pressure values ranges between 3.0-4.0 bars. Hydraulic model shows that the maximum pressure value is in node J-1626. Also during the period of supply, the water network will be under excessive pressure and will reach to zero pressure during no-supply time. This type of intermitted supply will affect the life of pipes and increasing the deterioration rate through increase the leakage and breakage rates figure (3-15) shows pressure and demand at node J-1626.

Results were mapped after integration between GIS and WaterCAD model. Figure (3-16) illustrates the critical pipes in Gaza city.

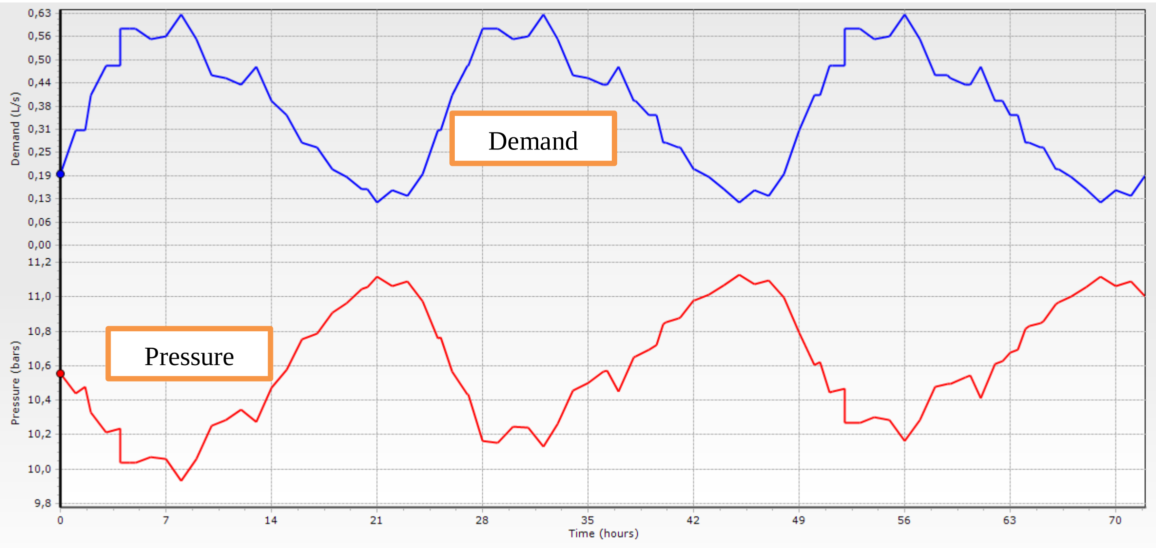


Figure (3-15) Pressure and demand at node J-1626

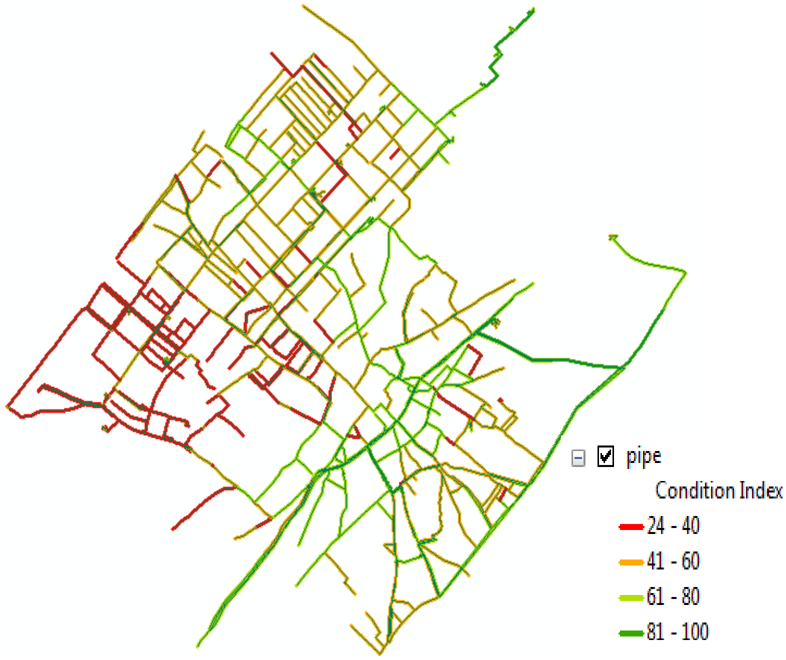


Figure (3-16) Condition index for water pipeline in Gaza City

As shown also in figure (3-16), the model calculated the condition scores for each pipe based on available database. We can indicate that 40% of water pipeline have score points less than 50 points and about 10% of total pipes length have less than 30 score points.

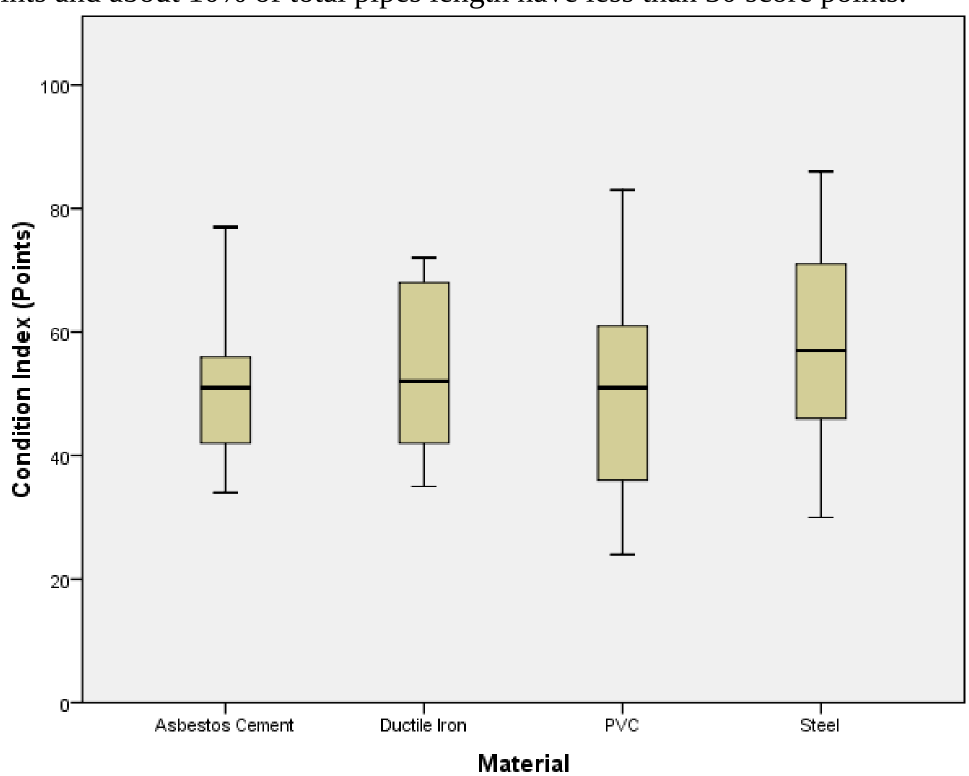


Figure (3-17) pipe condition index based on pipe material

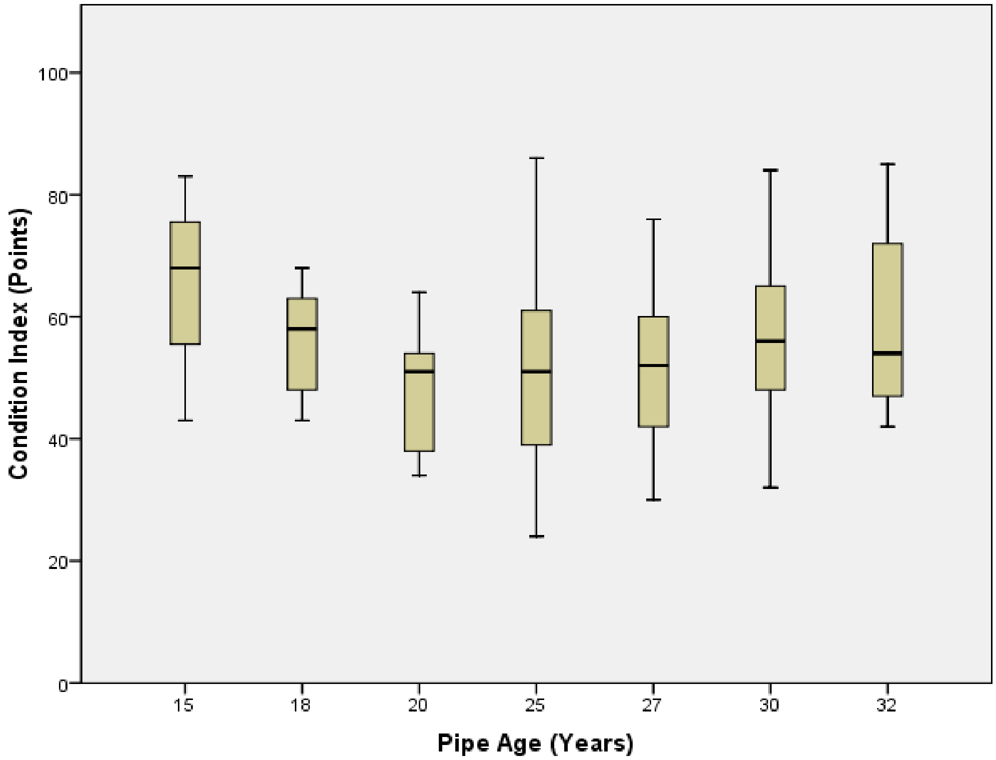


Figure (3-18) pipe condition index based on pipe ages

Scores of pipe condition index for PVC pipes ranges from 20 to 80 based on pipe ages, diameter and no of failures. The average pipe condition for all pipe material is between 40 and 60. Figure (3-17) shows pipe condition index based on pipe material.

Pipe condition scores based on pipe age are shown in figure (3-18). For example, the average score for pipe age 25 years is about 50 points ranged from 25 -90 points.

3.9 Conclusion:

A GIS-based hydraulic analysis model was developed to evaluate the condition assessment of the pipe. The model was fairly accurate in identify the critical pipes in water networks. The research represented an integrated GIS model based on hydraulic model used in management of water distribution networks. This model is simple to be applied in most of water utilities in developing and developed countries. This model based on simple data that almost available in water utilities. Important factors have been used to develop decision support system for maintenance and rehabilitation of water pipes. Implementing this model provide sustainable water network system to improve the water distribution networks. In addition, this research identifies the condition index scores for each pipe to provide permanent water supply that will meet the actual water demand and future water consumption.

Water network situation in Gaza city is critical and need to make several actions into rehabilitation of water networks. According results of this research, more than 40% of water pipeline have score points less than 50 points. This indicating that water networks need regular rehabilitation programs taking into consideration the condition assessment of each pipe.

Using the output of this model, the rehabilitation budget can be allocated based on pipe condition scores.

The GIS model results was validated with actual pipe condition and were successful in identifying assessment scores using limited data. Applying hydraulic-GIS model can provide good results in assessment condition of water pipes rather than just using GIS as archiving system for water database.

Chapter 4

4 Data Preparation of the Kuala Lumpur water network

4.1 Kuala Lumpur water network description

This chapter provides an overview and description of Kuala Lumpur water network case. Work methodology and data preparation for Kuala Lumpur have been described. Water distribution networks in Kuala Lumpur contain three kinds of pipes: transmission mains, distribution mains and service pipes.

Distribution main diameters within the DMAs vary between 100 and 250mm and, where possible, interconnecting ring systems have been formed to minimize head loss at peak demands. Unfortunately, the water company has maintained records of its operational activities just since 2006 (Syabas, 2010). Table (4-1) shows summary of water distribution activities in SYABAS-KL.

Table (4-1) Summary of water distribution activities in KL (SYABAS, 2010)

Item	Details
No of customers	7.3 million
No customer connections	1.579 million, 69% of the quantity is for domestic use.
distributed daily average	3,867 million litres of treated water / year which is 56 MLD (1.5%) more than in 2007 (3,811 MLD)
Water distribution assets	23,500 km water distribution pipes
	1,226 service reservoirs, elevated water tanks and suction tanks, 444 booster-pumping stations.
Water supply coverage in urban areas	100%
The main water resource	Surface water with raw water abstracted from the rivers and some are regulated by the dams.
No of Water treatment plant WTP.	3 plants (PNSB, SPLASH & ABASS)
On going projects	In the Hulu Langat District • Bulk Transfer from Sungai Semenyih to the Sungai Langat Water Distribution System. The project is now 85% completed. • The Klang water transfer project which it is currently in design stage for Bulk Transfer from Sungai Selangor Phase 3 Water Treatment Plant (SSP3) to the Klang area.
Non Revenue Water (NRW)	from 42.78% in Jan 2005 to 31.94% in Dec. 2008 for Selangor, Kuala Lumpur and Putrajaya
Total reduction in NRW	10.84%
Required NRW	15.0% Concession Agreement requires to reduce NRW level from 42.78% as at 1 January 2005 to 15.0% by 31 December 2015.
No of Leakege points (2006)	11,254 communication pipe leaks 2,434 trunk main leaks 13,688 leaks (Total)
Strategic programmes to reduce water losses by SYABAS	• Meter replacements, • District Metering Zones (DMZ) establishment • Active leak detection • Reservoir overflow controls.
Pipe Replacement in 2008	Approximately 4 km of old pipes has been replaced
Replacement method	“trenchless” technique (Static Pipe Bursting Method)

Kuala Lumpur faces a big challenge to reduce Non-revenue water NRW through improving water network and decreasing physical losses. Database covers the pipe failures from 2006 and 2010. Data set consists of about 2500 bursts and about 18,000 leaks that occurred over four years in Kuala Lumpur. Figure (4.1) shows overview for pipe failures and leakages locations in Kuala Lumpur.

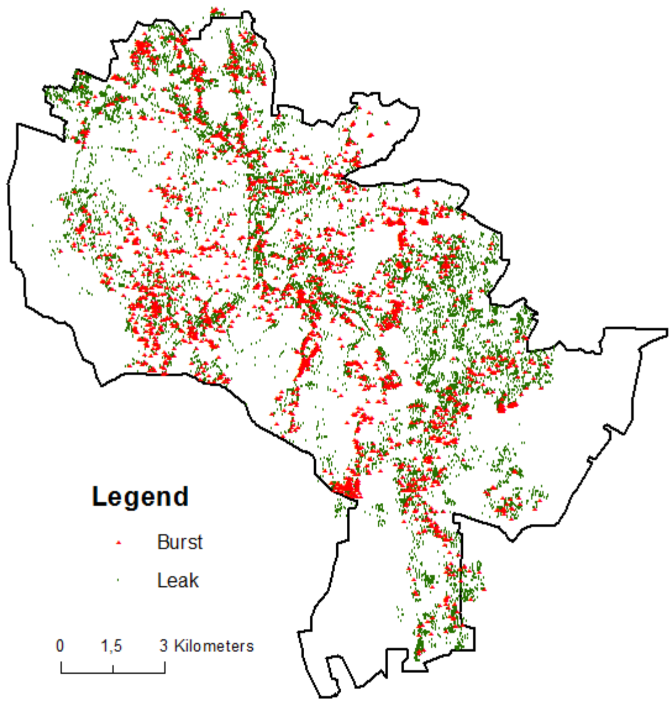


Figure (4-1) Pipe failures and leakage in Kuala Lumpur

4.2 Work Methodology

Work methodology for Kuala Lumpur (KL) Water network case compromise from three components. First component is the developing pipe failure prediction model using Generalized linear model (GLM) based on SPSS analysis. SPSS software is used for statistical analysis of water pipe failures. This model was developed for both individual pipes and District meter zone (DMZ) available in Kuala Lumpur.

Second component is spatial and temporal analysis of pipe failures using Geographic Information system (GIS) and Statistical Software (SPSS). This component focus on determining relationship between failures based on distant interval and time interval between events.

Third component was focus on AC pipes and developing Water Pipe Replacement Model (WPRM) to determine condition assessment of pipe network. This model including comparison between two condition assessment methods of water pipes; Ranking system using GIS and simple chemical test of AC pipes to provide more accuracy in the assessment results. Figure (4-2) shows the Kuala Lumpur water network components.

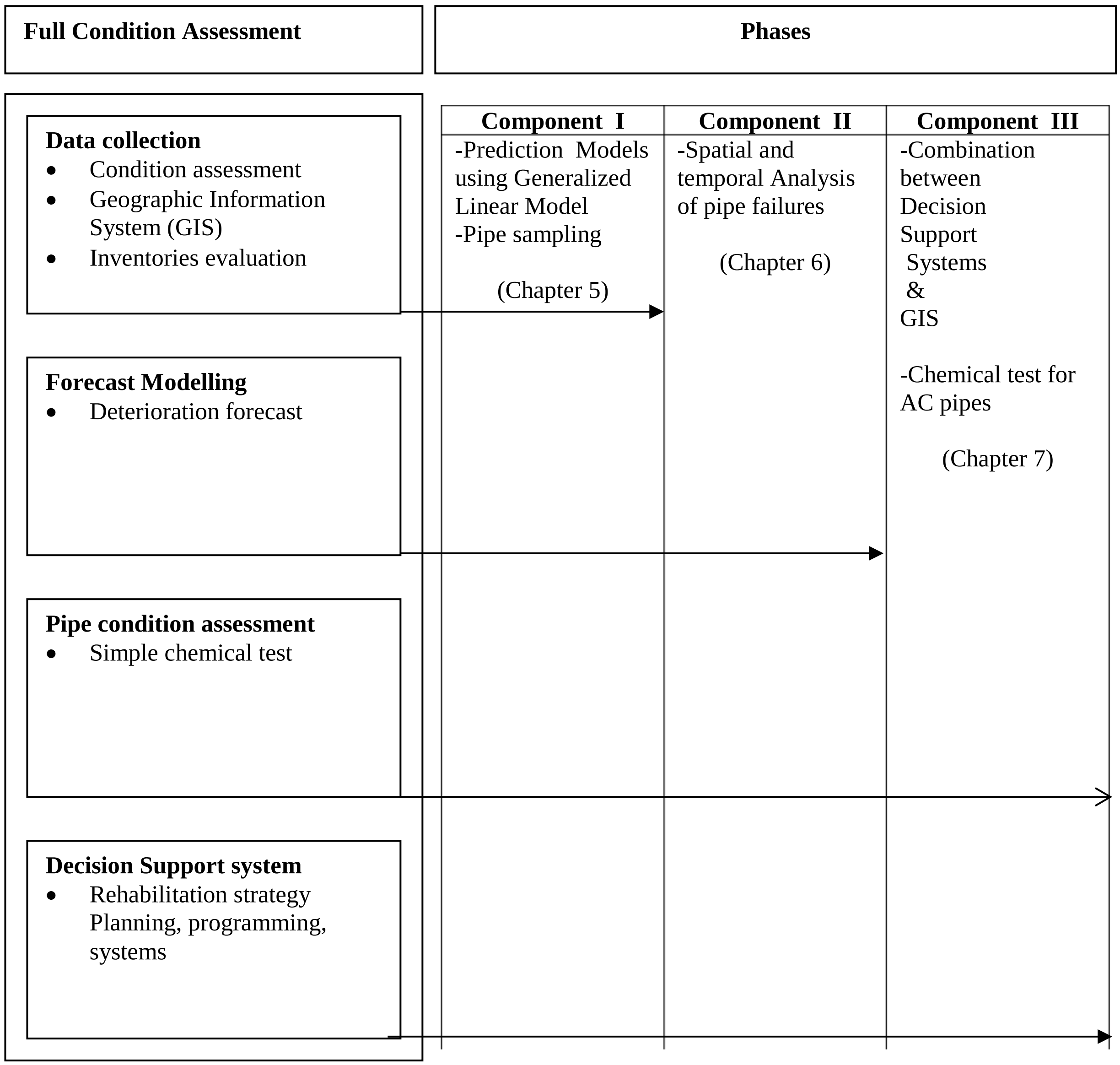


Figure (4-2) Condition Assessment components

4.3 Our Vision to Kuala Lumpur water network

This research provides Kuala Lumpur to be a leadership in the development of effective and sustainable international best practice pipe rehabilitation and maintenance systems in Asia. Also long-term sustainable improvement of pipe network is one of our goals in this research.

4.4 Major tasks in Kuala Lumpur:

- Evaluate condition assessment of pipe network in (pilot area)
- Provide Predictability and Preventability Indices.
- Provide pipe rehabilitation scenarios that have a high predictability index and a low preventability index.

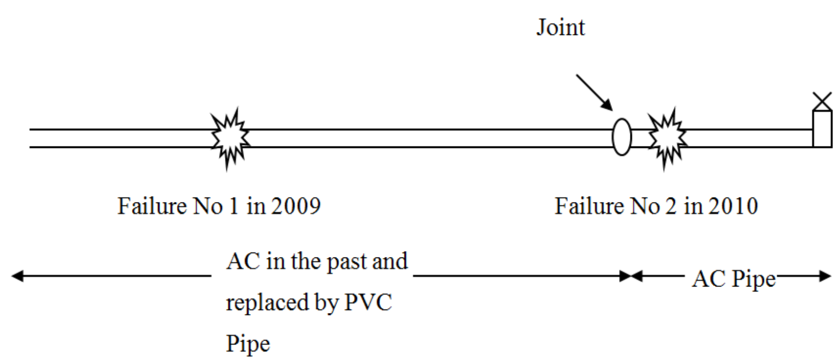
- Prioritize the most important factors of pipe failures.
- Building the foundation of condition inventory system.
- Facilitating strategic planning.
- Analysis of contributing factors for pipes deterioration AC pipes in specific and rehabilitation alternatives:
    - Pipe age
    - Climate (Rainfall effects on clay soils)
    - Break clustering

4.5 Data collection

Water network database have been collected from Syabas Company (Kuala Lumpur Water Company). Pipe samples have been collected from field in pilot area. Database in Kuala Lumpur is built based on GIS as inventory data. The following figures shows sample for pipe collection during field visit. These samples are used in next chapters to achieve condition assessment for pipes. Table (4-2) shows some field investigation for AC pipe failures and figure (4-3) shows some samples for pipe failures in Kuala Lumpur

Table (4-2) AC pipe sample investigation

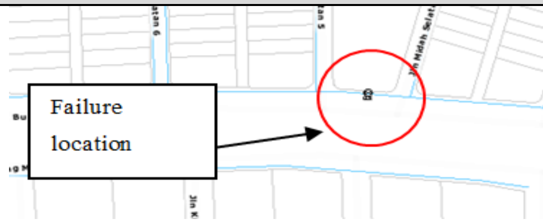
Case # 1	
Specification	**Detail**
Burst Date	28 Jun 2010
Pipe diameter	150mm
Pipe length	29m
Sample of pipe line sketch	



This failure is the second in one year in the same line.

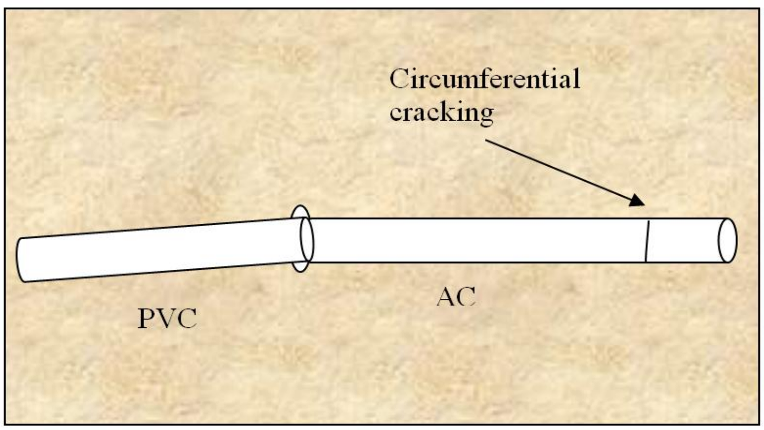
Decisions: The pipe replacement is the best solution for whole pipeline since there are two connection in short distance.

Case # 2



Specification	Detail
Pipe material:	AC
Pipe diameter: Location:	150 mm
Soil:	Jalan 3/105
Pipe depth	Clay
	1.3 m

Sample of pipe line sketch



There was failure before one month in the same line due to bending forces applied to the pipe. According to the field investigation, the backfilling was containing some of big rocks. This increase the probability of pipe failures occurrence due of bending forces. In addition, the pipe alignment is not correct which also increase the probability of failures in the future.

Decisions: Due to high rate of failures in this pipeline, the pipe replacement is the best solution for whole pipeline.

Joint failure

Failurte due to high water pressure

Replacement of AC pipe with PVC

Longitudinal failure due high pressure

AC pipe failure

Longitudinal failure

Failure Location

Failure of AC pipe surrounding by roots

Repairing failure

Joint failure of AC pipe

Joint failure

Vertical failure

Failure location

Removing water leakage from location of failure

Figure (4-3) Pipe failure samples from Kuala Lumpur

4.6 Selection of Pilot Project Area

Selection of Pilot Area will depend on several criteria as pipe history and conditions, No. of failures in the past, supply types, soil types, corrosion reasons, importance of the location, high water leakage, number of pipe failures and pipe age. Figure (4-4) shows location of pilot area.

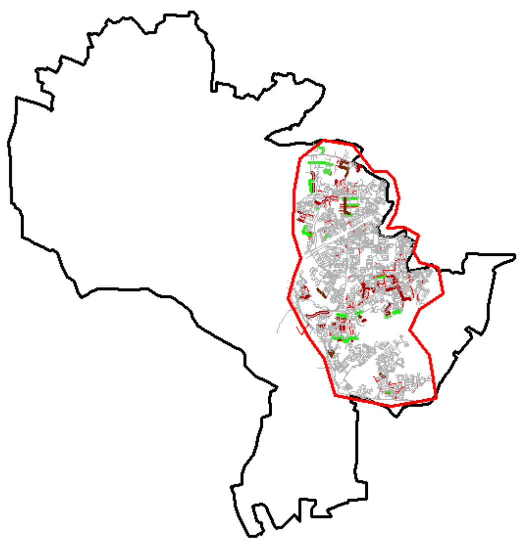


Figure (4-4) location of pilot area

4.7 Works Preparation

- Data analysis of water distribution network in Kuala Lumpur (KL)
  - Physical data for pilot area (population, demands, topography, supply arrangements, mains length, number of service connections, customer meter location, average pressure)
  - Drawings and records, billing data for selected area.

    - Measurements or estimates of system input volumes.
    - Estimates of authorised and unauthorised consumption estimates of non-revenue water components techniques and equipment.
    - Revision of Repair programme.
- General failure analysis of pipeline in KL.
- Analysis of current rehabilitation of pipeline in KL.
- The history of NRW reducing measures.
- Field visits
  Field visits have been done for many of pipe failure locations.
    - To appraise current practice of pipe rehabilitation in KL.
    - To have required pipe samples for pipeline failure in different location.
    - To identify and analyse factors of pipe deterioration.
- Analysing the decision making of rehabilitation and maintenance of pipeline.
    - Cost Analysis of life cycle of pipeline according the pipe assessment condition.
    - Improve the decisions of pipeline rehabilitation.
- Building the bases for the main structure points of GIS-Decision Support system
- Overview of pipeline inspection system

4.8 System Outputs:

- Preparing the technical condition assessment model for water network.
- Building of GIS-Decision Support System for Rehabilitation planning of water Network

4.9 Future success Indicators:

Future success indicators for our research project will be as following points:

1- Decreasing the pipe failures in water network according the condition assessment in the pilot area.
2- Decreasing the maintenance and rehabilitation cost using the Geospatial Decision support system.
3- Reducing the NRW in water network for the pilot area caused by physical losses.

4.10 Rehabilitation planning options

Several criteria should be considered to make the best selection of pipe rehabilitations scenario such as budget and current condition of networks. Based on these criteria the decision can be more suitable to improve the water network. Figure (4.5) shows some of rehabilitation options. Replacement strategy can be the best solution technically but not economic solution.

In addition, we can identify that repairing strategy will not improve the condition of pipes. The bad condition network will be continue with this condition after repairing some pipes since this is just temporary solution. Figure (4.6) shows also comparison for rehabilitation options and relationship with pipe condition.

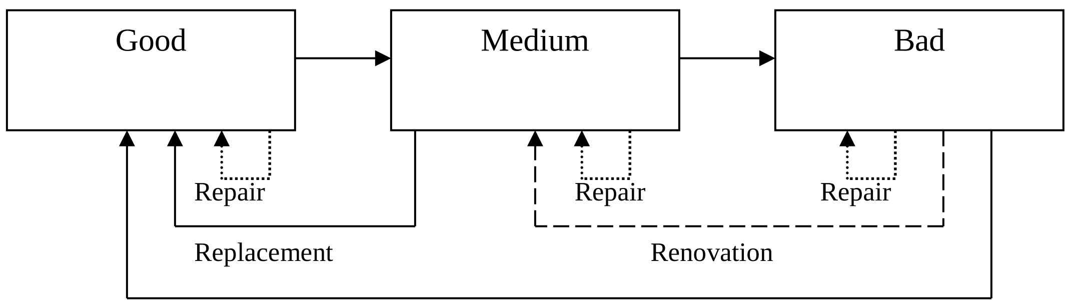


Figure (4-5) Rehabilitation options

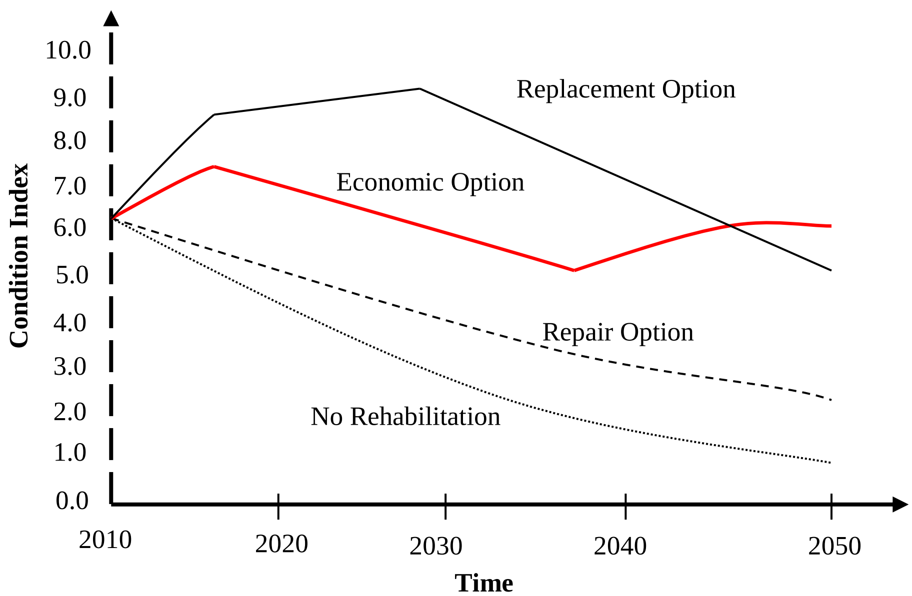


Figure (4-6) Comparison between rehabilitation options

4.11 Overall methodology of work plan

A summary of the overall methodology used in the condition assessment process is summarized in figure (4-7).

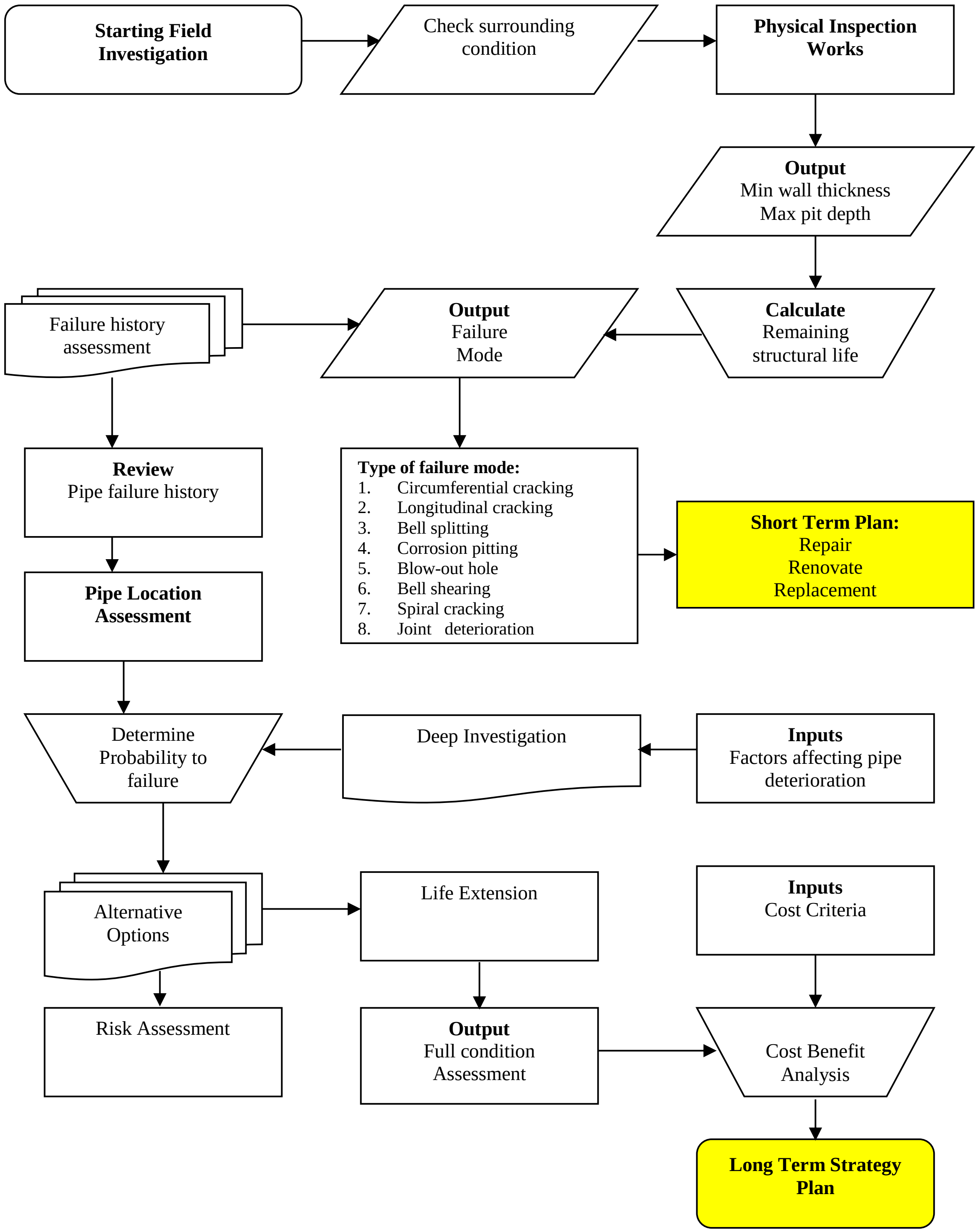


Figure (4-7) General methodology used in condition assessment process

Chapter 5

5 Analysis of Water Pipe Failures in Kuala Lumpur using Generalized Linear Model

5.1 ABSTRACT

Several models have been developed in the last years to assess the condition of water networks. Most of these models are based on a database with high quality but which are not applicable in many countries even in developed countries.

In this work, the Kuala Lumpur case, representing semi-developed countries, has been used to develop a new approach to improve the water network under crucial conditions. Kuala Lumpur (KL) is experiencing water losses at about 40% and high failure rates, which cause severe problems. This case can be a representative case for other South Asian countries and others.

Kuala Lumpur faced big challenges to reduce the water losses in the water network during the last five years. One of these challenges is to avoid the high deterioration of Asbestos Cement (AC) pipes. Kuala Lumpur has more than 6,500 km of AC pipes need to be replaced according to decision makers in Syabas Company (Kuala Lumpur Water Company).

This research presents a new approach for a geo-statistical model determining pipe failures in a water distribution network under crucial conditions.

Statistical methods which are appropriate to determine pipe failures are described, and these methods are applied in a case study using the water network database of Syabas Company.

The Geo-statistical model have been calibrated, verified and used to predict failures for both networks and individual pipes. Covariates which have a significant influence on the rate of occurrence of failures are documented.

A methodology was developed to analyze pipe conditions based on the data resulting from the probability of pipe. The likelihood of failures at a given pipe is estimated and coupled with the predicted number of pipe breaks as surrogates for pipe condition. These condition indices support decisions regarding replacement planning and can be coupled with economic assessment models in the development of future asset management strategies.

This research aims to make contribution in improving the prediction of pipe failures in water networks using Geographic Information System (GIS) and Generalized Linear Model (GLM).

Keywords: Failure Analysis, GIS, Geo-statistical model, AC pipes. GLM

5.2 Introduction

In this research, a methodology has been developed to evaluate the statistical and probability of pipe failure using Generalized linear model (GLM). The GLM has been developed for the water pipes of interest in Kuala Lumpur utilizing the survival data of the pipes, such as pipe characteristics and information on the installation conditions. The assumption of the GLM for the model has been validated, and the goodness-of-fit of the model was verified based on the analysis of model residuals.

The relationship between failure rates and pipe age have been discussed in several researches such as Shamir and Howard (1979), Walski & Wade (1987), Clark et al. (1982) and Malandain et al. (1999) and Andreou et al. (1987), .

5.3 Case Study description

Malaysian State of Selangor in 1997 faced a serious water crisis which caused by the El Niño weather phenomenon. This water crisis encouraged the Malaysian government to start to find solution to decrease the high NRW rate. Water utility in Malaysia estimated about 40 percent of the water produced was not invoiced, with leakage estimated at 25 percent, or around half a million m3 /day. Decreasing physical losses amount would provide sufficient water to serve the equivalent of 1.5 million people and then avoid the water shortage in Kuala Lumpur (Kingdom, 2006), (Syabas, 2010). Figure (5-1) shows the location of Kuala Lumpur case study. This research provides an analysis for the actual water network failures using generalized linear model.

Figure (5-1) Kuala Lumpur location

5.4 Methodology & Data Preparation

The main methodology in this section based on spatial analysis using GIS techniques. Figure (5-2) shows the flowchart of the methodology.

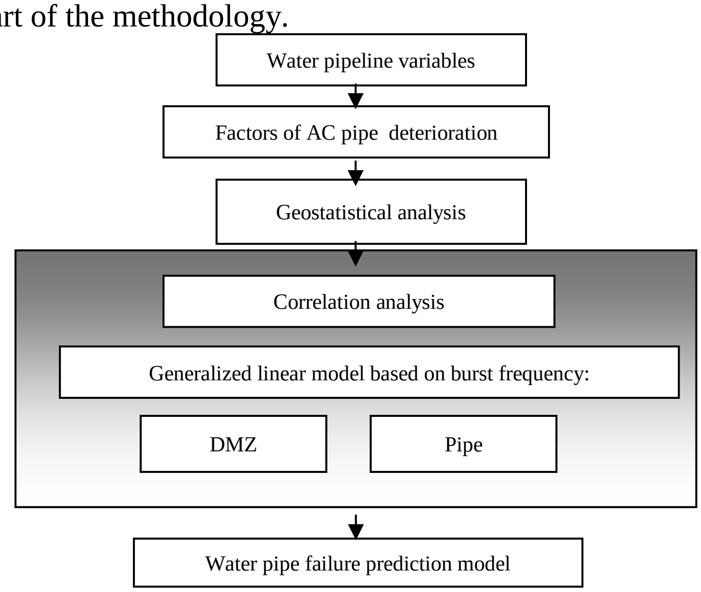


Figure (5-2) Flowchart of the methodology

Pilot area has been selected in Kuala Lumpur based on high rate of pipe failure and existing of DMZs. The area of pilot zone is about 40 km^2 and the total pipe length is 680 Km^2 with 612 pipe failure excluding pipe leaks.

The data in this case study were available at the pipe level and DMZ's for the period 2006–2010 and contains both asset information and recorded bursts and leaks. For each individual pipe, the database contains information on pipe diameter, material, year of the burst, length, number of properties supplied and the total number of bursts recorded during the 5 years. Furthermore, the number of bursts is known for each district meter zone. However, the water network is available for about 30% of Kuala Lumpur city. Geographical Information Systems (GIS) has been used to display and manipulate the pipe and burst database. Figure (5-3) shows a graphical representation of bursts and its location relative to a water networks.

Covariates

covariates that could have an influence on the rate of occurrence of failures should be included in the statistical models. Variables included in the analysis are as following Table (5-1):

Table (5-1) Analysis Covariates

Factor	**Description**
Length (L)	The length of the pipe (in *m*)
Diameter (D)	Diameter of the pipe in *mm*.
NPF:	The Number Of Previous Failures (NPF) of the pipe.
Pressure: (P)	Water pressure in main pipe
Intercept (α):	The interception parameter (α) for the GLM estimated by SPSS.
DMZ	District Meter Zone , if burst within DMZ =1; if not DMZ=0
Connection density	Connection density per pipe km
Flow (F)	Water Flow
MNF	Minimum night flow
Leak No	Number of leaks
Scale (ß):	The scale parameter (ß) for the GLM estimated by SPSS.

5.5 Regression Analysis:

Regression analysis can be used as statistical tool to discover relationships between variables, which used in prediction models. The goal of regression analysis based on (Berenson et al, 2002) and Longinu M (1999) is to develop a statistical model that can be used to predict the values of dependent variable or response variable based on the values of at least on explanatory variable or independent variable. The relationship between the variables based on the coefficient sign show an indication for the nature of the relation if increasing or decreasing relationship Longinu M (1999).

In this research, the generalized linear model has been applied to analyze the relationship between variables of pipe network and pipe failures using (SPSS Software).

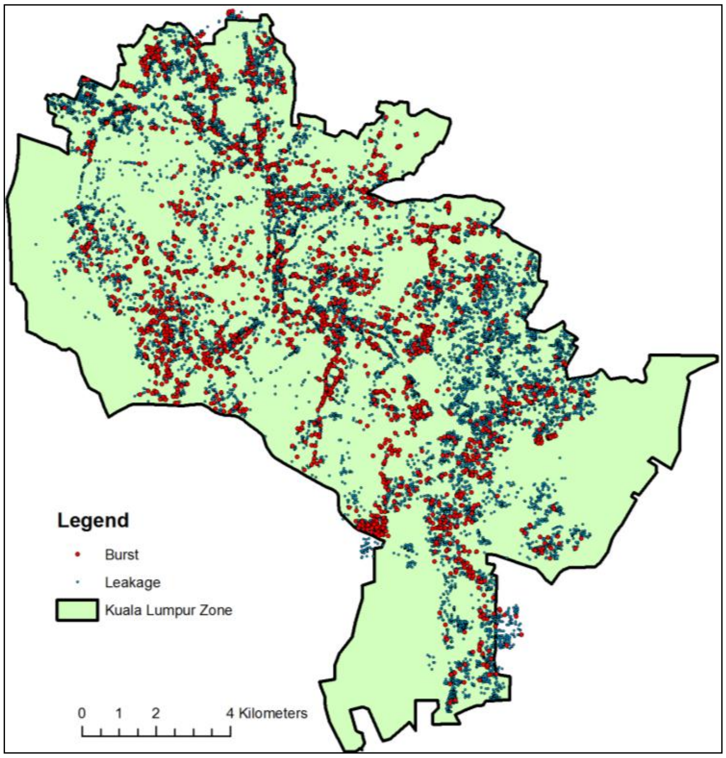


Figure (5-3) Pipe bursts and leaks in Kuala Lumpur

5.5.1 Correlation and Regression Analysis

Bivariate correlation analysis has been applied between pairs of variables of pipe failure database to identify trends in break patterns and relations among variables that could help in construction of the model (SPSS, 2012).

The Pearsons correlation has been calculated for several variables; number of failures, pipe length and diameter. The results of correlations are shown in table (5-2) between pipe length and number of pipe failures.

The Pearson correlation coefficient measures the linear association between two scale variables.

Table (5-2) Correlation among covariates

Correlations		Number of Failure	Pipe Length
Number of Failure	Pearson Correlation	1	.276**
Pipe Length	Pearson Correlation	**.276****	1

**Correlation is significant at the 0.01 level (2-tailed).

Smith (1994) has developed guideline for the interpretation of correlation coefficient as following interpretation for values of R^2 between 0 and 1 in Table (5-3).

Table (5-3) Interpretation of Correlation coefficient

Correlation coefficient	**Interpretation of correlation**
$R^2 > 0.8$	Strong correlation
$0.2 < R^2 < 0.8$	Correlation exists
$R^2 < 0.2$	Weak correlation

From Table (5-4) we could also identify that there is a relationship between pipe diameter and number of failure. We can identify that there is a strong correlation between number of failures and pipe diameter with R^2 equal 0.65.

Table (5-4) Relationship between length of pipe and Number of failure

Correlations		Diameter	No of Failure
Diameter	Pearson Correlation	1	-.651*
No of Failures	Pearson Correlation	-.651*	1

*. Correlation is significant at the 0.05 level (2-tailed).

It is obvious that there is correlation between number of failures and pipe length, which it is positive relation.

Figure (5-4) shows the Pipe length frequency in pilot area and table (5-5) shows the pipe diameter frequency for Mild steel, and AC pipes.

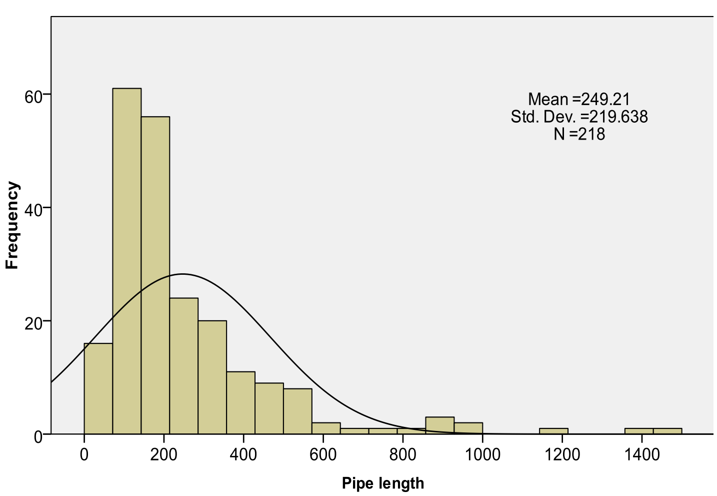


Figure (5-4) Pipe length frequency

	Frequency	%	Frequency	%
	MS		AC	
75	5	1.5	46	1.2
100	66	19.6	1441	38.5
150	83	24.7	1482	39.6
200	53	15.8	466	12.4
250	34	10.1	172	4.6
300	19	5.7	91	2.4
375	14	4.2	26	.7
450	17	5.1	2	.1
525	3	.9	9	.2
600	41	12.2	7	.2
950	1	.3	46	1.2

Table (5-5) Pipe diameter frequency for MS and AC pipes

5.6 Generalized linear model

Generalized Linear Model (GLZ) is a linear model specifies the linear relationship between a dependent variable, and predictor variables (Mu sigma, 2012)

YAMIJALA S (2007) has applied application of generalized linear model for pipe failure taking into consideration several variables. A Poisson GLM is a model commonly used for regression analysis of count data such as failures in an infrastructure system (YAMIJALA S, 2007).
Lindsey (2007) classified the GLM to three components; response Distribution or \Error structure, linear predictor and link function.
The GLM used in this analysis is of the form shown in equation

$$P(Y = y|x) = e^{\mu}\frac{\mu^{y}}{y}$$

where

$\mu =$ E(Y | x)

where Y is the number of breaks to be predicted given the explanatory variables as explained before and β are the regression parameters to be estimated (Lindsey, 2007).

SPSS will be used as main software in GLM analysis in this research.

(Boxall, et al , 2007) used considered pipe diameter , pipe length and pipe ages formulations for developing prediction function using GLM. In our research we used in addition of (Boxall, et al, 2007) variables, water flow, connection density CD and availability of DMZ. We considered the following function for developing the model λ (D, L, MNF, DMZ, CD and M).
We considered that the burst rate is non-negative, to produce a non-negative value for all possible variables (Boxall, et al , 2007). Based on that the failure prediction model of λ (D, L, P, DMZ, and M) = log λ (D, L, MNF, DMZ,CD, and M), this expresses the 'logarithmic link function' in our GLM.
The GLM has been expressed as a linear combination of terms involving the explanatory variables (Boxall, et al, 2007) , and coefficient is estimated from available data producing the following form:

γ(D, L, etc) = $\alpha + \beta_D$ D + β_LL + β_P MNF + β_{CD} CD +$ß_{DMZ}$ DMZ

According to this model, the burst rate will be determined if increase or decrease based on diameter, length, pressure and DMZ availability to produce the appropriate relationship between variables.
According to our methodology, the analysis is based on two types. Firstly, the analysis is based on number of bursts and leaks into DMZ. Secondly, the analysis is based on individual pipes.

5.7 Result Analysis

5.7.1 Regression model based on DMZ

In this section, the regression model has been done based on DMZ to identify the effect of several parameters on increasing pipe failures within DMZ.

The dependent parameter in DMZ regression model is No of burst and covariates are available of DMZ, density of connection, pipe length, No. of connection, flow/liter/sec, Minimum night flow and No of leaks. Table (5-6) summarizes the data range for each parameter. Pearson chi-square has been used as the method for estimating the scale parameter. (SPSS, 2012). The regression model is developed using SPSS software (IBM) version 18.

Table (5-6) Variables Database

Information about variables						
		N	Min	Max	Mean	St. deviation
Dependent Variable	Burst per Km	42	.00	4.117	1.06E0	1.03
Covariate	DMZ area	42	7.9E4	2.16E6	4.53E5	3.68E5
	Density of Conn.	42	17.4	264.1	130.34	58.17
	Length	42	2.80	42.70	9.99	7.71
	No of conn	42	283	3278	1102.07	689.08
	Flow	42	1.3	53.1	9.13	9.68
	MNF	42	1.5	64.6	11.47	11.80
	Leak No	42	21	300	95.21	63.91

The goodness-of-fit statistics table provides measures that are useful for comparing competing models (SPSS, 2012), the Value/df for the deviance and Pearson Chi-Square statistics gives corresponding estimates for the scale parameter (SPSS, 2012). This value is **0.79**, which is near to 1.0 for a Poisson regression so the model is reasonable.

Table (5-7) Tests of Model effects

Goodness-of-Fit Statistics			
	Value	df	Value/df
Deviation	26.901	34	.791
Scaled deviance	42.000	34	
Pearson-Chi-Square	26.901	34	.791
Scaled Pearson-Chi-Square	42.000	34	
Log-Likelihood[a]	-50.239-		
Akaike-Informations-criterium (AIC)	118.479		

This table is output from SPSS process

There are a number of ways to assess the relative goodness of fit of different Poisson GLMs. One also Akaike Information Criterion (AIC) (Akaike, 1974) can be used to assess the goodness of fit of GLM. Minimizing the AIC yields a model that maximizes the log-likelihood with the minimum number of parameters (SPSS, 2012).

Furthermore, the leaks frequencies in DMZ give an indication of general pipe deterioration in DMZ .There is relationship between increasing of pipe leaks and increasing of pipe bursts.

Table (5-8) shows Parameter estimation of GLM model based on DMZ and Table (5-9) shows correlations between variables based on DMZ.

Positive coefficients indicate positive relationships between predictors and outcome, which means increasing of failure rates. On the other hand, negative sign of a coefficient indicated for decreasing relationship (SPSS, 2012).

Table (5-8) Parameter estimation based on DMZ

Parameter	Regressions coefficient B*
(Constant Term)	.86
DMZ Area	-4.47E-7
Connection density	.001
Length	-.033-
No of Connection	-.001-
Flow	.014
Leak No	.013
(scale)	.640[a]

*values with low coefficient can be neglected, this table is output of SPSS process

Table (5-9) Correlations between variables based on DMZ

Covariates	DMZ area	Connection No	Mains length	Density Con.	MNF	Leak No	Burst No
DMZ area	1	.400**	.652**	-.355-*	.722**	.594**	**.337***
No of conn	.400**	1	.461**	.332*	.550**	.662**	**.346***
Length	.652**	.461**	1	-.459-**	.485**	.443**	**.280**
Con. density	-.355-*	.332*	-.459-**	1	-.042-	.063	**-.079-**
MNF	.722**	.550**	.485**	-.042-	1	.538**	**.257**
Leak No	.594**	.662**	.443**	.063	.538**	1	**.588****
Burst No	.337*	.346*	.280	-.079-	.257	.588**	**1**

This table is output of SPSS process

5.7.2 Regression model based on individual pipes

In this section regression model has been achieved based on individual pipes. Data filtering has been done to pipes neglecting pipes with small lengths. The model is based on Poisson method, which gives accurate results.

The dependent variable is Number of failure. The covariates are Pipe diameter, Pipe length and MNF. Two additional factors have been used; Material and DMZ (Pipe within DMZ=1and Pipes out DMZ=0).

Table (5-10) shows the variable categories for Material and DMZ. It is clear the AC pipe is the main pipe material in pilot area in water network (about 80%) and more than 50% of pipe outside the DMZ areas.

Table (5-10) variable categories

Variable categories			
		N	**Percent**
Material	**AC**	7189	79.9%
	CI	7	0.1%
	DI	211	2.3%
	HDP	26	0.3%
	MS	1465	16.3%
	SS	4	0.1%
	UPVC	86	1.0%
	Total	8998	100.0%
DMZ	**0**	4692	52.1%
	1	4306	47.9%
	Total	8998	100.0%

Table (5-11) Variable ranges

Variables information						
		N*	Min	Max	Mean	St.dev
Dependent Variable	Burst No/ pipe	8998	0	17	.05	.450
Covariate	Diameter (mm)	8998	100	1050	200	114
	Length Pipe (m)	8998	10	3200	58	105
	MNF	8998	0	34.1	7.10	11.4

*(N = pipe number)

Table (5-12) Parameter estimation based on GLM model

Parameter	Regressions Coefficient B*
(Constant Term)	-28.225-
[material=	1.037
[material=AC	26.187
[material=CI	1.037
[material=DI	26.008
[material=HDP	27.322
[material=Mild Steel	-1.789-
[material=MS	20.637
[material=SS	1.142
[material=UPVC	0
[DMZ=0]	0.185
[DMZ=1]	0
Diameter	-0.008
Length	0.004
Connection density (CD)	-0.005
MNF	0.033

*values with low coefficient can be neglected in the model. This table is output of SPSS process

5.8 Presenting Regression Results

All covariates in the model are significant. Pipe length has a negative effect on the inter-failure time. Pipe diameter is only significant for pipes with no previous failures .A larger pipe diameter prolongs the time to the first failure. Pipes that have been in service for many years are less likely to fail than pipes that are recently installed. The previous number of failures (NPF) has an important positive effect on failure probability. The failure increases with increasing number of previous failures. We have no information of soil type for each pipe

There is increasing in pipe failure in non DMZ areas and slightly increasing indication with increasing the MNF. The main advantage of this model approach is that it is simple to be used by water utilities. The model also can be modified to add more criteria according to available data on water pipes. This can be an important tool used by decision makers in water utilities. Table (5-12) shows parameter estimation based on GLM model.

5.9 Discussion of contributing factors of pipe failure

Number of Previous Failure NOPF

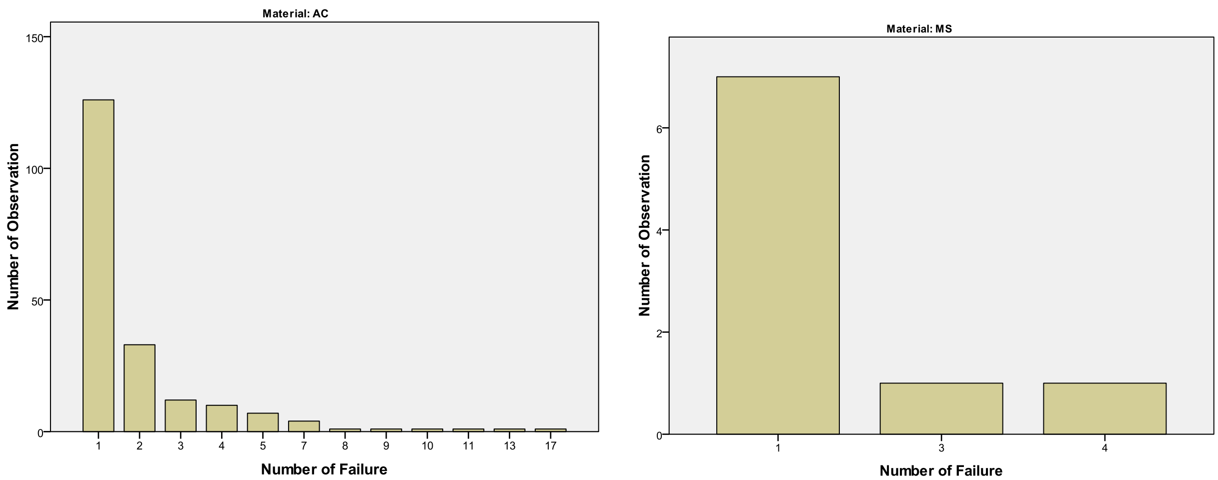


Figure (5-5) Number of observation based on Failure frequency in each pipe

We identified that about 130 pipes were failed just one time for AC pipes however there are about 40 pipes were failed two times. More detailed about distance and time between failures will be discussed in next chapter. Figure (5-5) shows number of observation based on failure frequency in each pipe

Pipe Length

According to regression analysis, there is a positive relation between pipe length and increasing of pipe failure. Firstly, in AC pipes it is obvious that there is one failure within pipe length of 10m and 500m and two failures within pipe length of 50m and 300m. Secondly, in Mild steel the database is not enough to determine the relation of pipe failure and pipe length Figure (5-6) shows number of observation failures based on pipe length.

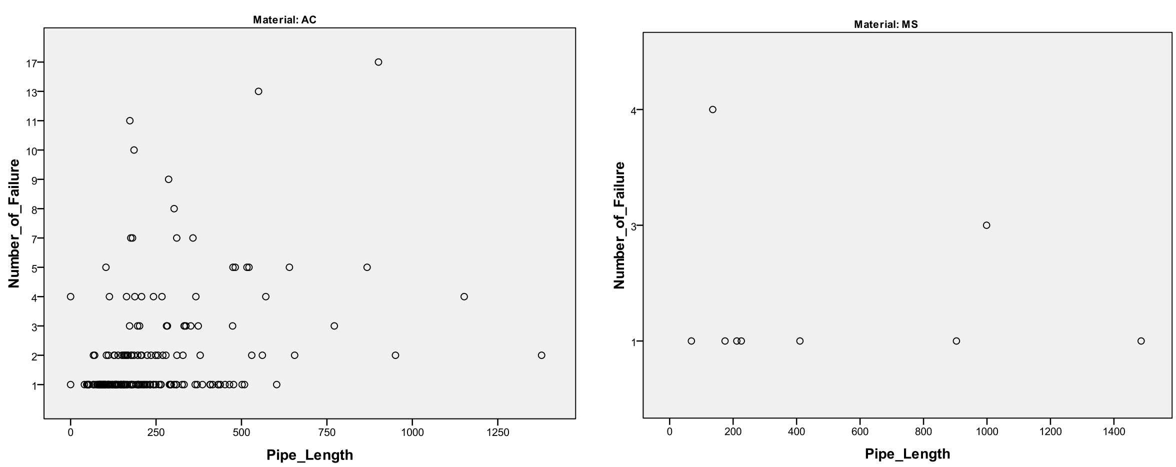


Figure (5-6) Number of observation failures based on pipe length

Diameter
Failure rates of smaller diameter are shown with high failure rates by previous studies (Walski et al, 1986, Kettler and Goulter, 1985 and Shamir and Howard (1979). In our GLM model, the approach show also increasing in pipe failures with smaller pipe diameters.

Material
Pipe materials have significantly changed along the years but it is often not available. Pipes are expecting to behave in different failure modes depending on material specifications.

Material strength characteristics define the ability of a given pipe to resist the loads to which it is exposed. In Kuala Lumpur AC pipes is the main pipe material, which has the highest pipe failure rate in water network.

Depth of pipe
Unfortunately, the data of pipe depth is not available. However, some records have been found from the field visits to pipe failure location.

In Kuala Lumpur, the pipe depth varies from 1.5 m to 2 m. this depends on pipe diameter and traffic loads. The minimum pipe depth in our pilot area is about 1.3 m.

Pipe depth is one element of consequence of failure. Harlow K (2010) explained that deep pipes are more critical than shallow pipes because the cost of failure is higher.

Water Pressure:
Pressure management of water network is the main factors to control the pipe failures in Kuala Lumpur. Water pipelines in higher-pressure zones are more likely to have a failure. Also the pressure in water pipes varies widely throughout the day and night, as people use more or less water (Syabas, 2010).

5.10 Conclusions:

The GLM model developed for failure frequency in Kuala Lumpur was based on different pipeline characteristics, reflecting several factors such as pipe diameter, length, pressure and failure history. This approach ensures that all data throughout the network is used in the most efficient way possible. More generally, it was shown that GLM statistical methodology is well suited to engineering type problems and its use should be actively encouraged.

Pipe deterioration model in individual pipes and DMZ has been derived from the GLM model and the methodology on how to use such a model to support asset management decision-making is presented. Contributing factors of pipe deterioration has also been discussed based on recent researches.

This research presents a new approach in using of generalized linear model to estimate pipe failures based on limited data available in water utilities. This model is applied for water network based on individual pipes and district meter zones. Many of water utilities have low data about each pipe in water network. Because of that, we applied this model to estimate water pipe failures also based on district meter zones. This model also can be modified to add new variables based on available data in water utilities.

Chapter 6

6 Spatial and temporal clustering analysis of drinking water network pipe failures

6.1 Summary

Although the spatial and temporal scale of pipe failure impacts are an important concern, analyzing pipe failures interactions is hindered by the quality of available data. This research presents a novel approach that aims to analyze spatial data to evaluate the water network reliability and to analyze the temporal data of failures. This analysis addresses how varying temporal and spatial resolution changes the water pipeline reliability value. A spatial and correlation analysis is used to determine the temporal and spatial scale.

We employed ArcGIS10 software to analyze the data. Water pipe failure database provided from the Syabas Company (Kuala Lumpur Water Company). Database covers the pipe failures from 2006 and 2010. This proposed approach is described and tested in a data set that consists of about 2500 breaks that occurred over four years in a 2500 km of main water supply network in Kuala Lumpur. Advanced geo-statistical and spatial analysis techniques in ArcGIS 10 have been used to present the failure clustering and relationship between distance and temporal intervals between failures. prediction maps have been created from pipe failures using the kriging tools in ArcGIS.

The spatial-temporal database has been provided for pipe failure in Kuala Lumpur. We use advanced application of spatial analysis to evaluate the occurrence of spatial clustering in the cases using different temporal windows. Spatial clustering of pipe failures was detected at different temporal and spatial scales.

The results presented in this research indicate that the there is a relation between spatial and temporal interval between failures especially for AC pipes. According to statistical spatial analysis, the pipe failures in Kuala Lumpur expected to be occurred in clusters. Also this research presents the importance of clustering to understand the factors contributing in pipe failures. Furthermore, the research presents the technical implication of our approach results. The technical department can make the accurate decisions based on clustering of database. It is clear that the main failures are in AC pipes with diameter 100mm. Pressure management using District Meter Zone (DMZ) has no actual effects to reduce the pipe failures due to high deterioration of AC pipes. Water pressure management is temporary solution to reduce pipe failure. According the long-term plan, the sustainable improvement of water network become more effective in the schedule of pipe replacement of AC pipes.

Keywords: Failure Analysis, GIS, Geo-statistical model, AC pipes.

6.2 Introduction:

The main objectives of the research presented here are (a) to provide the methodology for pipe failure assessment taking into consideration the spatial and temporal variability of various objective and subjective uncertainties in water network management, and (b) to provide a methodology of pipe failure clustering and its importance in decision support system using GIS techniques.

6.3 State of knowledge

Several studies have been conducted in spatial and temporal analysis models such as Goulter and Kazemi (1988). Yamada et al. (2010) presented that spatially distributed clustering is an important due it can clarify pattern characteristics and background processes. (Stone et al, 2002) also presented the importance of spatial analysis techniques in rehabilitation planning based on geographic clustering of pipe failures. Oliveira et al., (2010) presented an approach: hierarchical density-based clustering applied to point events constrained by a network. He described the performing spatial density- based clustering of break point events constrained by a network.

In addition, there is some researches addressed clustering of events such as. Sugihara et al., (2009) who proposed computational methods for the point cluster analysis on a network without addressing locally weighted clustering issues. Yiu & Mamoulis, (2004) proposed approaches to both compact and connected clusters and discuss the use of shortest path network distances for partition, hierarchical and density clustering.

6.4 Methodology:

The research consists of two sections; first section describes the spatial clustering based on advanced applications of geostatistical Analysis of pipe failure in Kuala Lumpur using GIS techniques. This includes which includes Average Nearest Neighbor Distance (ANND) tool in ArcGIS. Second section describes the spatial analysis of pipe failure based on distance and temporal interval between failures. Figure (6-1) shows the structure of our research in this chapter.

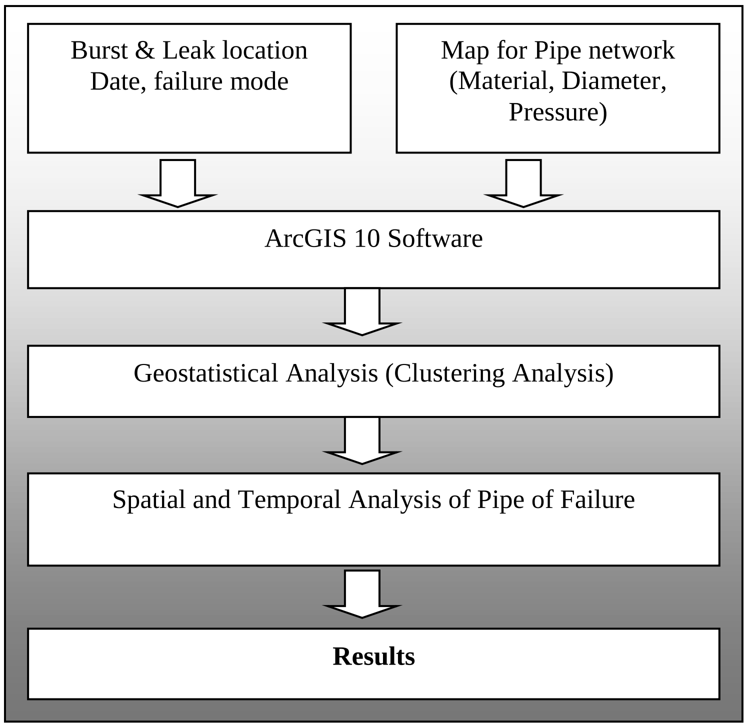


Figure (6-1) Research structure

Our goal in this research is to describe the spatial pattern of water pipe failure across the study area of Kuala Lumpur and to explain why clustered responses occur in specific locations. We test the following hypotheses. Firstly, the pipe failures are spatially correlated with temporal analysis in Kuala Lumpur. Secondly, there is special characteristic response of the pipe failure clusters and if it is significantly different from the rest of the study area.

6.5 Spatial clustering based on advanced applications of Geostatistical Analysis

ArcGIS software has been used to analyze the spatial clustering of pipe failures to understand the influence factors of pipe failures for each cluster.

This section aims to compare the information provided by the definition of (non-spatial) groups of pipes with similar diameter and material to the information provided by spatial clusters of pipes.

Zeitouni K (2010) defined Geostatistics as a tool used for spatial analysis and for the prediction of spatio-temporal phenomena. In this research, Geostatistics has been used to analyze location of pipe failure based on "kriging" technique.

Figure (6-2) shows a sample of the dataset for clusters analysis. This section provide an approach to spatial data clustering of networked infrastructure failure data, which is presented and demonstrated by applying it to a drinking water pipe failures dataset of Kuala Lumpur database.

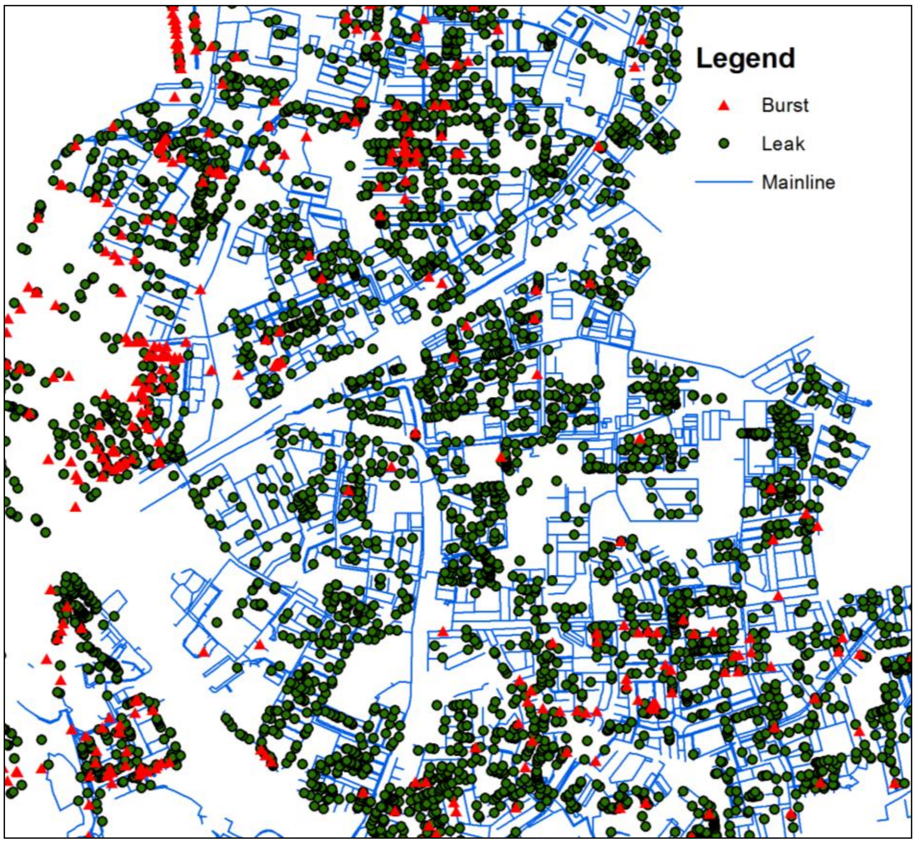
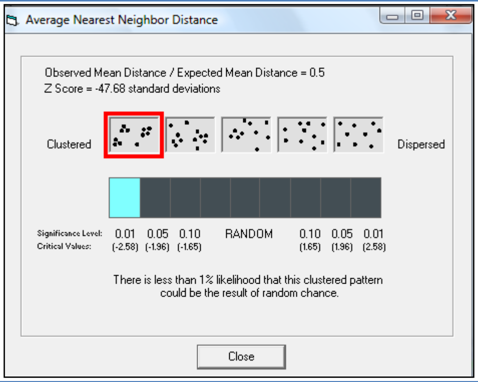


Figure (6-2) sample of the dataset for clusters analysis.

Average Nearest Neighbor

The Average Nearest Neighbor (ANN) tool is one of ArcGIS tools. ANN has been used in this research to measures distance between failure locations. Averages distance between nearest pipe failure are measured using of ArcGIS. Based on the average distance between failures, we found that pipe failures are clustered since average distance is less than hypothetical random distribution (ArcGIS, 2010).

Table (6-1) Average Nearest Neighbor results



Average Nearest Neighbor	Summary
Observed Mean Distance:	70,25
Expected Mean Distance:	141,12
Nearest Neighbor Ratio:	0,49
Z Score:	-47,68
p-value:	0,00

For our data case, table (6.1) which is produced from ArcGIS software shows that, the mean nearest neighbour distance (NND) is calculated as 70.25 meters based on ArcGIS generation. The expected mean NND is calculated as 141.12 meters. two values of observed and expected mean are compared using the normally distributed Z statistic. The Z value from the table (6-1) of the normal distribution is -47.68 which less than -1.96, and negative Z value indicates that a clustered pattern exists as clear in the figure in table (6-1) (ArcGIS 2010).

Clustering based on density distribution functions using Kernel Density for point features:

Kernel Density has been used based on (ArcGIS, 2010) to calculate the density pipe failures in all of Kuala Lumpur region. Figure (6-3) shows the failure density on Kuala Lumpur based on kernel density analysis and figure (6-4) shows the density of pipe leaks in Kuala Lumpur per km^2. Pipe leaks also are analyzed just for small diameter pipes while the leakage in main pipe is considered as failure according to Syabas company definition. Locations of high failures and leaks density rate are clear in the figures. The failure density increasing in the center of the city and the density of leaks is more increasing in the middle and north of Kuala Lumpur.

6.6 Correlation between spatial and temporal intervals of Pipe failures

Spatial-temporal data analysis plays an important role in many applications. Current practices in analyzing data with spatial and temporal components focus on pipe failures. In this research, we aim to develop an analysis approach that can assess spatial-temporal correlations among pipe material. In this section distance between failures have been analyzed using GIS techniques. We calculate the nearest distance between 3 failures using of Hawths_Analysis_Tools_for_ArcGIS9 (Hawth's, 2011).

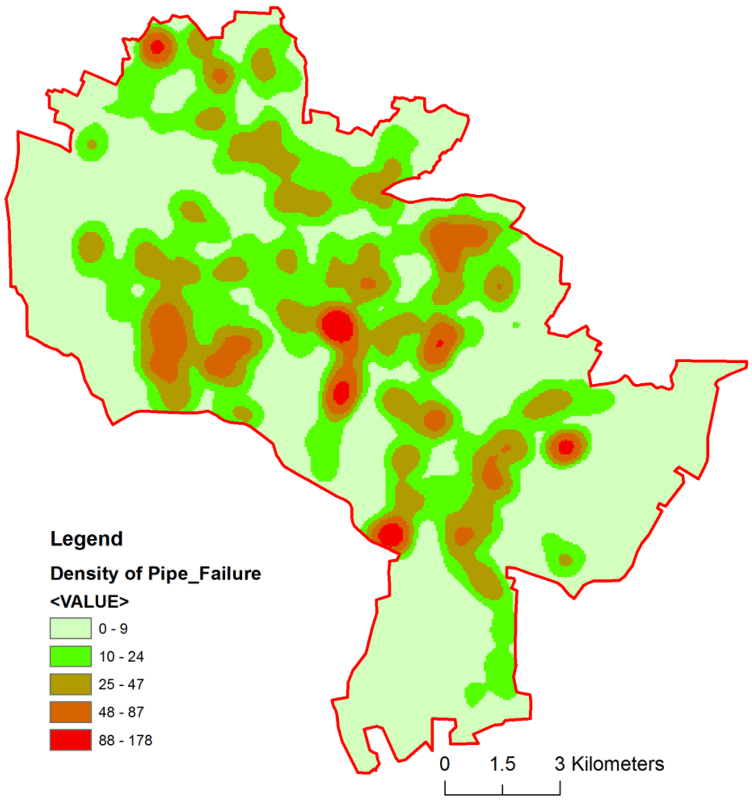


Figure (6-3) Pipe failure density per km^2

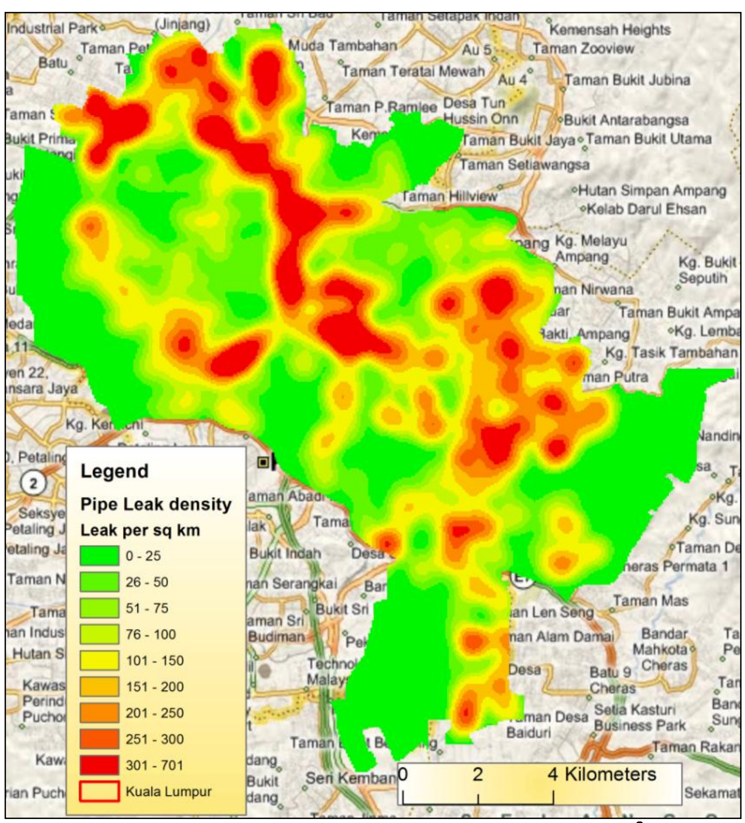


Figure (6-4) Density of pipe leaks per km^2

Figure (6-5) shows the concept of our analysis. This concept applied on about 2500 failures. We calculate the maximum, minimum and average of intervals distance between pipe failures. Table (6-2) shows the descriptive statistics of the pipe failures in Kuala Lumpur. The analysis has been limited on the pipe diameter 100mm and 600mm.

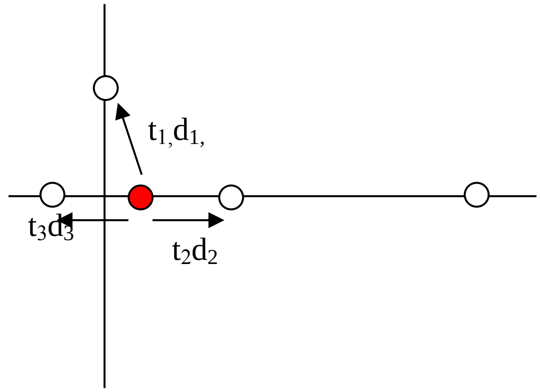


Figure (6-5) the methodology of distance calculation.

According to preliminary statistics of distance intervals, the minimum interval distance between failures is zero, which means that this failure has been repeated in the same location. The maximum distance between failures is 596m and the mean interval distance is 70m.

Table (6-2) Descriptive statistics of pipe failure

Descriptive Statistics	**N**	**Mean**	**Std. Deviation**	**Min**	**Max**	**Percentiles**		
						25th	**50th (Median)**	**75th**
Pipe diameter	2459			100	600	100	150	150
Distance Interval	2463	70.25	79.725	0	596	14.42	43.42	96.60
Temporal Interval	2463	251.78	241.871	0	1045	42.00	184.00	398

We used the Pearson's correlation to find a correlation between distance and time variables. Table (6-3) shows the Pearson's correlation, which it is about 0.2, which mean that there is a significant and fairly positive correlation between distance and temporal intervals between failures.

Table (6-3) Pearson's correlation between distance and temporal intervals within pipe failures

Correlations	Temporal Interval	Distance Interval
Temporal Interval	1	.209**
Distance Interval	.209**	1

**. Correlation is significant at the 0.01 level (2-tailed).

Relationship between temporal and distance intervals have been analyzed. Figure (6-6) shows the distribution of failure for all pipe material. Frequencies of pipe failures based on time and distance intervals based on pipe material and pipe diameter are shown in Appendix I.

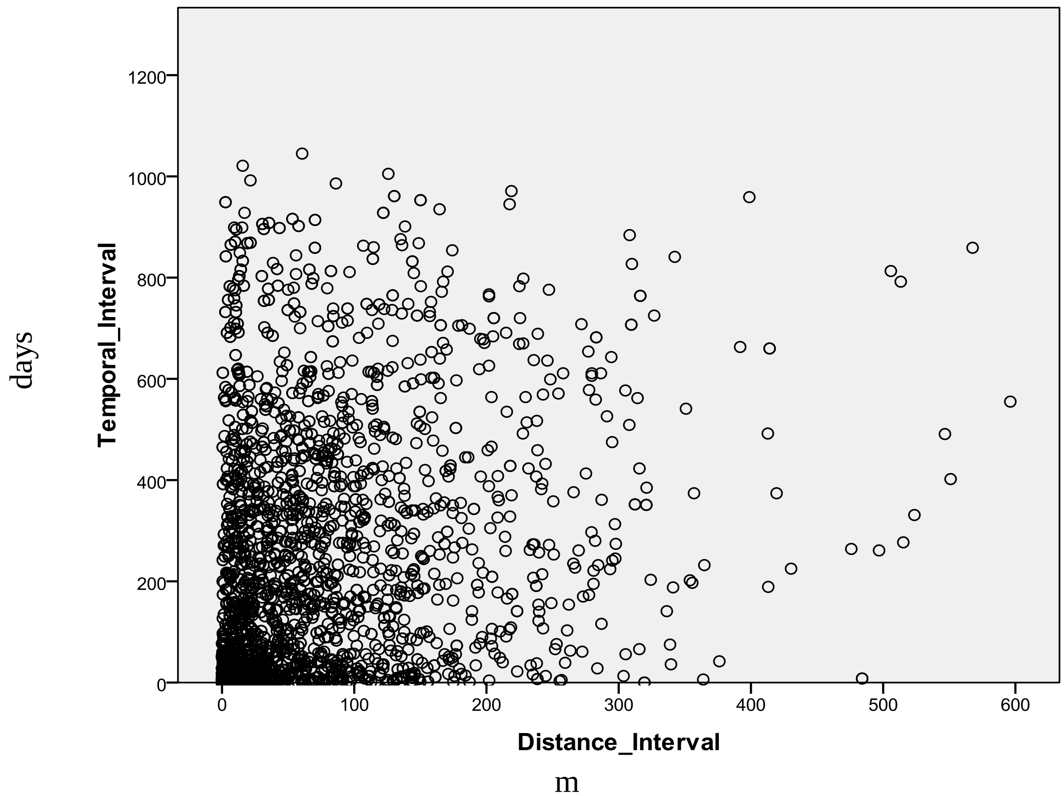


Figure (6-6) relationship between distance and temporal intervals for pipe failure in KL

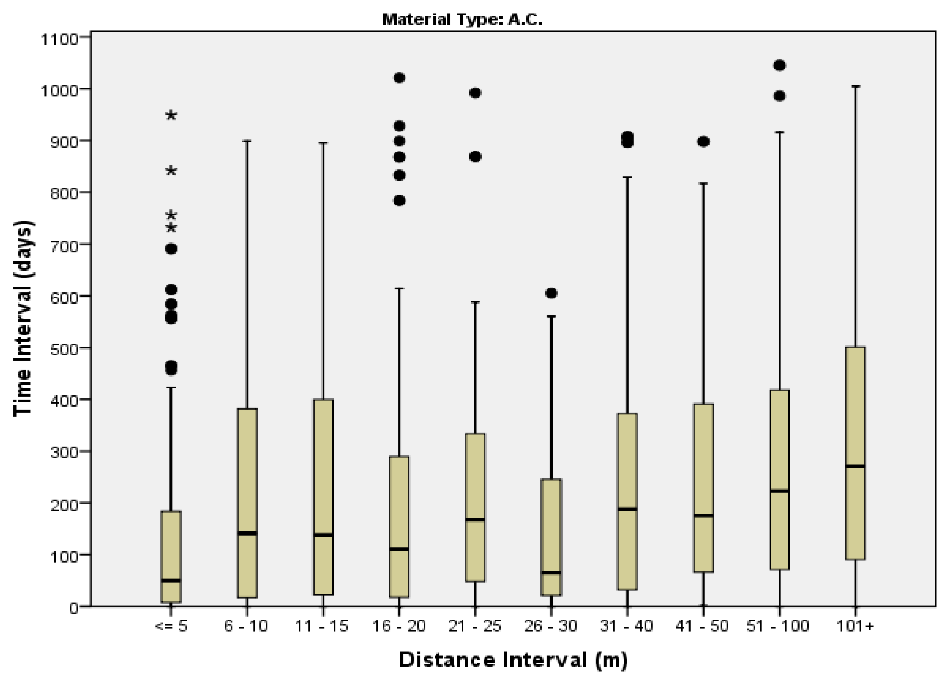


Figure (6-7) Box plot for the relation between distance and time interval between AC pipe failures

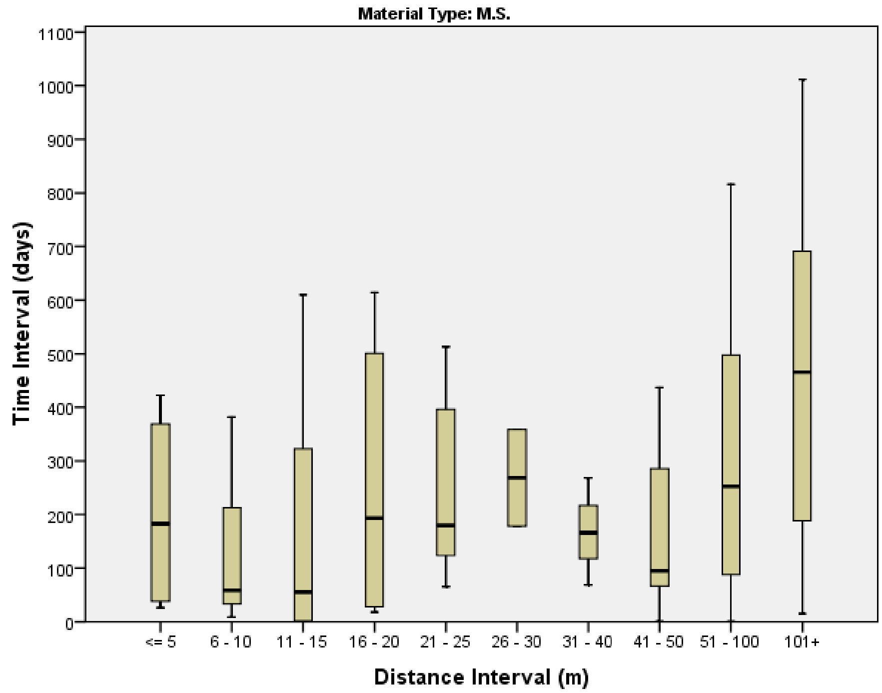


Figure (6-8) Box plot for the relation between distance and time interval between MS pipe failures

Table (6-4) Frequency tables of distance intervals between pipe failures based on uniform class intervals

Distance Intervals (m)		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	**<= 5**	**261**	**10,3**	**10,6**	**10,6**
	6 - 10	194	7,6	7,9	18,5
	11 - 15	174	6,8	7,1	25,5
	16 - 20	**160**	**6,3**	**6,5**	**32,0**
	21 - 25	115	4,5	4,7	36,7
	26 - 30	95	3,7	3,9	40,6
	31 - 40	178	7,0	7,2	47,8
	41 - 50	**153**	**6,0**	**6,2**	**54,0**
	51 - 100	542	21,3	22,0	76,0
	101+	591	23,2	24,0	100,0
	Total	2463	96,9	100,0	
Missing	System	80	3,1		
Total		2543	100,0		

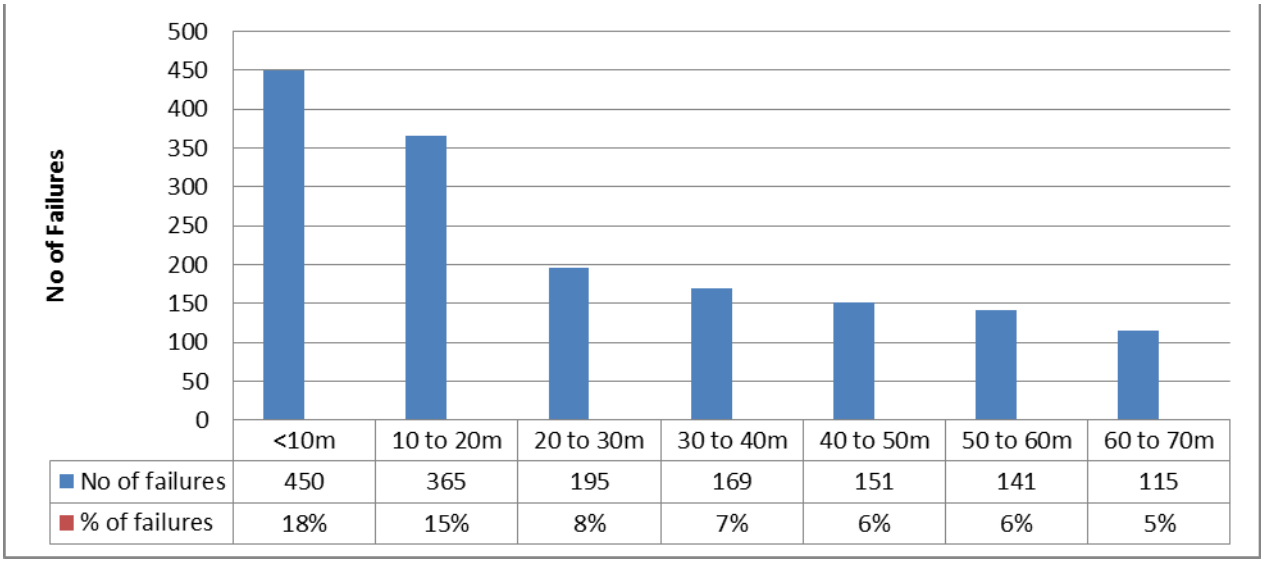


Figure (6-9) distance intervals between failures and failure frequencies

Table (6-5) Frequency table of time intervals between pipe failures based on uniform class intervals

Time interval (days)		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	0-5	259	10,3	10,5	10,5
	5-10	73	2,9	3,0	13,5
	10-15	65	2,6	2,6	16,1
	15-20	**56**	**2,2**	**2,3**	**18,4**
	20-50	214	8,5	8,7	27,1
	50-100	256	10,2	10,4	37,5
	100-200	368	14,7	14,9	52,4
	200+	1172	46,8	47,6	100,0
	Total	2463	98,4	100,0	
Missing	System	40	1,6		
Total		2503	100,0		

6.6.1 Explore the different parts of the boxplot:

Box plots are an important tool to illustrate location and variation changes between different clusters of intervals. By using of Box plot, the position of median in the data can be shown, (SPSS, 2012). Figure (6-7) and Figure (6-8) explain the time intervals between failures for AC pipes and MS pipes respectively. The dark line in the middle of the boxes is the median of time interval based on SPSS software analysis. The box is much shorter for AC pipes than for MS pipes in the range of less than 5 m. This is clear that time interval between failures varies less in AC pipes (0 and 190 days) than MS pipes (20 and 380 days). The T-bars of the boxes extend to 1.5 times the height of the box. The points are outliers. These are defined as values that do not fall in the inner fences. Outliers are extreme values. Stars are extreme outliers. These represent failures that have values more than several times the height of the boxes (SPSS, 2012).

We assume that pipe failure with distance interval less than 5 meters is repeated in the similar location of the last pipe failure. This distance may occur due to digitizing error of pipe failures in the GIS map. Table (6-4) and figure (6-9) show the frequency of distance intervals between pipe failures based on uniform class Intervals. It is clear that about 10% of pipe failures have been repeated in the same location. More than the 50% of neighbor pipe failures has distance interval less than 50 meter. This gives highlight about the high risk of repeated of pipe failure within this distance. This is used as an indicator for pipe deterioration.

Also time intervals have been analyzed based on the neighbor failure. It is clear from Table (6-5) that the time interval between failures is less than 20 days for about 20% of pipe failures. And more than 10 % of pipe failure occurs in less than 5 days between failures. This is also an additional indicator of time interval between neighbor failures (SPSS, 2012).

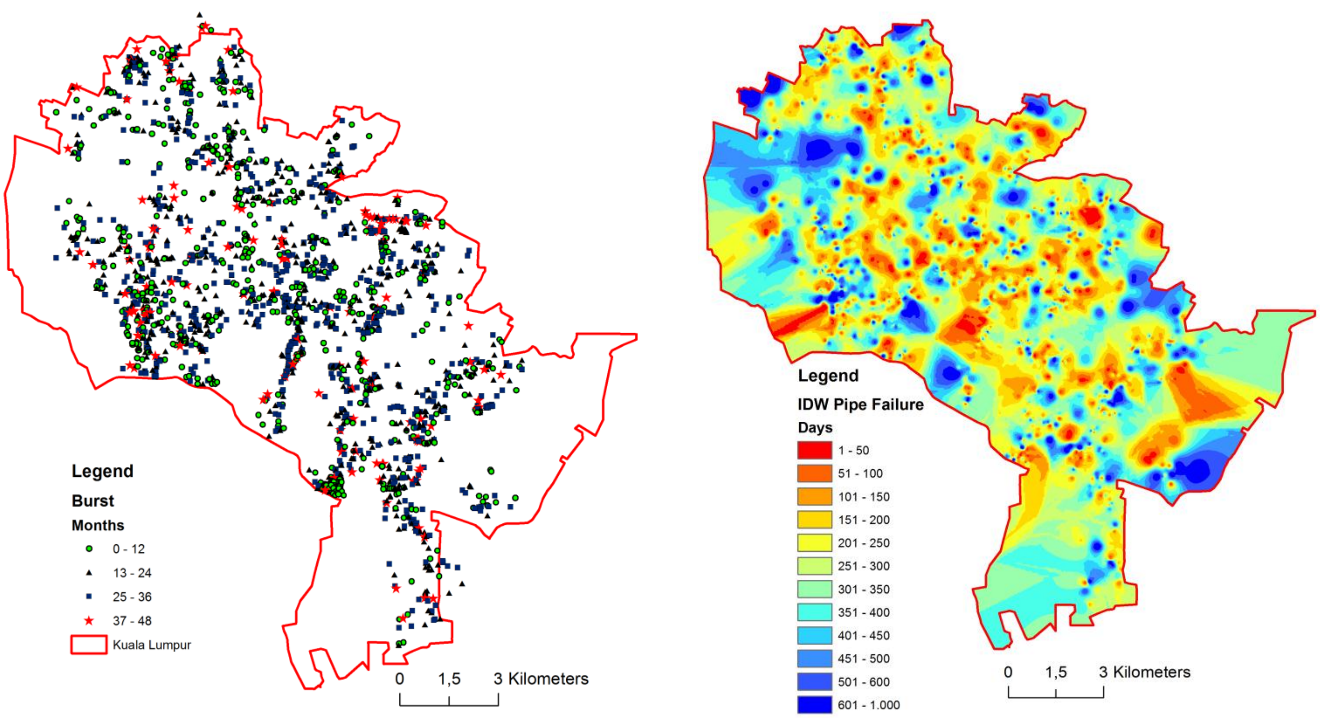


Figure (6-10) spatial analysis of pipe failure by temporal interval between failures based on Inverse Distance weight (IDW)

Spatial analysis has also been used to build a temporal map for pipe failure distribution. Figure (6-10) shows spatial analysis of pipe failure by temporal interval between failures based on Inverse Distance weight (IDW). This map shows the clustering of failures with shortest time intervals between failures. According to this map, the clustering of pipe failures with short time interval can be identified which gives an indicator of frequency of high failure rate.

6.7 Analysis of results and findings of the study

The condition of water pipes is influenced by a number of factors. These factors include the environmental variables and structural characteristics such as pipe diameter, wall thickness, and pipe material. External loads and rainfall and soil characteristics that influence the failure rate of pipes are generally similar for the pipes in a neighborhood. Spatial clustering of water pipes of a network results in homogeneous classes of pipes in terms of external deteriorating factors.
Several parameters affect external deterioration of AC pipes including the soil acidity and alkalinity (Liu Z, 2012). This section will present the analysis clustering and influence of some factors contributing with pipe deterioration based on spatial and temporal distribution.

Cluster assessment:

Spatial clustering results are analyzed in order to make focus on how spatial clusters can provide indication of pipe deterioration for decision maker.

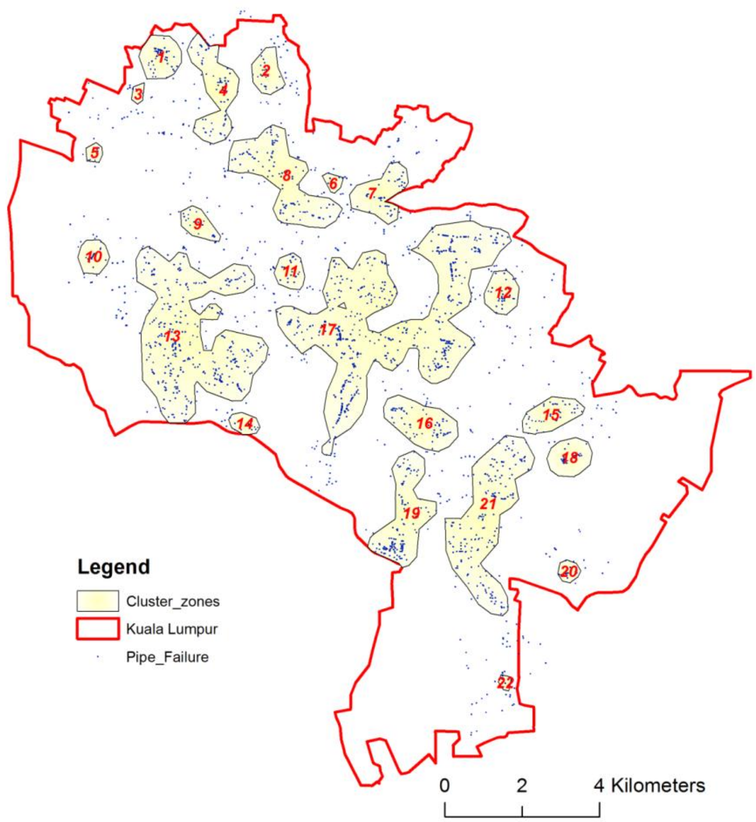
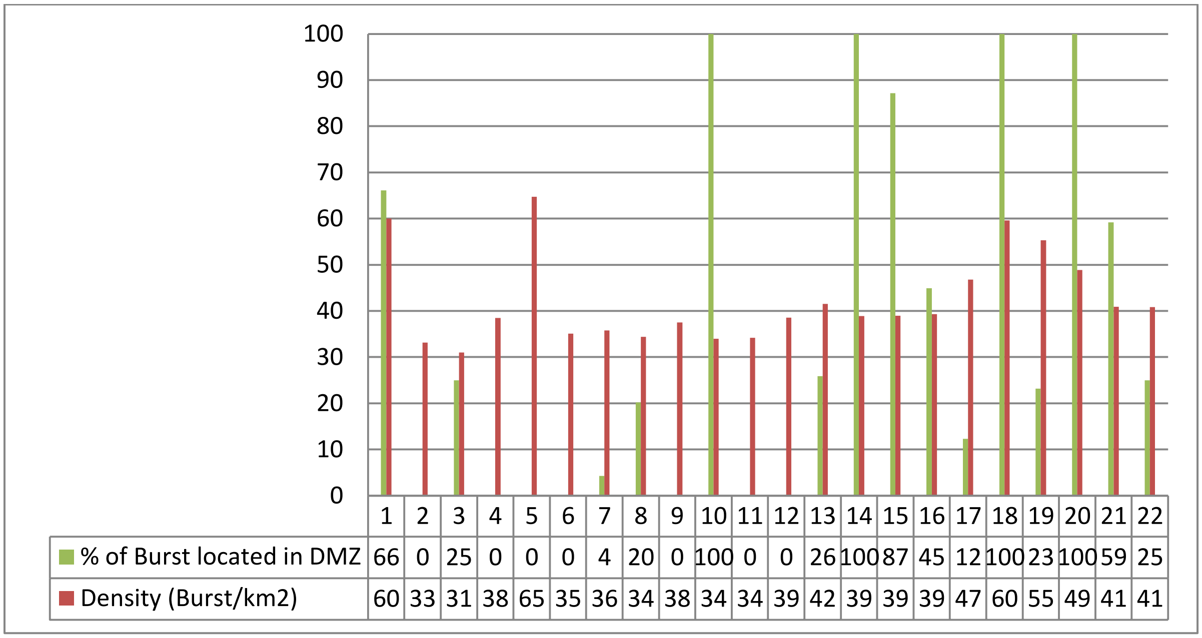


Figure (6-11) Cluster zones for pipe failures in KL



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
% of Burst located in DMZ	66	0	25	0	0	0	4	20	0	100	0	0	26	100	87	45	12	100	23	100	59	25
Density (Burst/km2)	60	33	31	38	65	35	36	34	38	34	34	39	42	39	39	39	47	60	55	49	41	41

Figure (6-12) Density analysis of clusters zones in Kuala Lumpur

We described in previous sections that the pipe failures located as clusters. In this section, each cluster zone has been analyzed based on specific parameters, pipe diameter, district meter zones and failure density have been used in cluster analysis. Figure (6-11) shows cluster zones of pipe failures in KL. Failure density rate per km^2 has been calculated for each cluster. Figure (6-12) shows the failure density for clusters. It can be identified from figure (6-12) the highest density rate for each cluster. This can be used as condition assessment indicator for these zones. As an example, cluster zones no (1, 5, 17, and 18) have failure density about 50 burst per km^2. This is used to plan rehabilitation priority zones based on failure density of each clusters.

Pipe Size

The relative number of pipe burst for each pipe size have been classified and analyzed. Figure (6-13) shows that the highest percentage of failure occurs in diameter 150mm (39%) and 100mm (37.3%) which considered about 76% of total failures in pipes. The average of pipe breaks decrease with increasing of pipe diameter. Also figure (6-13) shows the burst frequency for each diameter and material which clearly indicate the high rate of AC pipe failures for diameter 100 and 150mm.

Figure (6-14) and Figure (6-15) show the pipe failure rate for AC pipes and MS pipes respectively. It is clear from Figure (6-14) that pipe diameter 100 AC pipes has the failure rate three times pipe diameter 150mm. this brought into focus to review the pipe design of 100mm diameter which may not suitable for the water pressure and soil load. Figure (6-16) shows the pipe failures for each pipe diameter based on cluster zones. We could identify that cluster zone no 17 has the highest failure observations with high percentage of pipe diameter 100, 150 and 200mm. this figure give an overview for the number of pipe failure in each zone for each diameter. An appropriate plan can be achieved using the specification and type of failure frequencies in each cluster zone. In addition, boxplot in Figure (6-17) has been plotted to present the distribution of pipe diameter of failures. The boxes in the graph represent 50% of pipe failure observations.

Pipe Diameter	Failure Number	Percentage
100	1523	37.3
150	1590	39.0
200	526	12.9
250	207	5.1
300	110	2.7
375	43	1.1
400	2	.0
450	26	.6
525	3	.1
600	49	1.2
950	1	.0
Total	4080	100

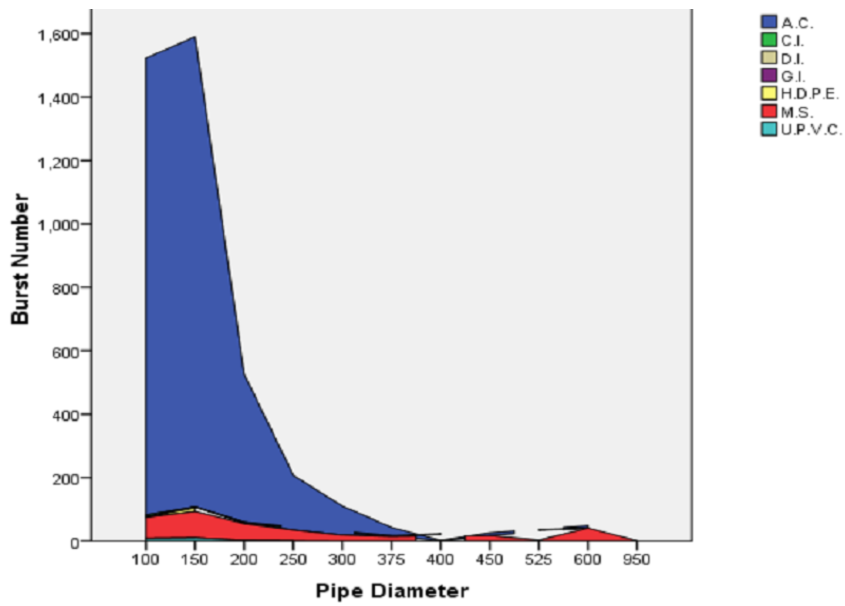


Figure (6-13) Burst frequencies for each diameter and material

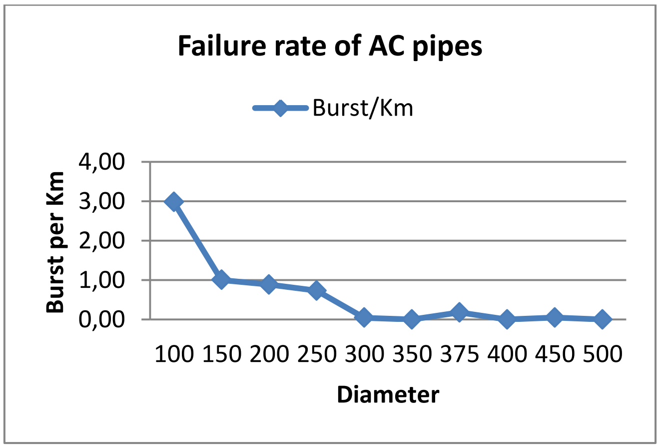


Figure (6-14) Pipe failure rate of AC pipes per Km

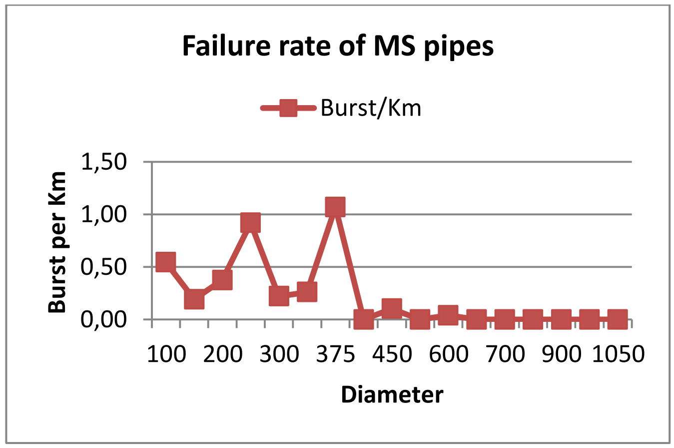


Figure (6-15) Pipe failure rate of MS pipes per Km

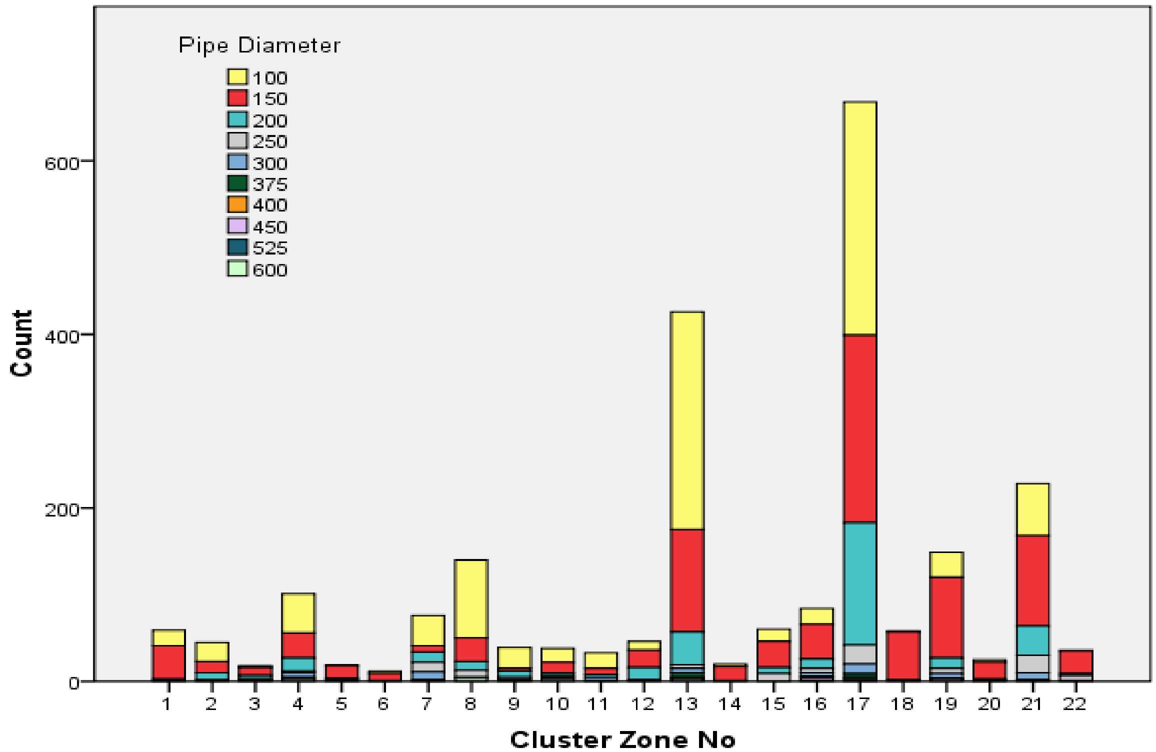


Figure (6-16) Counts of pipe failures for each cluster zones based on material types

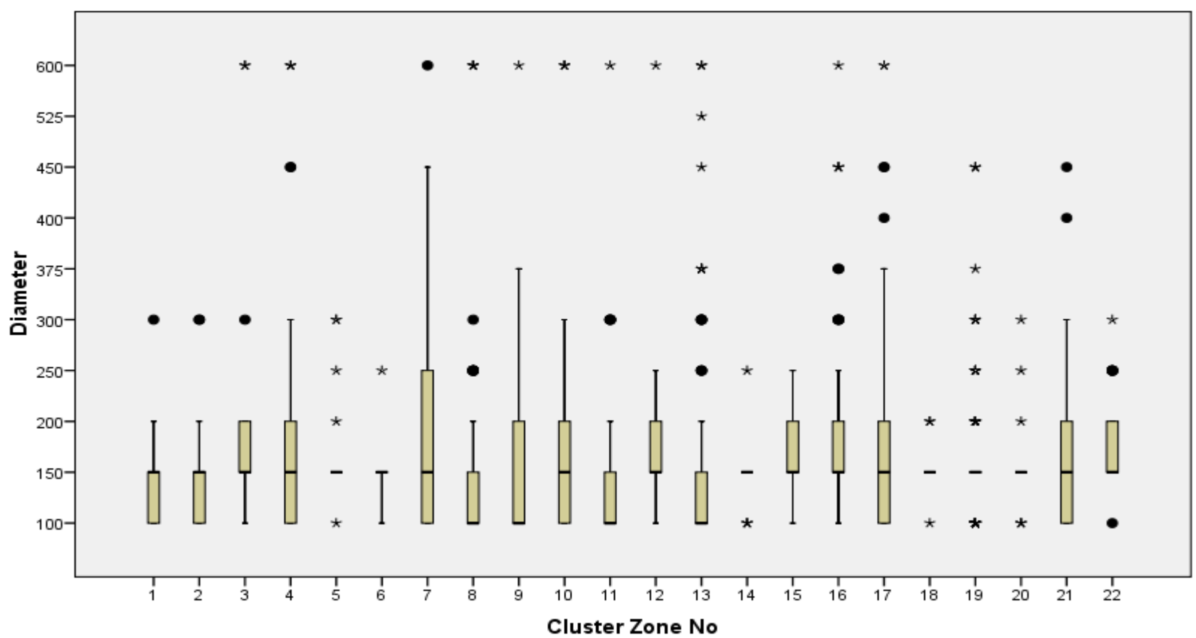


Figure (6-17) Boxplot for pipe failures per diameter based on cluster zones

Influence of pipe materials

The main pipe material in Kuala Lumpur is AC, which presents about 60% of total water network. Figure (6-19) shows Pipe Material classifications in Kuala Lumpur. The failure rate of pipe based on material differs for various pipe materials. Figure (6-18) includes an analysis of relative failure rates for different pipe materials, based on a study of the information collected from Kuala Lumpur. Failure rate per km for AC pipes 1.66 failures per km and MS is 0.14. we could identify the high failure rate of HDPE which it is 4,66 failures per km.

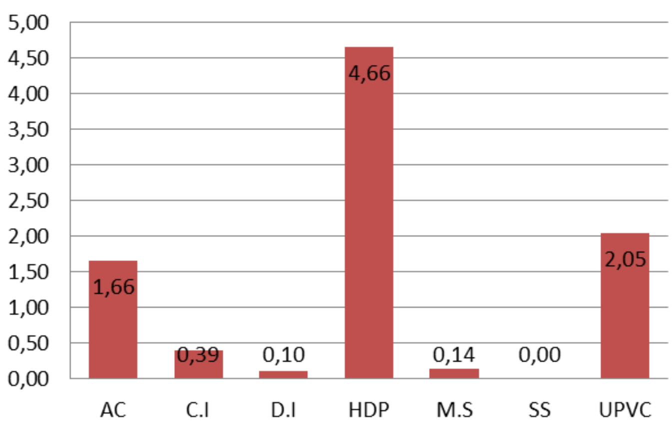


Figure (6-18) Pipe failure per km for each pipe material

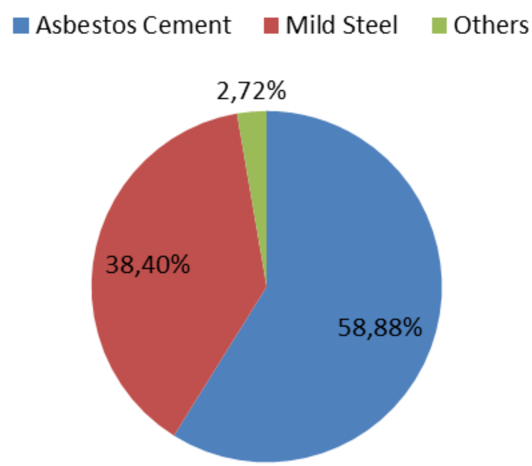


Figure (6-19) Pipe Material classifications in Kuala Lumpur

Influence of DMZ

Total area of DMZ's is 17 km^2 which cover about 17% of the total area of Kuala Lumpur. This indicates that many areas in Kuala Lumpur are out of pressure management zones. Figure (6-20) shows the DMZ location in Kuala Lumpur and connection density per km for each DMZ. In Kuala Lumpur center, there is high density of pipe failure with no DMZ, which needs high focus in management and maintenance.

Pressure management using District Meter Zone (DMZ) has temporally effects to reduce the pipe failures. This due to high deterioration of AC pipes. Water pressure management is temporary solution to reduce pipe failure. According the long-term plan, the sustainable improvement of water network may be effective in the schedule of pipe replacement of AC pipes.

Influence of Rainfall on pipe failure rate

Rainfall is a determining factor in the failure process of pipes, especially in expansive soil bedding. Rainfall history of Kuala Lumpur during that period of from 2006-2010 was analyzed. Figure (6-21) shows histograms of monthly records of rainfall in Kuala Lumpur in 2006– 2010.

Several authors tried to find the relationship between rainfall and failure rate. (Sægrov et al. (1999) found failures rate increasing in summer peak due of attributed to drying and uneven shrinkage of clay soils while the winter the frost loading or thermal contraction effects increase failure rate (Dehghan, 2009). Andreou (1986) observed pipes with that smaller diameter have higher failure rates in the winter. Spatial analysis of rainfall distribution over Kuala Lumpur has been used. Figure (6-22) shows also spatial analysis of rainfall intensity in Kuala Lumpur in year 2009.

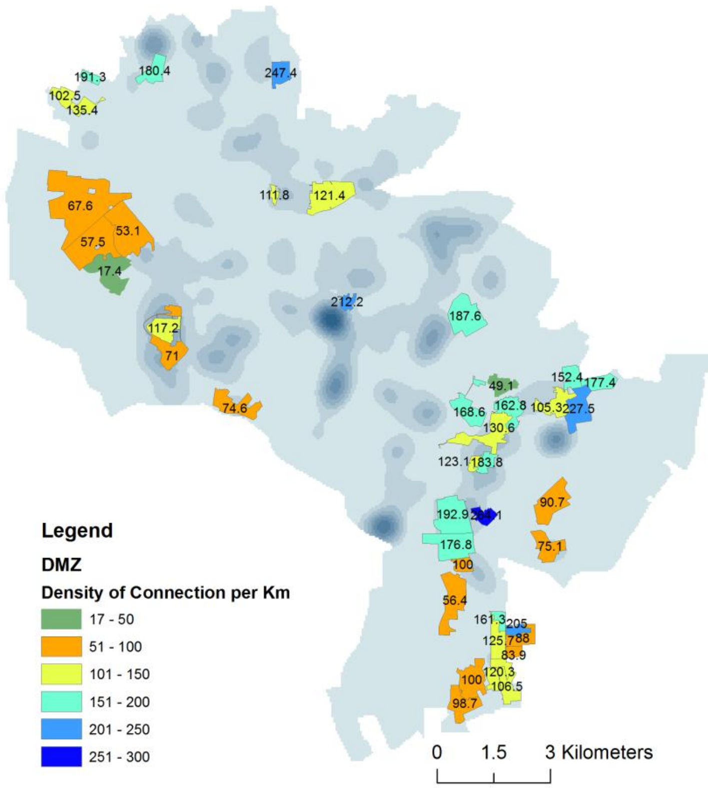
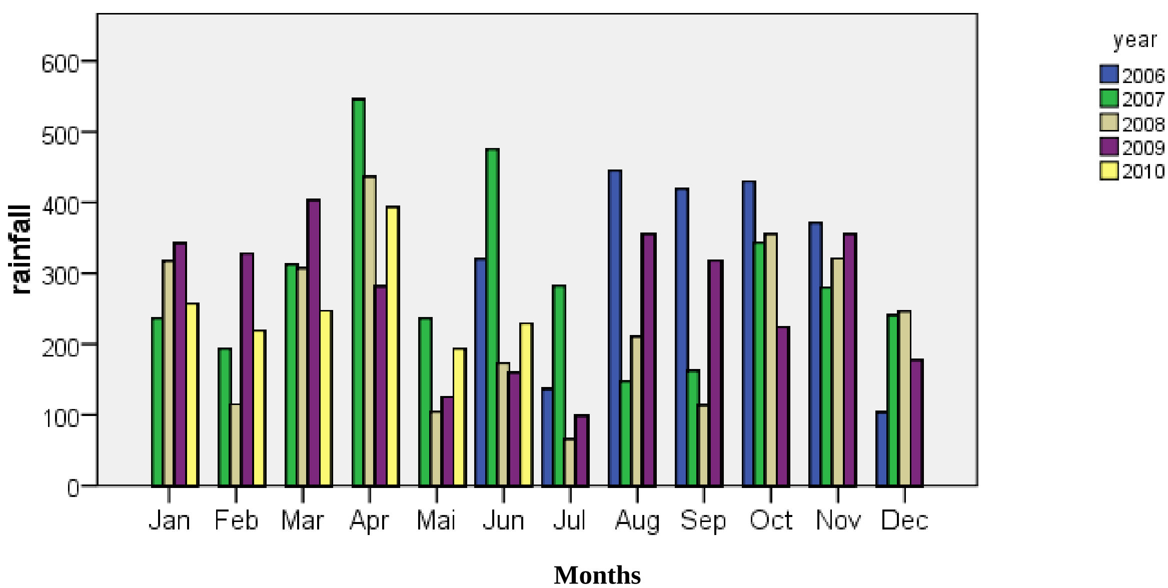


Figure (6-20) Connection density per km in DMZ's



Figure(6-21): Histograms of monthly records of rainfall in Kuala Lumpur in 2006– 2010

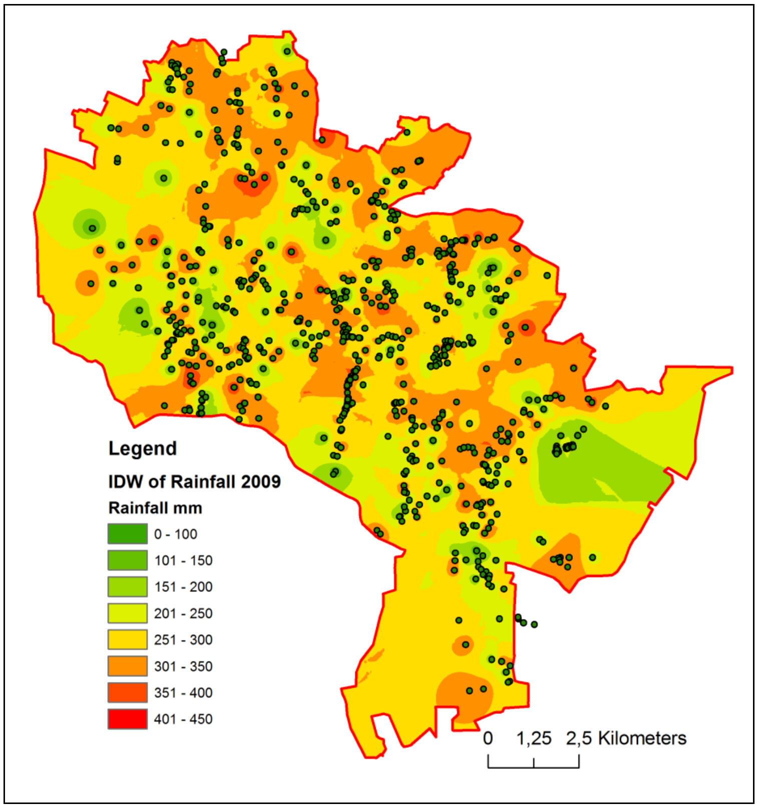


Figure (6-22) Spatial analysis of rainfall intensity in Kuala Lumpur in year 2009

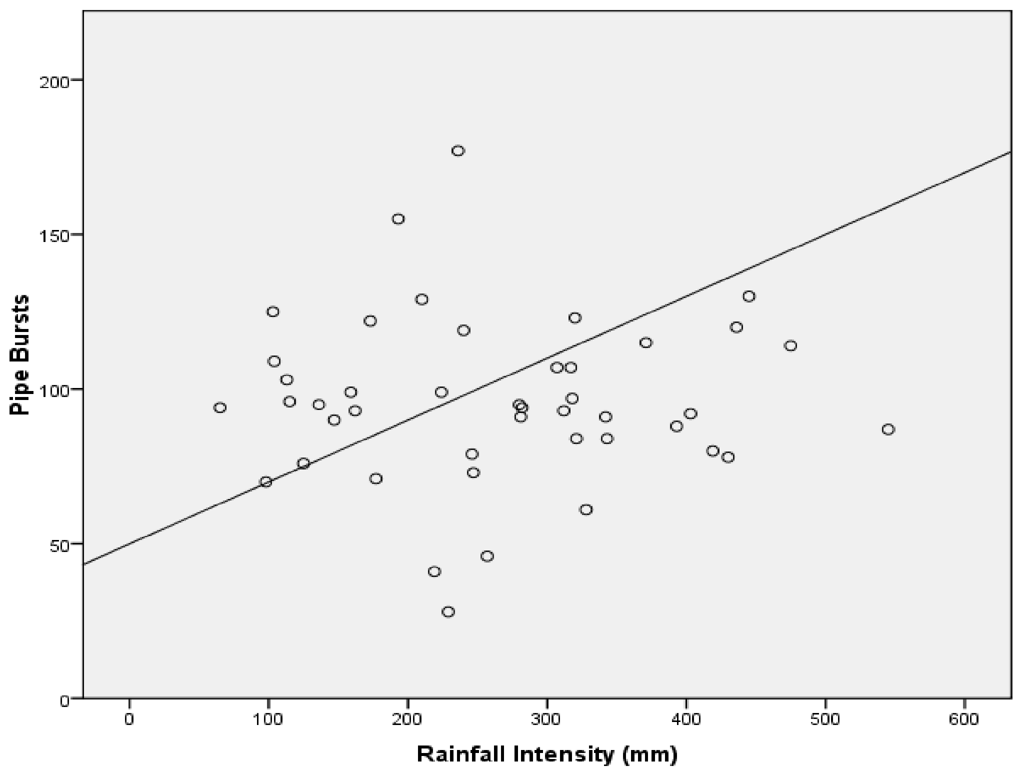


Figure (6-23) Relationship between the rainfall data and number of failures

The correlation between the rainfall data and number of failures has been plotted in Figure (6-23). The rainfall data are plotted versus number of failures. It is obvious that there is a corresponding increase in the number of pipe failures with increasing the rainfall intensity. However variation is appear on AC pipes that it is more than MS pipes in figure (6-24).

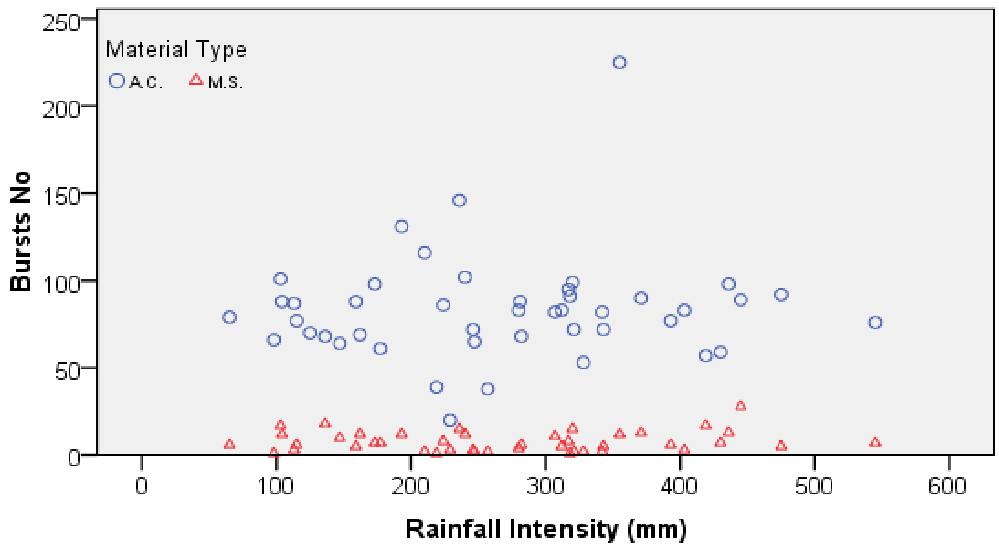


Figure (6-24) Relationship between rainfall intensity and failure No. for AC and MS pipes

Influence of surrounding connection pipe leaks on main pipe failure rate.

There is few researches review about the influence of surrounding leaks of small diameter on the failure of the main pipes. This section we tried to analyze the relation between main pipe failure and small pipe diameter leaks. Figure (6-25) shows a strong correlation between failure and leaks. Random observations have been done to show the time intervals between surrounding pipe leaks and main pipe failures. From these observations, we identified that pipe leaks increase the probability of main pipe failure. This section needs more investigations in further researches. However increasing the soil moisture due to leakage of small diameter pipes around and outside AC pipes, decrease the strength of pipe in weakest point.

Also pipe connections density increases the probability of pipe failure which be considered in pipe failure risk analysis.

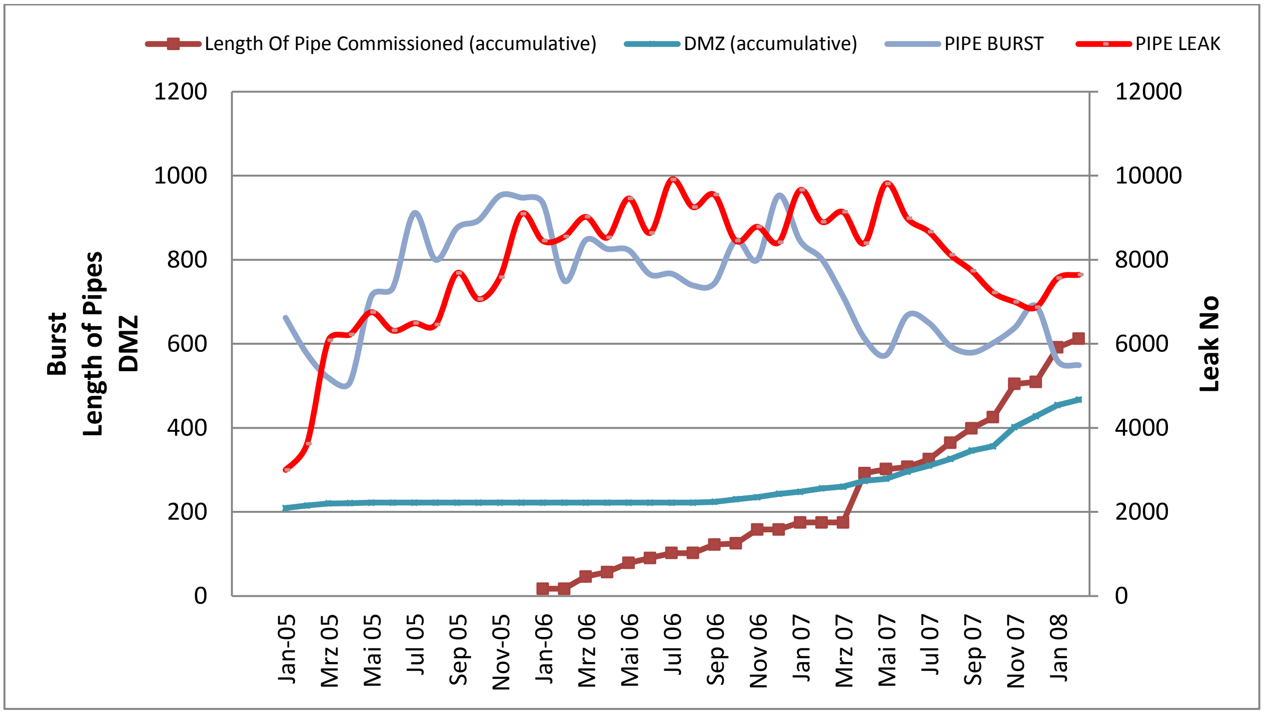
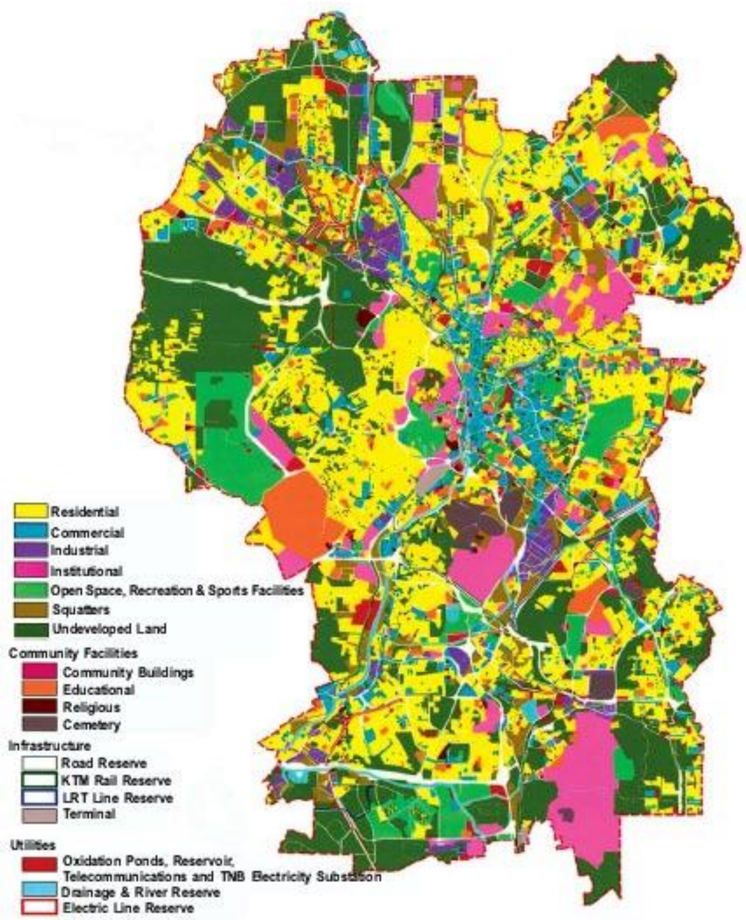


Figure (6-25) Burst frequency in comparision with leaks , length of pipes and DMZ (Syabas, 2010)

Influence of Landuse on pipe failure rate:

Mainly Land use can be divided to residual areas, commercial areas, industrial areas and open area. Figure (6-26) shows the land use classification in Kuala Lumpur. Water supply system under these sectors needs high considerations to reduce risk of pipe failures. Because of high water pressure in these areas, we have found that the failure rates for pipes served high water demand areas are more than residential area. Figure (6-27) shows a Spot area for land use in Kuala Lumpur. We identified that there are high failure rate in commercial and institutional zones. Furthermore, the failure rate increase in the main roads due to high traffic loads. Figure (6-28) shows the high rate of AC pipe failures in main roads.



Land Use Catagory	Area (in hectare)		%	
Residential		5,489.56		22.66
Commercial		1,091.71		4.51
Industrial		553.05		2.28
Institutional		1,620.80		6.69
Open Space, Recreational and Sports Facilities		1,579.56		6.52
Community Facilities		1,382.44		5.71
Community Buildings (community centre, market,library)	*38.50*		*0.16*	
Educational	*964.84*		*3.98*	
Religious	*104.56*		*0.43*	
Cemetery	*274.54*		*1.13*	
Undeveloped Land		5,756.74		23.77
Squatters		570.63		2.36
Infrastructure		5,029.62		20.77
Road Reserve	*4,798.80*		*19.81*	
Rail Reserve	*104.79*		*4.33*	
Terminal	*126.03*		*0.52*	
Utilities		1,146.94		4.73
TOTAL		**24,221.05**		**100.00**

Figure (6-26) Land use classification in Kuala Lumpur[1]

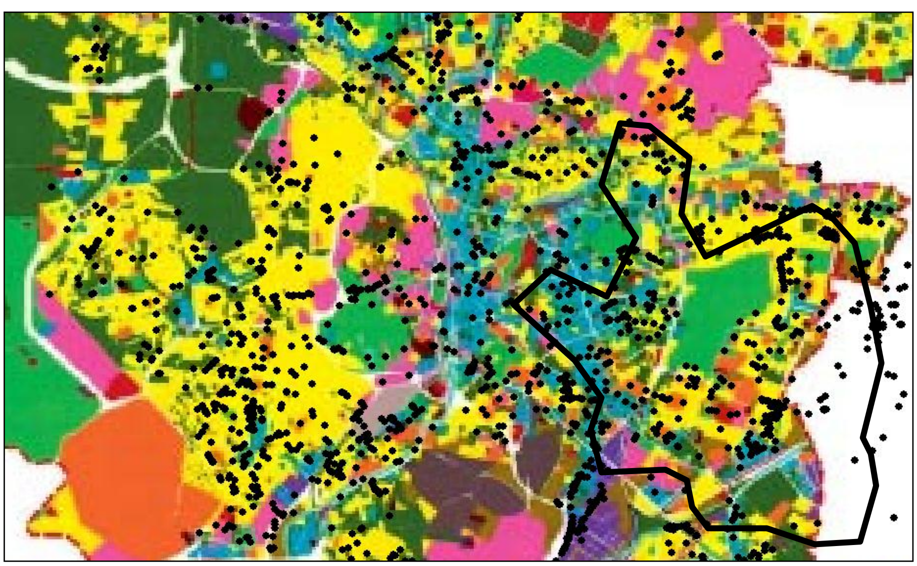


Figure (6-27) Spot area for commercial and institutional areas in Kuala Lumpur

[1]Source: Ministry of federal territories and urban Wellbeing-Kuala Lumpur

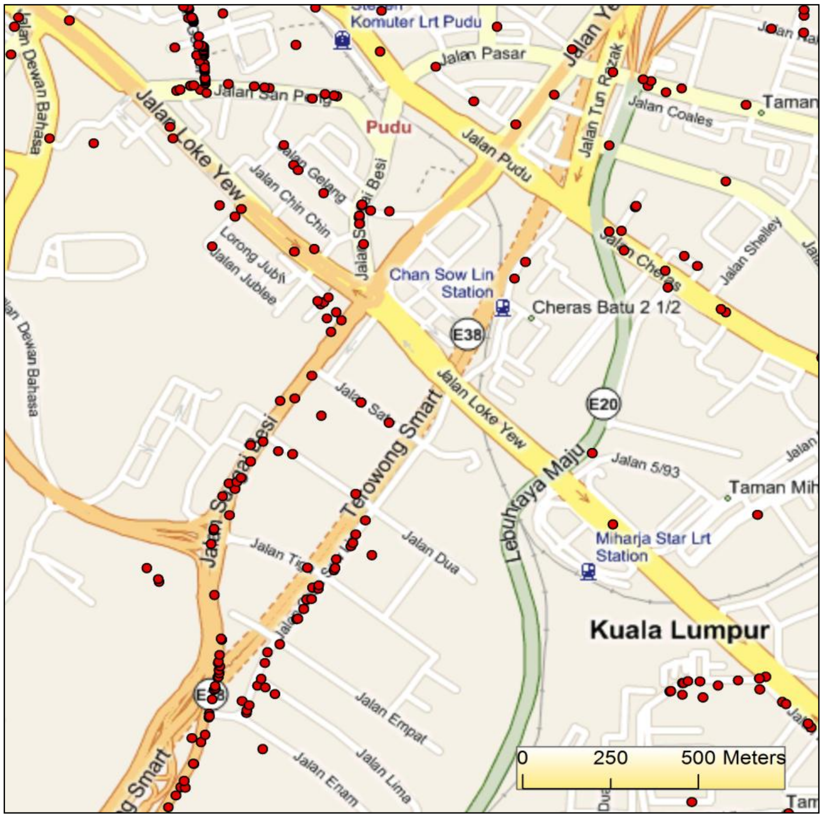


Figure (6-28) Focus on frequencies of AC pipe failures in one zone of Kuala Lumpur

6.8 Technical Implications and findings

This research presents the technical implication of using cluster analysis of pipe failures. The water utilities can make the accurate decisions based on clustering of database, which used in pipe condition assessment. Each cluster has its own burst rate based on pipe material and pipe diameter. A geographic information system (GIS) has a great importance in decision support system in pipe failure analysis. Mainly there are two technical implications founded from this research:

Firstly, this research explains an application technique, which has potential to be useful tool in pipe condition assessment based on clustering analysis. In addition, cost-benefit analysis can be achieved based on the failure rate for each clustering group. Location of DMZ’s can be accurately planned based failure rate for each cluster.

Secondly, we add a new condition assessment factor for water network evaluation; Temporal and distance interval between failures. The priority of pipe replacement is based on several criteria such as number of pipe failure, failure mode, pipe age, etc. this research explain a new significant factors for pipe deterioration which it is the time and distance intervals between failures. Furthermore; a correlation has been done between time and distance intervals. This is used as prediction for pipe failure risk. In Kuala Lumpur there are more than 50% of pipe failures occurred within distance 40 to 50 meter. Also 10% of pipe failures have been repeated failed in the same location. This could be used as indicator of pipe deterioration or unsuitable repair for failures.

6.9 Conclusions

Geo-statistical and Spatial Analysis techniques play an important role in the analysis of water mains failure. These methods help in obtaining significant concentration about exploratory settings and prediction tasks. The uses of spatial autocorrelation measures are a step toward a possible identify the time and distance between pipe failures. A close correlation has been observed between the spatial distributions of pipeline damage and temporal interval. The research reports on the development of an integrated GIS based decision support system for asset management of urban water distribution networks. Cluster analysis is an important tool for understanding the failures in each cluster zone. Results are encouraging, providing a clear picture of main patterns in the Kuala Lumpur with a reasonable interpretation of the identified clusters of pipe failures, especially with AC pipes.

In addition, this research presents a new approach of using GIS in analysis of water network and finding relationship between failures based on temporal and distance intervals. This can be used to expect and estimate number of failures in the zone taking into consideration clustering of pipe groups. Clustering of pipe groups can also be done based on pipe ages, pipe material, diameter, customers complains and failures rates.

Chapter 7

7 Simplified approach for AC- pipe condition assessment using simple test based on GIS techniques

7.1 Summary

Condition assessment of water pipes is needed to develop a alternatives for future plans to avoid pipe failure and to predict the remaining service life of water pipe (Hunaidi, 2010). Performance evaluation is required to address the rehabilitation and replacement programs. However, Condition assessments of water pipe are often complex, difficult and expensive undertakings (Hunaidi, 2010). In addition, the available techniques of condition assessment need huge amount of data while many of water companies have limited data for pipelines. This research presents a simplified approach to evaluate and assess the condition of Asbestos Cement (AC) pipes. Water network in Kuala Lumpur is a case study from South Asia countries. Syabas Company (Water Company in Kuala Lumpur) facing challenges to replace about 6500 km of deteriorated AC pipes (Syabas, 2010). This required scheduling the pipe replacement based on AC pipe condition. . In the present study a scientific approach has been adapted to presents a multi-criterion selection and ranking system for the pipes. The methodology developed in this research based on pipe statistical failure model and simple chemical tests. The condition index has been created for each AC pipe. GIS technique has been used to rank water pipes based on condition index. WPAM Water Pipe Assessment Model has been developed based on condition index of pipes. WPAM is built in ArcGIS10 software.

AC pipe Condition index is developed using limited data; failure mode, diameter, water pressure, land use. Chemical test is used also to increase the condition index accuracy by combination between the statistical data of pipe and its physical characteristics.

Keywords: AC pipe, GIS Statistical data, Kuala Lumpur, WPAM

7.2 Introduction

Condition assessment is needed to describe current condition of pipes and estimating remaining service lives of pipe systems. Water utilities in developing countries often have challenge of limited data to make decisions. The problems of deteriorated water pipes have become a major issue around the world. Due to high complexity of available assessment models of pipeline, water utilities started to develop its own ranking system for pipe priority. These models should be adapted with available data. Also currently ranking system of pipeline depends mainly on statistical models. This increases the inaccuracy in decision making since available models have no actual relation with real condition of pipelines. This research present a simplified model merges between statistical analysis and experimental test to evaluate and assess the actual condition of pipeline. This aims to produce a methodology that could improve the sustainability of pipe improvements. We developed mainly a methodology to assess Asbestos Cement (AC) pipes statistically and experimentally. In this research, we proposed a simplified model to rank AC pipes based on proposed condition index for each pipe. Also (Rajani & Kleiner, 2001) found that AC pipes are deteriorated due to of cement leaching which weaken the cement matrix in AC pipes after chemical process. Also they found that acids in the soil causing concrete corrosion or deterioration.

Condition index is based on contributing factors of AC pipe deterioration. We divided these factors for two categories; primary factors and secondary factors. The Primary factors are as following; Number of previous pipe failures, Pipe Diameter, water pressure. The secondary factors are; Number of pipe connections, rainfall intensity. Each factor has condition index based on its importance on AC pipe deterioration. The simplified model needs less factor information, and balances the performance and complexity. This method incorporated empirical estimation and practical decisions, reducing investigation cost, and improving the accuracy of assessment of AC pipe.

This research aim to understand the current condition of the AC pipes Kuala Lumpur and the practices used to manage and comprehensive survey was carried out for water network of Kuala Lumpur. In this research, study a scientific approach has been adapted to presents a multi-criterion selection and ranking system for the pipes. Chemical test is used also to increase the condition index accuracy by combination between the statistical data of pipe and its physical characteristics.

Water Pipe Assessment Model (WPAM) has been developed using the analysis of historical pipe failure in Kuala Lumpur. Condition index for each criterion has determine using depending on statistical analysis of pipe failure and using effects of contributing factors of AC pipe deterioration from several references in addition of technical experience of AC pipe failure.

7.3 Methodology

This model approach is developed to estimate the current and future condition of AC water pipes, including tools to predict pipe failures. Based on the results of this model, long-term investment needs are estimated as well as annual rehabilitation scenarios selected and ranked. In this method we combine between direct inspection (AC pipe sample test) and indirect inspection method using failure history of AC pipes and contributing factors of AC pipe failures. Mainly there are two component for analysis the condition assessment of AC pipes; Geostatistical Analysis and Chemical test. Geostatistical Analysis has been based on data provided from GIS. Pipe ranking system has been developed using Condition index. Condition index based on 10 criteria. These criteria are as following ; Material, Diameter, Pipe length, Failure modes, pipe age, Number of previous failure, Number of previous leaks, water pressure, soil type and Traffic Load. Figure (7-1) shows the methodology approach component.

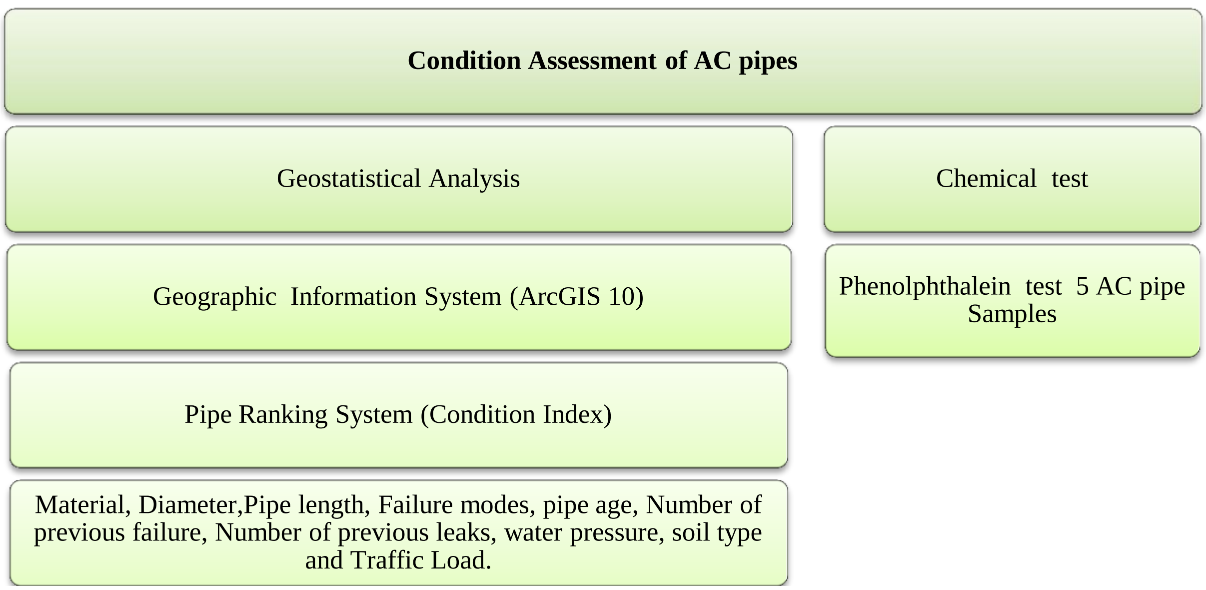
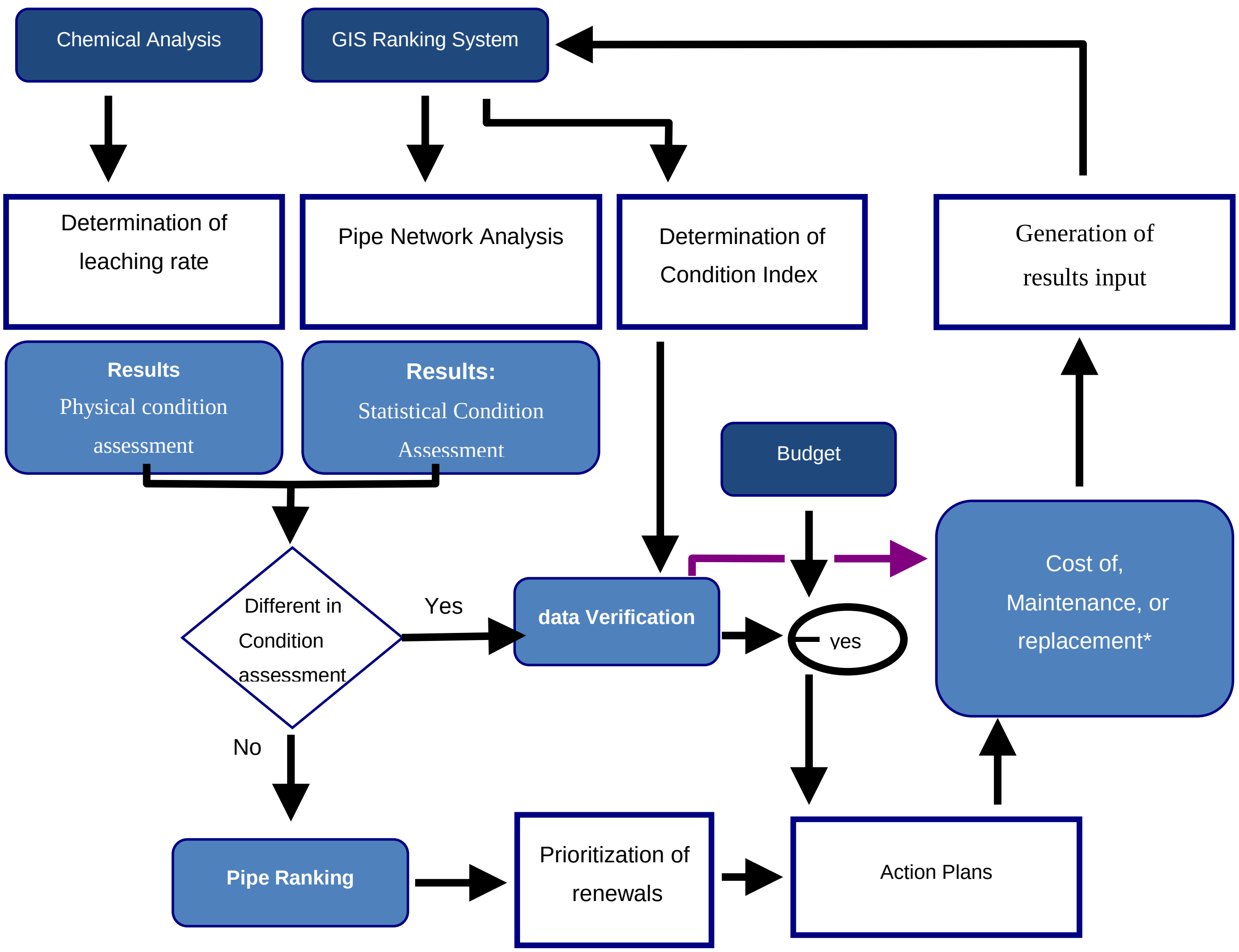


Figure (7-1) Work Methodology

Workflow model

The workflow model has been developed using two methods; chemical analysis and GIS ranking system. Chemical analysis used to determine the leaching rate of AC pipes which gives an indicator of the physical condition of the AC pipes. Ranking system used the pipe database with 10 criteria. These criteria are Material, Diameter, Pipe length, Failure modes, and pipe age, Number of previous failure, Number of previous leaks, water pressure, soil type and Traffic Load. Results of Water Pipe Assessment Model (WPAM) used to define the condition class for each pipe. Chemical analysis using phenolphthalein indicator used to determine the leaching rate, which will be assistance factors for obtaining an accurate results and verification of obtained data. In case of big differences between condition assessment using statistical data and condition assessment using chemical analysis of AC pipe, verification must be done for data input for pipe. The budget of renewal pipes can be prepared based on the prioritization of pipe renewals. Figure (7-2) shows the workflow model and the component process.



*Cost of maintenance and replacement are not included in this research

Figure (7-2) Workflow model

7.4 Data collection and preparation

The research survey was designed based on two methods. The first method is to collect current data of AC pipes from Syabas Company database. This includes pipe failures, current management practices, and renewal ranking system of AC pipes used in Syabas. The second method is to collect samples from AC pipes after pipe failures. Several pipe failures have been investigated to make a comprehensive overview for failure location and surrounding conditions of the pipes. AC pipe failures are analyzed and correlated to pipe inventory and working environment and verifying it based on collected samples (Syabas, 2010).

ArcGIS has been used in data analysis and data verification. Some estimation has been made in pipe database. Pipe ages have been estimated based on pipe material groups which have been provided from Syabas company. Also unknown pipe material has been estimated based on pipe clustering using GIS. Renewal raking system has been created based on analysis of historical pipe failures of AC Network (Syabas, 2010). Figure (7-3) shows the work steps of building the model from statistical analysis of the main criteria and then building the WPAM based on ArcGIS and finally check the results by determination of calcium leaching depth using Phenolphthalein.

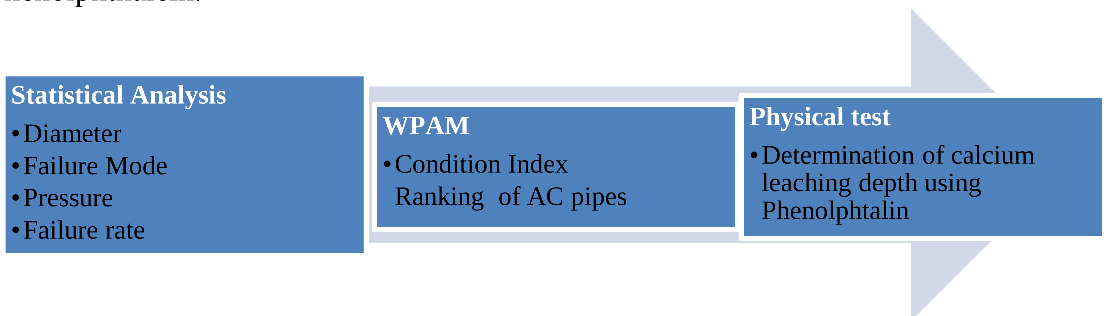


Figure (7-3) work steps of model building

7.5 Case Study:

Kuala Lumpur city has several challenges to reduce water losses in water networks. Several projects have been achieved to reduce NRW from 40% (2005) to 33% (2010). However, one of the main challenges is high deterioration of AC pipes. They used in Kuala Lumpur pressure management techniques to reduce these failures in AC pipes. However, this is not permanent solution, since they needs plans to replace deteriorating AC pipes. The replacement of 6,500 km of AC pipes need huge financial budget. This need to replace AC pipes based on pipe priority and condition of pipes. AC pipe condition assessment is essential to determine or rank the pipes based the priority and to develop a suitable replacement plan water network. Limited data of water networks makes the use of available rehabilitation models be difficult (Syabas, 2010).
The main objective of this research is to use the simple data available in Syabas Company (the water company of Kuala Lumpur) to develop the effective AC pipe replacement plans based on pipe condition index.

The main pipe material in Kuala Lumpur is AC, which presents about 60% of total water network. Figure (7-4) shows pipe failure rate of AC pipes per Km based on pipe diameter and figure (7-5) shows pipe material classifications in Kuala Lumpur.
The failure rate of pipe based on material differs for various pipe materials. Figure (7-6) includes an analysis of relative failure rates for different pipe materials, based on a study of the information collected from Kuala Lumpur. Failure rate per km for AC pipes 1.66 failures per km and MS is 0.14. We identified the high failure rate of HDPE which it is 4,66 failures per km.

7.6 Analysis of AC pipes in Kuala Lumpur

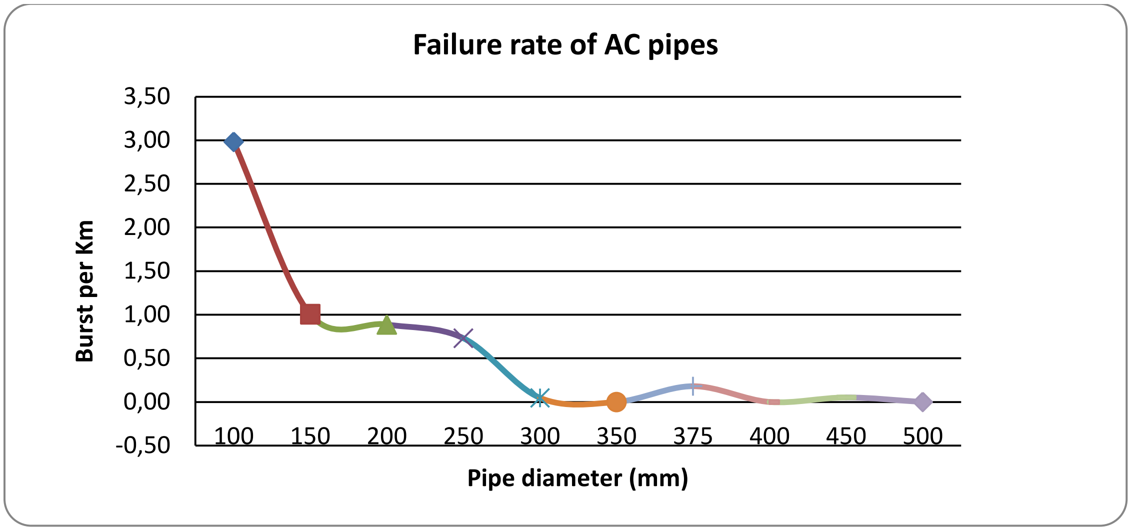


Figure (7-4) Pipe failure rate of AC pipes per Km based on pipe diamater

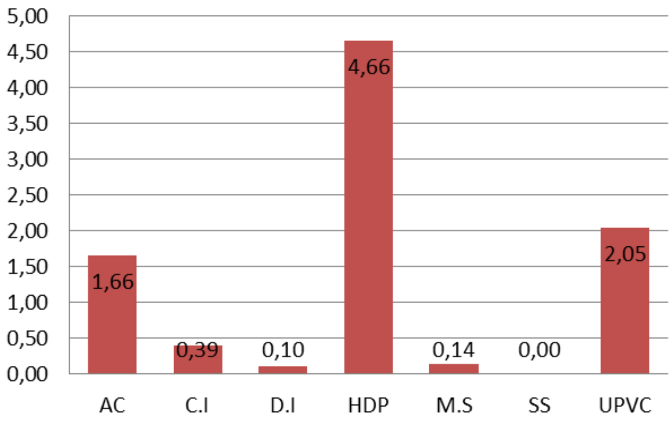


Figure (7-5) Pipe failure per km for each pipe material

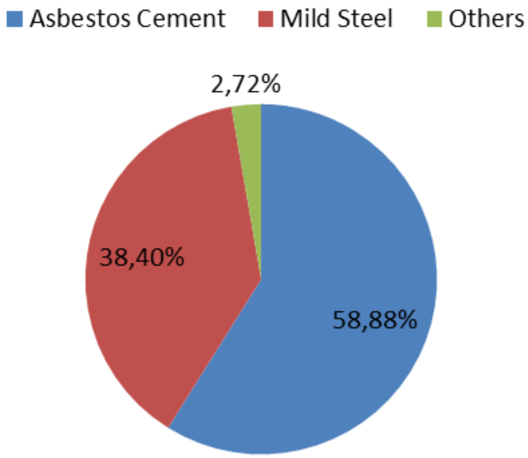


Figure (7-6) Pipe Material classifications in Kuala Lumpur

This section the relation between main pipe failure and small pipe diameter leaks has been analyzed. Figure (7-7) shows a strong correlation between failure and leaks. Random observations have been done to show the time intervals between surrounding pipe leaks and main pipe failures. From these observations, we identified that pipe leaks increase the probability of main pipe failure due to soil movements by water with load variation of traffic on the ground. Also increasing the soil moisture due to leakage of small diameter pipes around and outside AC pipes, decrease the strength of pipe in weakest point. In addition, pipe connections density increases the probability of pipe failure which be considered in pipe failure risk analysis. The present pipe network can be summarized as follows in Table (7-1).

Table (7-1): Length of Pipe network in Kuala Lumpur (Syabas, 2010)

	TYPE OF PIPES	LENGTH (km)	AGE
1	Asbestos Cement (AC)	5,978.00	>30 years
2	Mild Steel (MS)	3,481.15	< 30 years
		8,123.15	> 30 years
3	Cast Iron (CI)	36.64	> 40 years
4	Ductile Iron (DI)	401.00	> 20 years
5	Non-Metallic Pipe	4,423.00	10 – 30 years
6	Others	2,252.00	> 30 years
	TOTAL	**24,694.94**	

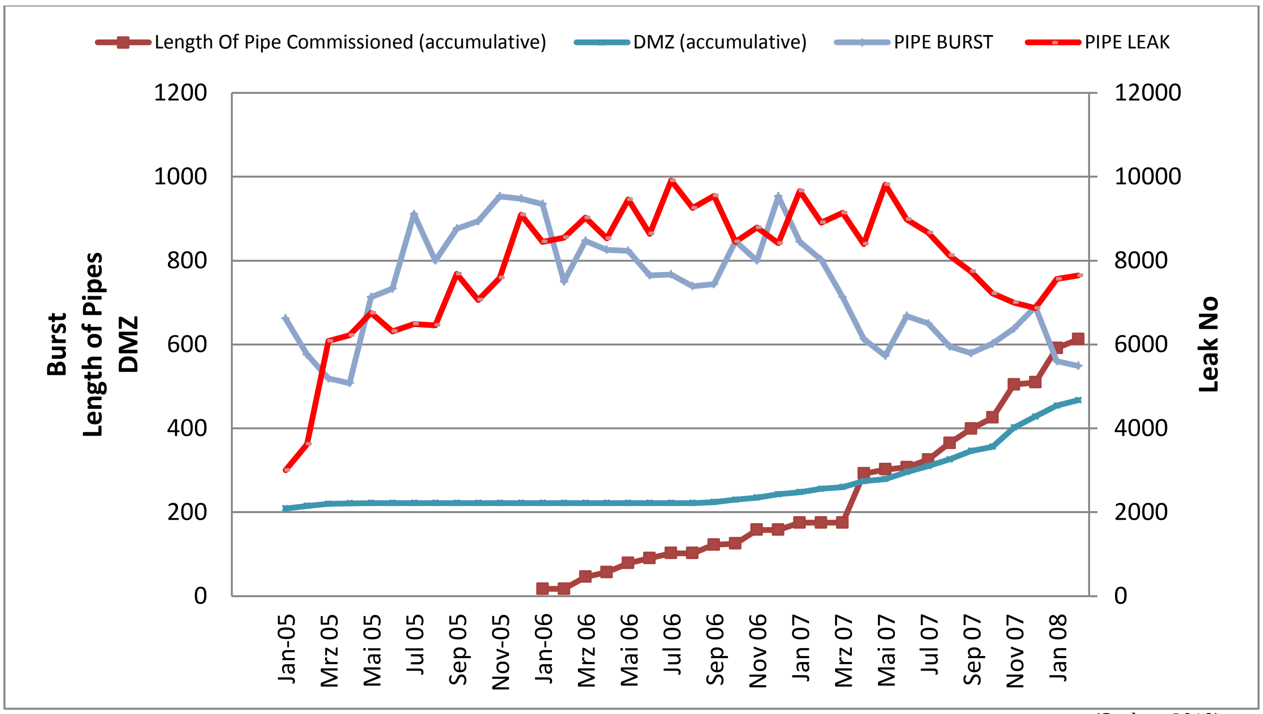


Figure (7-7) Burst frequency incomparision with leaks , length of pipes and DMZ (Syabas, 2010)

7.7 Asbestos cement pipes specifications:

Several factors encourage the world to use AC pipes in water distribution system (AWWARF , DVGW 1996). Olson (1974) summarized these factors; (1) AC pipe is resistant to corrosion, particularly structural deterioration, both internally and externally. (2) AC pipe has enough strength to withstand the high internal forces imposed by water hammer and shock earth loads from earthquakes. (3) AC pipe has contributed to high water quality. (4) AC pipe does not rust and cause discoloration of the water. (5) AC pipe is lightweight, economical, and easy for the contractor to install. These qualities result in lower installation costs. (6) AC pipe has a permanently smooth interior wall, so pumping costs are low. AC pipes were originally believed to be resistance to deterioration. (Olson 1974) & (AWWARF , DVGW 1996).

AC pipe dimension ranges from 58 mm - 600 mm in diameter (AWWARF , DVGW 1996). The main diameter used in Kuala Lumpur water network is 100, 150 and 200 mm. Table (7-2) shows the nominal size and outside diameter for AC pipes. Outside diameter has been used in visual observation to identify the thickness deterioration of AC pipe samples.

Dorn et al. (1996) summarized the techniques for assessing the condition of water pipes or water distribution systems. These techniques classified into four categories; Internal assessment, External assessment, Chemical testing and Historical data analysis. Figure (7a-8) shows the classification groups of condition assessment techniques of AC pipes.

7.7.1 Internal Corrosion of Asbestos Cement Pipes

Internal corrosion of AC pipes are caused by leaching of cement mortar in the pipe due to the formation of calcium carbonate depending on water quality such as pH, and alkalinity. (AWWARF, DVGW, 1996).

Table (7-2) AC pipe dimensions according to AS4139-1993

Nominal Size	Outside Diameter	Nominal Size	Outside Diameter
58	77.6	375 B	413.0
80	95.6	375 C	426.2
100	121.9	450 A	492.2
150	177.3	450 B	492.2
200	232.2	450 C	507.0
225	259.1	525 A	571.5
250	286.0	525 B	571.5
300 A	333.8	525 C	587.2
300 B	333.8	600 A	650.2
300 C	345.4	600 B	650.2
300 D	345.4	600 C	667.0
375 A	413.0		

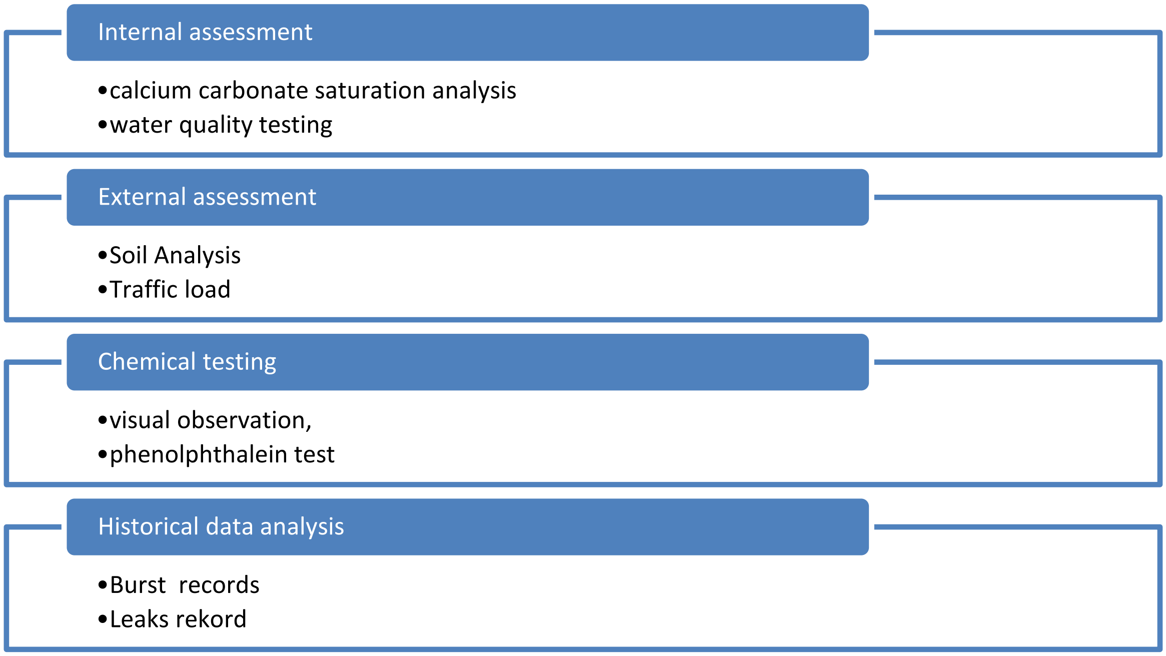


Figure (7-8a) shows the classification groups of condition assessment techniques of AC pipes.

7.7.2 Monitoring Asbestos-Cement Pipe Condition

The monitoring of AC pipes condition has been explained by the chemical analyses of distributed water and evaluation of the state of pipelines in use. Based on chemical analysis, the aggressivity of water toward AC pipe has been equated with the calcium carbonate saturation index, in one form or another. Increasing of calcium and pH in water passes through a AC pipe network can be indicated that further investigation might be necessary (AWWARF, DVGW, 1996).

There are two approaches have been used to describe the actual situation of AC pipes and impact of water on pipe material: fiber control in the distributed water and the evaluation of the state of the pipe (AWWARF, DVGW, 1996).

7.7.3 AC Pipe manufacturer

AC pipes were produced by a different manufacturers and specifications. Processes and chemical compositions varied between manufacturers, which affect pipe chemical and mechanical properties of AC pipe, it is very useful to know the name of the manufacturer of a given AC pipe (Hu, Y.et al. 2010). Unfortunately, this factor did not mentioned in pipe database of Kuala Lumpur pipe network. However and in special cases, there are relation between failure rates and pipe manufacturer due some differences between actual pipe specifications and standards.

7.7.4 Failure modes and deterioration types of AC pipe:

Degradation of cement materials can occur due to high aggressivity of the water (acid waters or waters aggressive to calcium carbonate (AWWARF, DVGW, 1996).

(Hu and Hubble, 2007) divided AC pipe failure into four types: circumferential, longitudinal, hole and joint failure. Circumferential and longitudinal, indicate the orientation of a crack in the pipe, with circumferential being across the pipe and longitudinal along its length. Circumferential breaks are, typically, the result of bending stress (beam failure) due to soil differential movement or inadequate bedding support (Hu and Hubble, 2007). Longitudinal Crack is the main failure mode in Kuala Lumpur water network due to water pressure increasing effects. Mainly longitudinal breaks caused by internal pressure and external loads such as soil cover, live loads caused by traffic (Hu and Hubble, 2007). Figure (7b-8) shows classification of pipe failure used in Syabas Company.

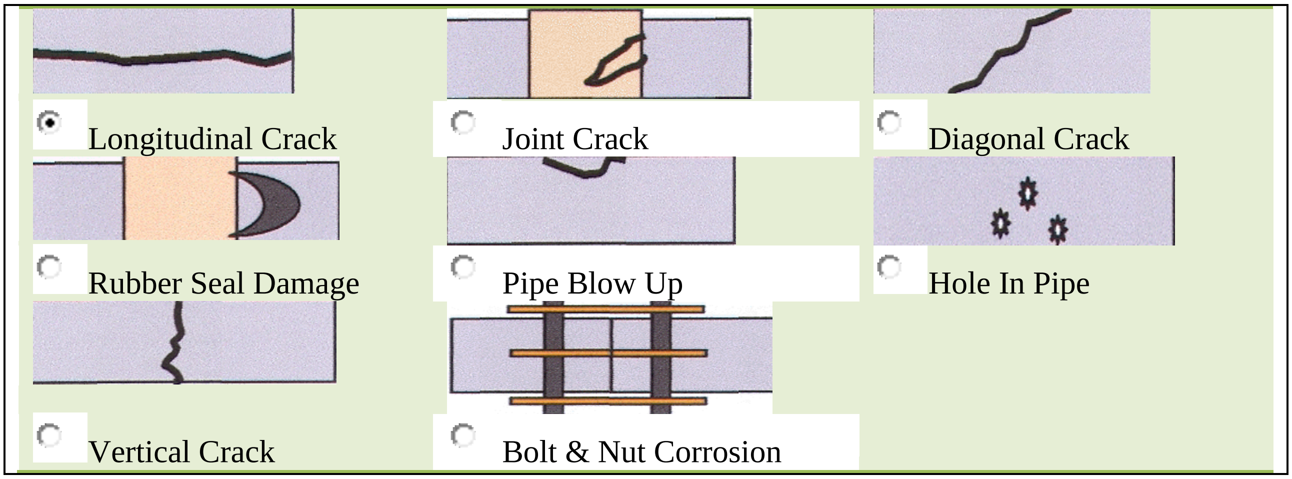


Figure (7-8b) Classification of pipe failure used in Syabas Company (Syabas, 2010)

7.8 Condition Assessment of AC pipes

Condition assessment is the process to establish a record of the state of the critical aspects of water pipes. Two methodologies have been used in condition assessment of AC pipes; Condition assessment using GIS techniques and condition assessment using phenolphthalein test.

Condition assessment using GIS techniques have several positive advantages. Using GIS can visualize an overview of the condition assessment of pipes, which increase the vision of decision maker and increase the accuracy of results. Furthermore, GIS merge between several layers in one database.

In this section, a comparison has been presented between existing conditions assessment models in KL-Malaysia with Wiesbaden System –Germany.

7.8.1 Ranking system used in Kuala Lumpur

Pipe ranking system in KL is focus on the condition assessment of pipes in each zone. Condition assessment based on four criteria; 1) Burst record, point system increase four points for each burst/km/year in each zone, 2) Leak record, which gives 1 points for each leak/km/year, 3) Minimum Night Flow (MNF), which gives zero points for MNF less than 5 l/s until 10 points for more than 40 l/s, 4) Non revenue water (NRW):0 points for less than 500 m3/day and ranges until 10 points for NRW more than 4,000 m3/day (Syabas, 2010). Table (7-3) shows in detail pipe ranking system used in Kuala Lumpur.

Kuala Lumpur water system takes into consideration the pipe condition in each zone. This approach increases inaccuracy in ranking of individual pipe.

Table (7-3) Pipe Ranking system used in Kuala Lumpur (Syabas, 2010)

Criteria No	Criteria	Points	Description
1	**Burst record**	4	4 points for each case of burst/km/year
2	**Leak record**	1	1 point for each case of leak/km/year based on 1 burst equivalent to 4 leaks in term of repair cost and value of water loss where Average leak repair cost + water loss : RM 700 + RM100 = RM 800 Average burst repair cost + water loss: RM 2,500 + RM 700 =RM 3,200
3	**MNF (l/s)**		Minimum Night Flow
	x < 5	0	
	5 ≤ x < 10	2	
	10 ≤ x 20	4	
	20 ≤ x 30	6	
	30 ≤ x 40	8	
	x ≥ 40	10	
4	**NRW (m3/d)**		Non-revenue water (NRW) = Total Daily Flow - Billed Consumption
	x < 500	0	
	500 ≤ x < 1,000	2	
	1,000 ≤ x < 2,000	4	
	2,000 ≤ x < 3,000	6	
	3,000 ≤ x < 4,000	8	
	x ≥ 4,000	10	

7.8.2 Ranking system used in Wiesbaden -Germany

Ranking system used in Wiesbaden water network is RECON: Rehabilitation of Supply Nets on base on Economical Assessments. The model integrated failure data into a Geographical Information System. The system used to locate the line sections in the network, which must be primarily renewed, determine the sanitation of line sections where technically and economically reasonable (Ohmer, 2009).

GIS System Criteria:

Main criteria of GIS system is Number of the failure and there are additional criteria as following

- Pipe Age
- Supply importance
- Aggressive ground conditions
- Landslides
- Building distance
- Traffic load

Point System:

Point system is a system to give point value for each criterion depending on the importance of these criteria. According to this system, there will be priorities for maintenance of the pipeline in the network. Table (7-4) shows the value of each criterion in the point system.

Priority allocation of water pipes:

- Red: Priority 1 = 31 to 100 points
- Yellow: Priority 2 = 21-30 points
- Blue: Priority 3 = 0 - 20 points

Optiplan Model: This model used to calculate demand and pressure zones to avoid stagnant and to show the water moving in the network (Ohmer, 2009).

Table (7-4): Value of each criterion in point system (Ohmer, 2009)

Criteria	Description	Points
Failure	1 Failure /100m = 10 Failure /1000m	10
	2 Failure /100m = 20 Failure /1000m	20
	3 Failure/100m = 30 Failure /1000m	30
	4 Failure/100m = 40 Failure /1000m	40
	5 Failure /100m = 50 Failure/1000m	50
Extra points for Failure	Failure from the current year	5
	Failure from the last year	4
	Failure from before the last year	3
Age		
GG *	From 60 Years	2
	From 90 Years	4
	From 120 Years	6
GGG without Isolation*	From 40 Years	2
	From 70 Years	4
	From 100 Years	6
GGG with Isolation*	From 100 Years	2
	From 120 Years	4
	From 140 Years	6
Steel	From 60 years	2
	From 80 years	4
	From 100 years	6
PE	From 40 years	2
	From 60 years	4
	From 80 years	6
With PVC	From 40 years	4
Other materials	From 80 years	4
Importance of the supply		5
Aggressive ground conditions	only GGG and steel without insulation*	5
Landslides		5

Building Distance	between 0 - 1 m	2
	DN 150 up between 1-2 m	1
	> DN 150 to DN 400 between 1-3 m	1
	> DN 400 to DN 600 between 1-4 m	1
	> DN 600 between 1-5 m	1
Traffic load	Only major roads = 2 points	2
* See table (8-1) for explanation		

7.9 Developed Water Pipe Ranking Model (WPRM):

This section presents a new ranking system approach depending on few parameters. Parameters have been classified and prioritized based on its effects on pipe deterioration. The model is built-in GIS system (ArcGIS 10) through a simple interface.

The condition of each pipe is assessed based on several indicators. These indicators are combined to give a single measure of the relative condition of each pipe.

One of the main problems faced by the water utility in Kuala Lumpur is the deterioration of the AC pipe network of the water distribution system. Assessment of pipe conditions could have difficulties since the pipes are buried. The advanced techniques need huge budget to use it in condition assessment. This section presents a simple ranking system for pipes for condition assessment. Therefore, there is a need to prioritize pipes based on an assessment of pipe condition.

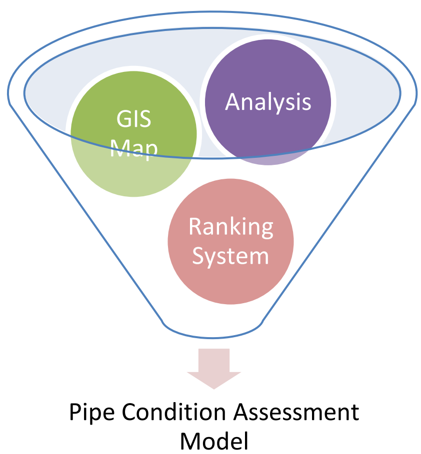


Figure (7-9) Component of the model

Ranking of pipes are based on statistical analysis of network history and visual observation using chemical test in case of pipe bursts. We give a highlight on the pipe condition to identify the most important pipes to be replaced and the low priority of pipes.

Ranking system define between 100 (the best) and 0 (the worst) condition grades, from the best condition for pipes to the worst condition which need immediate rehabilitation action.

Condition classification

Condition assessment of pipe network classified to 10 criteria. Each criterion has been defined based on statistical analysis of historical pipe failures. Table (7-5) shows the condition index for each criterion. For example, the condition index of pipe material is 15. Based on statistical analysis of pipe failures about 60% of pipe failures occurred in AC pipes, for that AC pipe takes zero point (the worst case).

Table (7-5): assessment criteria and condition points

Criteria	Condition Index
Material	15
Diameter	13
Pipe Length	6
Failure Mode	8
Pipe age	20
NPF/km N of Previous failure	12
NPL/km N of Previous Leaks	7
Pressure (DMZ)	6
Soil	7
Traffic	5

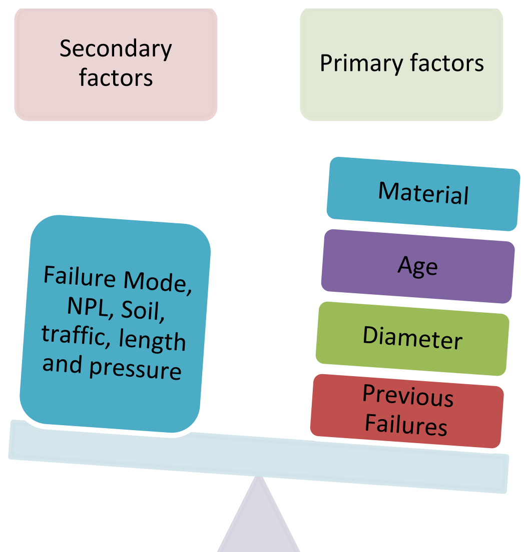


Figure (7-10) Primary and secondary factors

Primary factors for AC pipe condition assessment are material, age, diameter and number of previous failures. These factors represent 60 of total assessment points. The secondary factors represent 40 % of assessment points. Secondary factors are failure mode, number of previous leaks, soil, traffic, length and pressure. Figure (7-10) shows primary and secondary factors and table (7-6) shows the condition assessment criteria and condition index points.

Table (7-6): Condition assessment criteria and condition index points

Criterion	Index
Material	
AC	Material Index = 0
DI	Material Index =12
SS	Material Index =15
CI	Material Index =10
HDPE	Material Index =5
UPVC	Material Index =7
MS	Material Index =13
Diameter	
Diameter =100	Diameter Index = 4
Diameter =150	Diameter Index = 8
Diameter =200	Diameter Index = 10
Diameter =250	Diameter Index = 11
Diameter =300	Diameter Index = 12
Diameter > 300	Diameter Index = 13
Pipe Length	
Pipe Length < 5	Length Index = 6
Pipe Length < 10 and > 5	Length Index = 5
Pipe Length < 20 and > 10	Length Index = 4
Pipe Length < 30 and > 20	Length Index = 3
Pipe Length < 40 and > 30	Length Index = 2
Pipe Length > 40	Length Index = 0
Failure Mode	
No Failure	Mode Index = 8
Failure Mode = CF	Mode Index = 4 ,
Failure Mode = LF ,	Mode Index = 2
Failure Mode = pipe deterioration	Mode Index = 0
Pipe age	
[Pipe_age] < 5	[Age_Index] = 20
[Pipe_age] > 5 and [Pipe_age] <10	[Age_Index] = 17
[Pipe_age] > 10 and [Pipe_age] <20	[Age_Index] = 12
[Pipe_age] > 20 and [Pipe_age] <30	[Age_Index] = 7
[Pipe_age] > 30 and [Pipe_age] < 40	[Age_Index] = 5
Pipe_age] > 40	[Age_Index] = 2
NPF/km (FpK)	
[Failure_Km] = 0	[FpK_Index]= 12
[Failure_Km] < 0.5 and [Failure_Km]> 0	[FpK_Index] = 8
[Failure_Km] < 1 and [Failure_Km]> 0.5	[FpK_Index] = 6
[Failure_Km] <2 and [Failure_Km]> 1	[FpK_Index] = 4
[Failure_Km] <3 and [Failure_Km]> 2	[FpK_Index] = 2
[Failure_Km] <5 and [Failure_Km]> 3	[FpK_Index] = 1
Failure_Km] >40	[FpK_Index]=0

NPL (Number of Previous Leakage)

- [Leak_Km]< 1 [Leak_Index] = 7
- [Leak_Km]< 5 and [Leak_Km]>1 [Leak_Index] = 6
- [Leak_Km]< 10 and [Leak_Km]>5 [Leak_Index] = 5
- [Leak_Km]< 20 and [Leak_Km]>10 [Leak_Index] = 4
- [Leak_Km]> 20 [Leak_Index] = 0

Pressure (DMZ)

- Inside DMZ [Pressure Index] =6,
- Outside DMZ [Pressure Index] =0

Soil

- [Soil_Type]= Clay [Soil_Index]=0
- [Soil_Type] =Unknown [Soil_Index]=4
- [Soil_Type] = Sand [Soil_Index]=7

Traffic

- [Traffic_Type]= Low [Traffic_Index]=5
- [Traffic_Type]= = High [Traffic_Index]=0

Condition evaluation

Evaluation factors are used for weighting the condition assessment of pipes. The maximum summation of points of condition index is 100, which mean the best condition of the pipe. The minimum points of condition index is zero which mean the worst case. The ranking order is defined by condition classes to be more understandable. Condition class 0 requires immediately rehabilitation activities, whereas condition class 4 means no need of action. The amount of condition points can be adjusted by the engineer, depending on the position and density of the failures.

A final ranking order of priority pipes is found by the ranking order of the evaluation numbers. It is obvious that the methodology is simple and could be adjusted easily based on statistical data. Therefore, it could be widely applied. Table 7 shows the condition classes for condition index

Table (7-7): Condition classes for condition index

Total condition index	Condition class
0-20	0
20-40	1
40-60	2
60-80	3
80-100	4

The structural and hydraulic deterioration of AC pipes have been one of the major causes for the interrupted service of water distribution system in Kuala Lumpur. However, maintaining the intended performance of AC pipes is not an easy task because of the limited budget for maintenance and rehabilitation and massive lengths of pipes (6500 km). The need for deterioration models, which can predict current and future condition of pipes, is increasing because the predicted information can be used for budget planning. Development of deterioration model for AC pipes based on GIS is the primary aim of this research. The secondary aim of this study is to identify significant factors that affect the performance of this model.

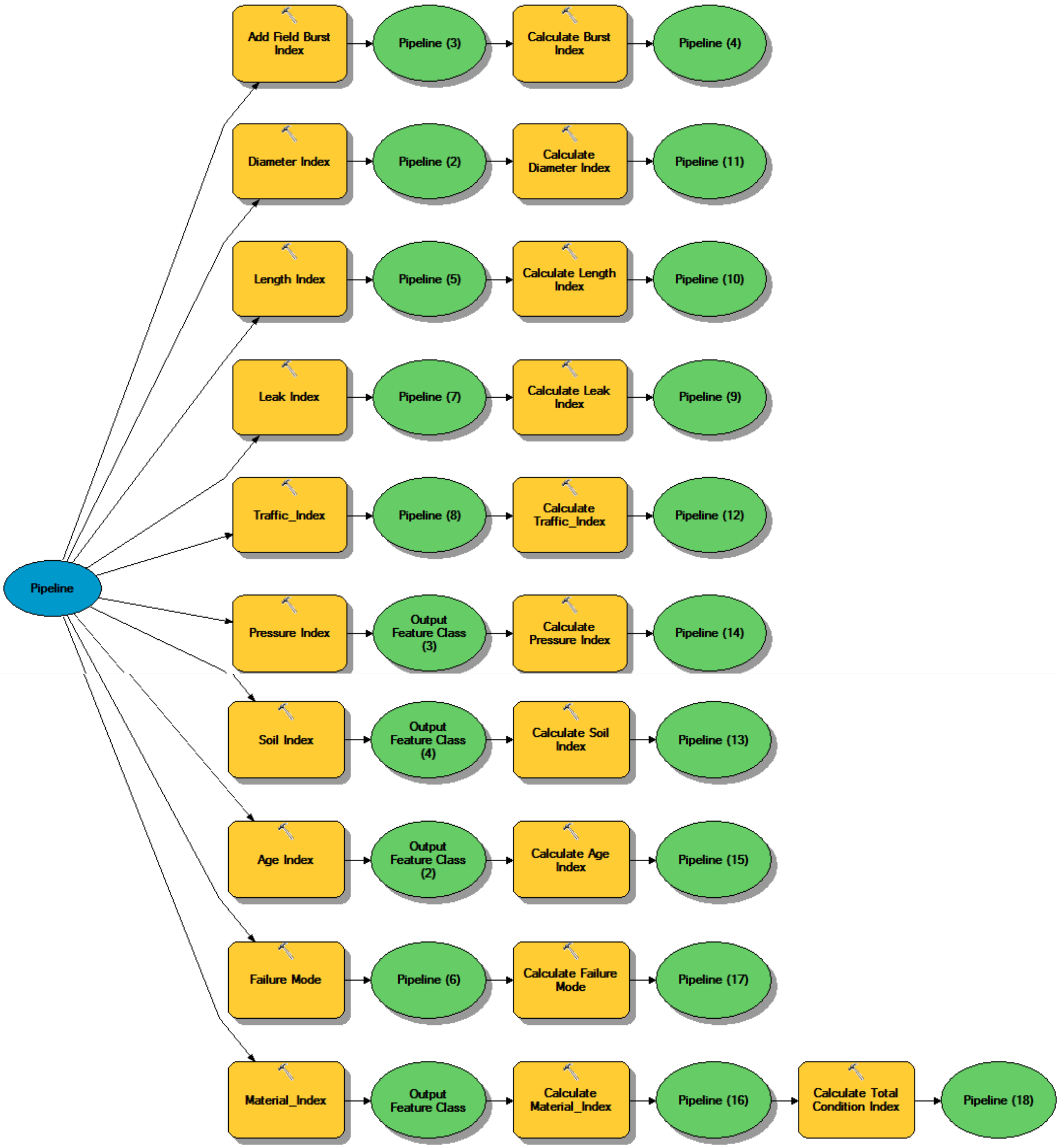


Figure (7-11) Water pipe assessment model structure

Model Design

WPAM has been designed using Model builder in ArcGIS. All required data has been constructed in to comprehensive Geodatabase. Figure (7-11) shows the Water Pipe Assessment model structure. This model has simple structure without complicated equation, which could be applied easily in water utilities.

7.10 Result analysis

According to the results of WPAM minimum condition assessment index for pipes is 21 and the maximum condition is 62 and the average condition assessment for the whole water network in Kuala Lumpur is 45. Figure (7-12) shows frequency distribution of pipe condition index in Kuala Lumpur. Two pipe samples have been assessed in table 8 using the model and have been plotted in figure (7-13). Figure (7-14) shows the pipe condition ranking for the pilot area in Kuala Lumpur.

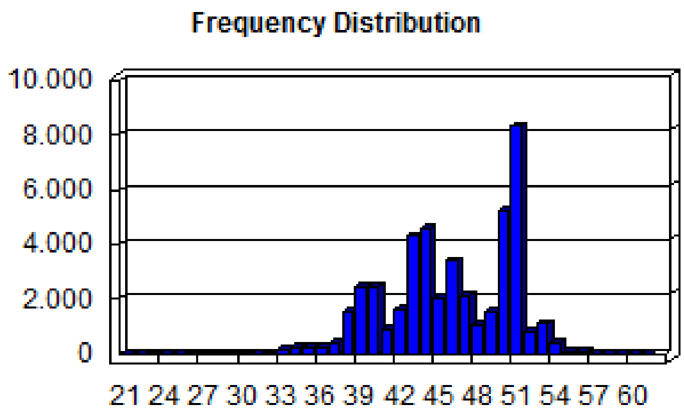


Figure (7-12) frequency distribution of pipe condition index in Kuala Lumpur

Table (7-8) Condition assessment index samples

Criteria	Best Condition Index	Pipe 1	Condition Index	Pipe2	Condition Index
Material	15	AC	0	AC	0
Diameter (mm)	13	250	11	150	8
Pipe Length (m)	6	29	3	5	6
Failure Mode	8	Longitudinal	2	Circumferential	4
Pipe age	20	30	5	30	5
NPF/km	12	2	12	1	6
NPL /km	7	3	3	1	6
Pressure (DMZ)	6	1	6	1	0
Soil	8	Sand	8	Mix	4
Traffic	5	Low	5	High	0
Total Condition Index	**100**		**55**		**39**

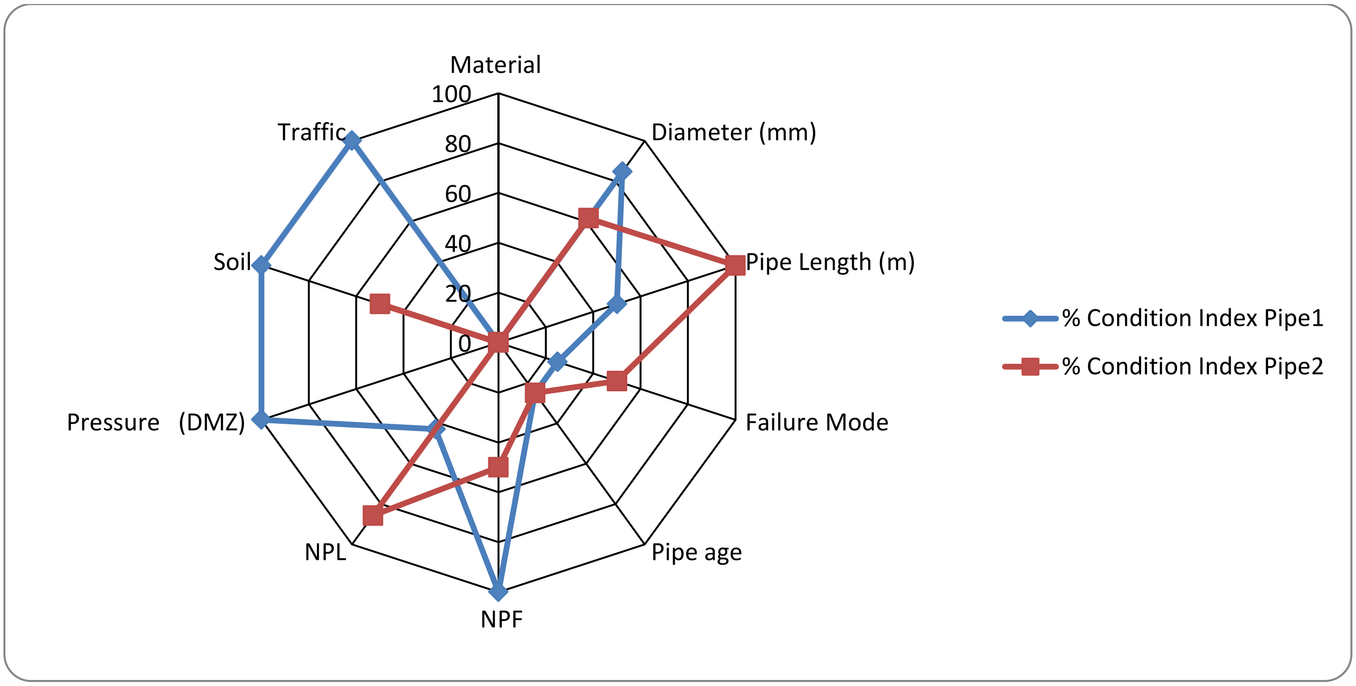


Figure (7-13) Condition assessment index samples

7.11 Condition assessment using phenolphthalein test

Asbestos cement pipe dose not degrade in a similar way like ferrous pipe since pitting failure not happened in AC pipes. AC pipe degrades by leaching of lime (calcium hydroxide) from the cement matrix. The degree of leaching is quantified by the use of pH indicator solution for cut pipe surface, which shows locations leaching point of lime causing a loss of strength. Phenolphthalein is acid has been used in this research as an indicator for cement mortar leaching. Appearing of pinkish violet color on the AC pipes indicates that there is high leaching of cement mortar in AC pipe (Advanced Engineering Solutions, 2007).

7.11.1 Phenolphthalein indicator:

Sub samples of AC pipes were selected for phenolphthalein indicator and examining the area of maximum cement mortar-leaching attack. A subsample was cut from pipe section and polished prior to phenolphthalein indicator. Figure (7-15) shows a view of AC pipe sample as received condition after burst.

According to our visual observations, the sub sample of AC pipes section appeared to demonstrate cement mortar leaching on both internal and external diameter surfaces.

Chemical analysis was carried out on the two samples of AC pipes using phenolphthalein indicator. Figure (7-16) and figure (7-17) show the deteriorating area due to cement mortar leaching.

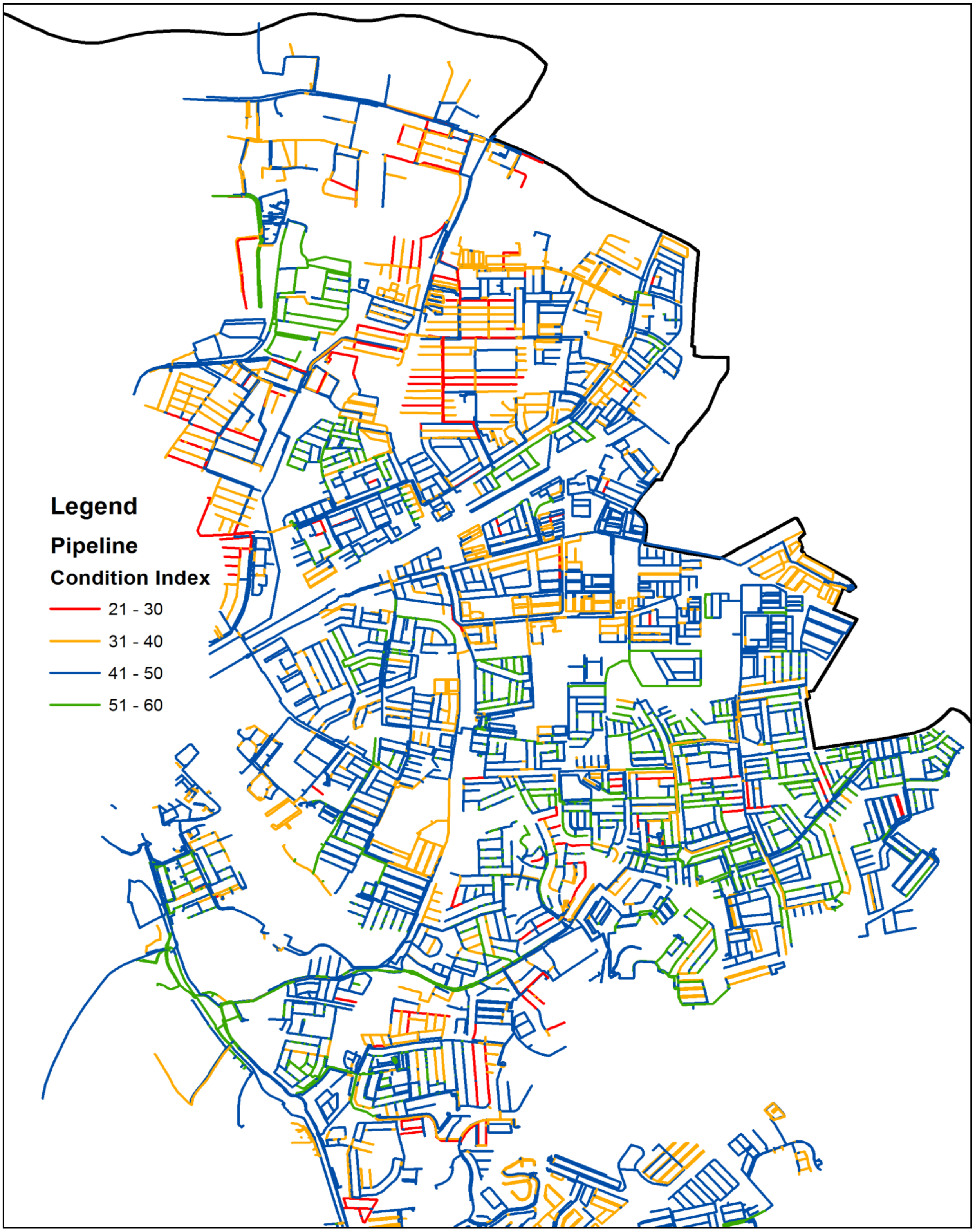


Figure (7-14) Pipe condition ranking

Figure (7-15) View of AC pipe Sample as received condition after failure

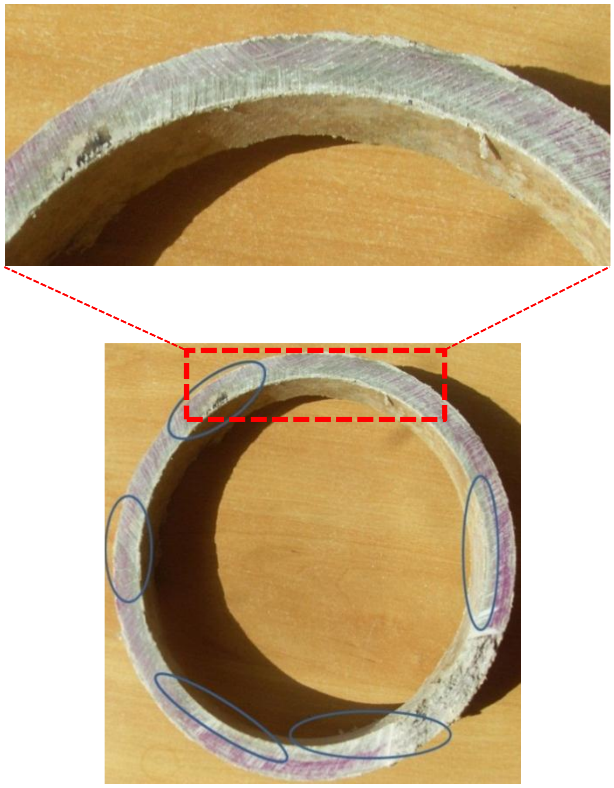


Figure (7-16) Pink staining indicates areas relatively rich in calcium (non-leached); non-pink areas indicate calcium depleted regions (leached).

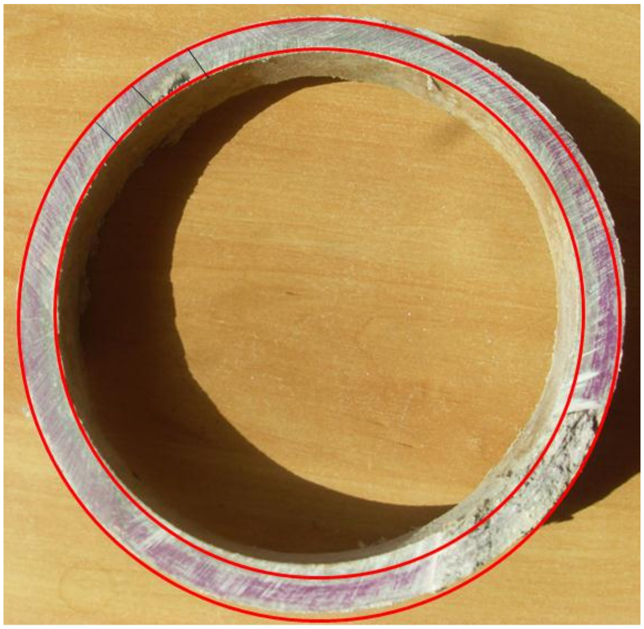



Figure (7-17) The area of maximum cement mortar leaching on each ring section is selected for sub-sampling and further testing.

7.11.2 Visual assessment

According to the visual assessment, the leaching rate was
determined on selected surface areas using caliper and presented in table below.
The degree of Lg leaching rate is calculated as follows (Becker, 2011)

$$L_g = \frac{Aw}{At} \times 100\%$$

Lg = Leaching degree
Aw = White colour area of the pipe wall thickness
At= Total area of pipe wall thickness

Pipe No.	Age	Lg (inside the pipe) %	Lg (outside the pipe) %	Average %
Pipe 1	**35**	**45**	**15**	**30 %**
Pipe2	**20**	**30**	**5**	**17,5 %**

7.12 Results of analysis

In this research Leaching of the cement mortar binder from both the inside and outside diameter surfaces have been analyzed. Leaching of the cement mortar increases the degradation rate of pipe strength. Cement mortar leaching can vary dramatically from pipe section to pipe section and external attack can be highly localized due to variations in the pipe bedding and local soil conditions. Levelton (2011) has been shown that the depth of leaching of AC pipes is approximately proportional to a function of time. So using of pipe age and depth of leaching, depth of attack can be estimated as stated by Levelton (2011). Factors of AC pipe leaching and deterioration are due to aggressiveness of water and soil types.

Calculations have been carried on leaching rate to estimates of additional service life to failure.

Based on the calculations verification can be made to assess the service life of AC pipe and build the ranking system between AC pipes. Average leaching degree for Pipe sample no. 1 is 30% that indicate high leaching degree in this pipe. In Pipe sample no 2, the average leaching grade is 17, 5 which has less rate than Pipe no .1. This can be an indicator that Pipe No.1 has the priority to be replaced before Pipe No.2. Leaching attack rate could be a proportional to a function of service life of the pipe since it is shown that leaching grade increase in pipe with longer time under service. However, due low number of pipe samples, this needs more investigation in future.

7.13 Plan of Action

The present study, results in a management tool for sustainable and efficient management of water distribution networks. The management tool analyzes historical data, links it to visual investigations and through that to indicate of the risk of failure and determine the priority of pipe replacement. The following points have to be taken in consideration after producing the results from model to check the leaching grade in AC pipes:

1- Focus is given on area with no DMZ to check the ability of AC pipes strengths against pressure differences.
2- Focus on the area with high important buildings like schools and hospitals.
3- Focus is given to small diameter and then to roads with high traffic.

Rehabilitation strategies in future can be applied based on condition assessment of AC pipes and budget cost of pipe rehabilitation taking into consideration pipe location and pipe size.

7.14 Conclusion

The objective of this research describe a ranking model for AC pipe renewal based on a combination of chemical pipe inspections and statistical analysis of pipe condition. The model is developed using ArcGIS.

In order to estimate the water distribution condition-state probabilities, the following methodologies are needed:

- Geostatistical Analysis of pipe failures to build the ranking model for pipe condition and renewal plans
- Simple test to verify of AC pipe condition using phenolphthalein to determine the leaching grade.

WPAM model shows a new approach in building ranking system for water pipes condition using limited data available in water utility. Comparison also has been achieved for selected pipes between the condition of AC pipes resulting from model and chemical test which shows nearly similar results.

There are several advantages of modeling statistical of condition-state assessment. The proposed model can be used as ranking system for pipes depending on simple calculations. Decision makers can modify easily the criteria factors based on database analysis. The weight of criteria factor is determined based on historical database, the failure experience and sample test using phenolphthalein indicator. In addition, the simulations done can be useful to evaluate critical areas in the Kuala Lumpur water network.

The results obtained show that the model performance is efficient depends on limited data; pipe material, diameter, number of previous failures and water pressure. The model used to improve the sustainability of water network.

The output from the condition assessment model can be used to estimate future budget needs for rehabilitation and to address the important pipe candidates needs for replacement. This model combined between statistical models within GIS techniques based on simple database, which is available in water utilities.

The model is a new approach to assist water companies to build renewal plans and identify the most appropriate renewal actions, taking into consideration pipe assessment condition.

Chapter 8

8 Overview for plastic pipes failures Analysis

8.1 Summary:

Plastics pipes have been used in the recent years as strong competition for traditional piping materials such as cast and ductile iron, steel. However, several water utilities concern about the life expectancy of plastic pipes due limited available data. However plastic pipes are less expensive to transport, handle, install, and maintain than other pipe material (Stewart, 2005).

This research gives overview about plastic pipe failure analysis. Two cases have been studied; case 1: water plastic network in Bodenheim city and case 2 is comparison between 30 years old plastic pipe with iron pipe in similar location conditions.

8.2 Contributions for plastic pipe failures

8.2.1 Reasons for plastic pipes failures

There are several sources for plastic pipe failures such material deficiencies, production, bad installation, environmental factors, inappropriate storage and transport. Plastic pipes also can be deteriorated due the pipe aging. Third party failure can be considered as main threats to the safety of pipes due to inappropriate installation to other pipes (Farshad, 2006).

8.2.2 Types of plastic pipe failures

Farshad (2006) classified types of failures for five categories as following:
Mechanical failures, arises due external forces that exceed the strength or the maximum strain capability of the material. These failures include cracking and bursts.
Thermal failure, occur from exposing the pipes to high temperature or cold weather. The plastic pipes tend to get brittle at cold weather. Plastic pipes may warp, melt and twist in high temperature.
Chemical failures, chemical agents may affect the pipe material properties. Residual stress, high temperatures and external loading tend to aggregate the problem of chemical ageing.
Environmental failure, environmental factors like humidity, microorganisms, heat, oils can affect the material properties causing cracks and changing colours.
Brittle and ductile failures, low temperature and high loading speed together with residual stress may lead to brittle response of pipes causing rapid crack propagation.

8.2.3 The Hydraulics Behavior Effects on Plastic Pipes

Surges or water hammer is caused after rapid closure of pipe valve leading to high strong pressure inside the pipe due rapid differences in water velocity. This causing cracks in plastic pipes or in many cases failures based on material quality (Oliphant, 2012). Figure (8-1) shows the hydraulics behavior (water hammer) effects on plastic pipes.

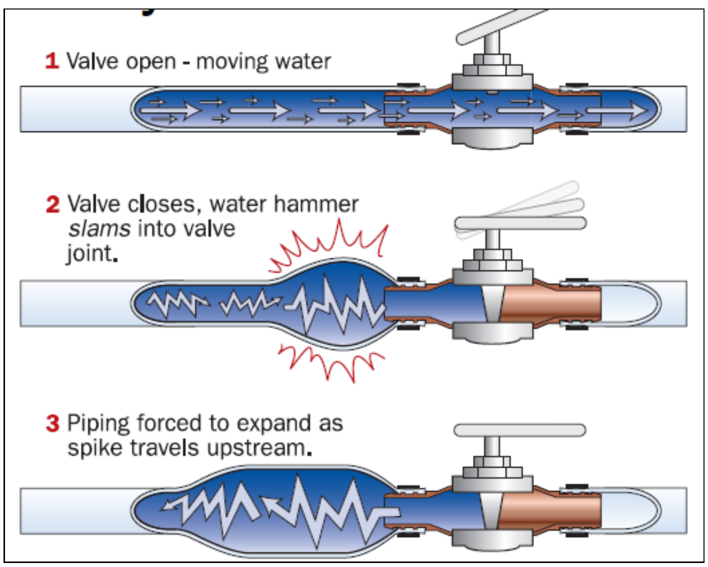


Figure (8-1) The hydraulics behavior effects on plastic pipes (water hammer) (PlumbingMart, 2012)

8.2.4 Crack propagation

Rapid Crack Propagation is more likely to occur in larger pipe diameter (Palermo ,2010). Crack propagation has been described for PE and PVC materials by Oliphant (2012). Slow crack growth morphology (SCG) is occurred by PE regardless of the temperature or load cycle (Oliphant ,2012). However in PVC material shows with faster stress cycle and lower temperature in the same morphology under certain conditions (Oliphant, 2012). Figure (8-3) provides photo for advancing crack in PE pipes. The microfibrals spanning the crack face in the process zone restrain the advancement of the crack until they are drawn down, elongate and rupture. Failures also in PVC show similar fracture morphology as shown in Figure (8-2) (Oliphant ,2012), Bernal-Lara T, et al (2006).

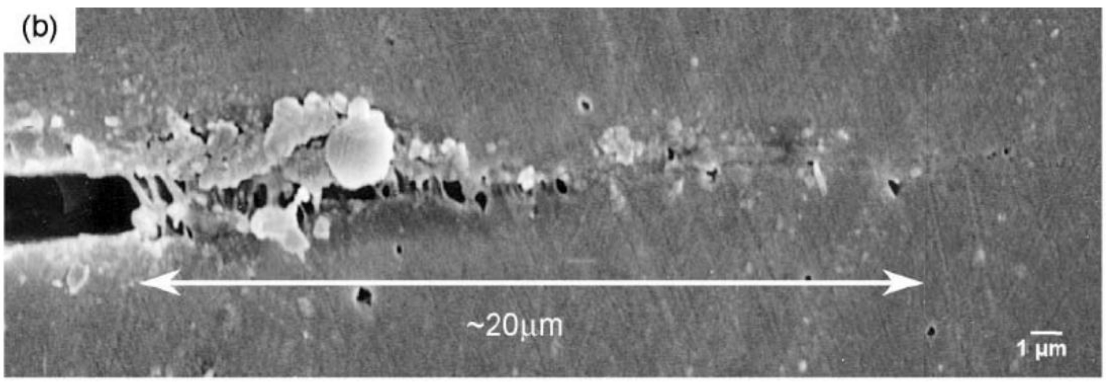


Figure (8-2): Fatigue Slow Crack Growth in PVC , Oliphant (2012)

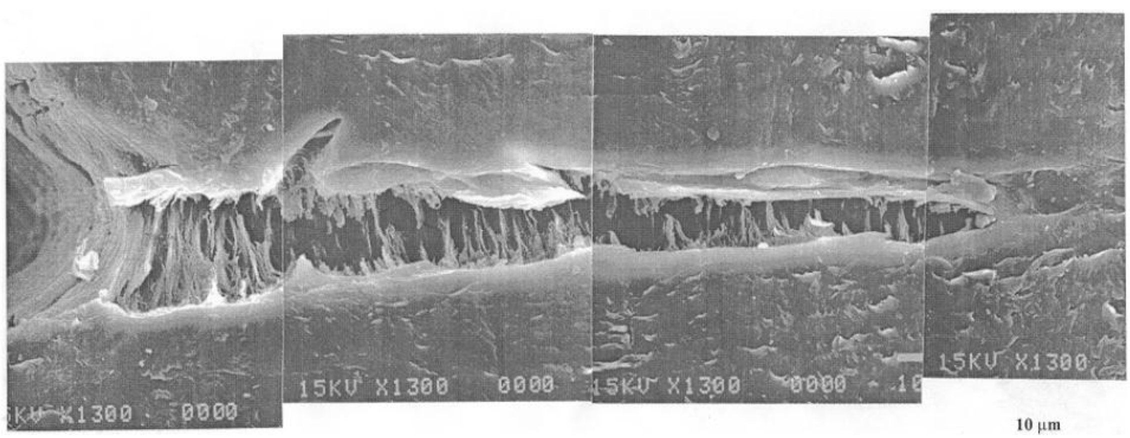


Figure (8-3): Slow Crack Growth Mechanism in PE Pipe, Oliphant (2012)

Effects of chemical Contamination on pipe degradation

There are low risks of pipeline systems being exposed to concentrated dangerous chemicals. Since most company are now regulated and the genuinely contaminated site locations are well-known (Heathcote , 2009).

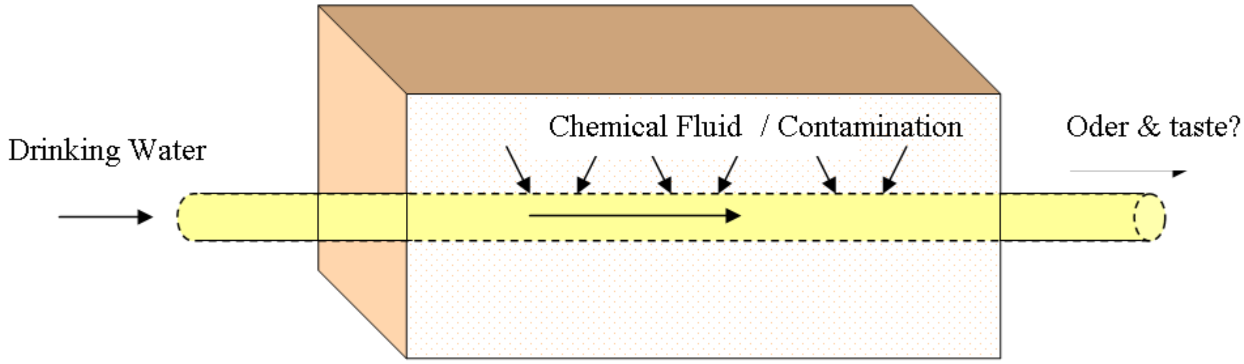


Figure (8-4) Effects of chemical Contamination on pipe degradation

8.3 Methodology

Our simple methodology to determine the cause of plastic failure is used Visual Inspection of the failed part. Several plastic failed pipes have been collected from different locations.
Plastic pipes in Bodenheim water network have been analysed using SPSS. Failure analysis has been done based on pipe diameter, pipe types pipe materials.
On the other hand, 30 years old plastic pipe have been analysed in comparison with iron pipe in the same location to identify the quantity of deposition.

8.4 Case No. 1

8.4.1 Water network system in Bodenheim city, Located south of Mainz in Germany

The Bodenheim drinking water network has a total length of about 178km. More than 55% of this network is made of PVC pipes and about 25 % made of PE pipes and has an average age of about 30 years, ranging from 40 to 0 years. The average failure rate, as recorded in a water utility database, shows there for PVC 0.28 failure /km/year and for PE is 1.71 failure/km/year. There are several reasons for failures such as overloading of the pipe or material defects as results for several researches. Figure (8-5) and Figure (8-6) show Bodenheim Water network map classified by material groups and diameter groups respectively.

.

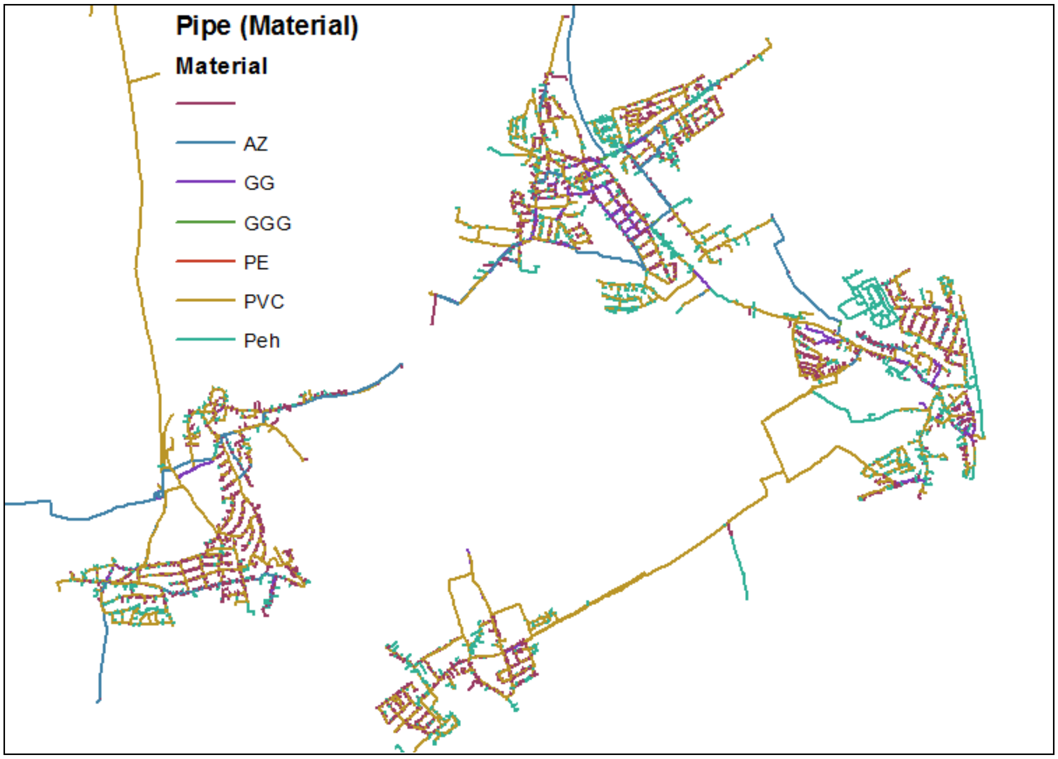


Figure (8-5) Bodenheim Water network map classified by material groups

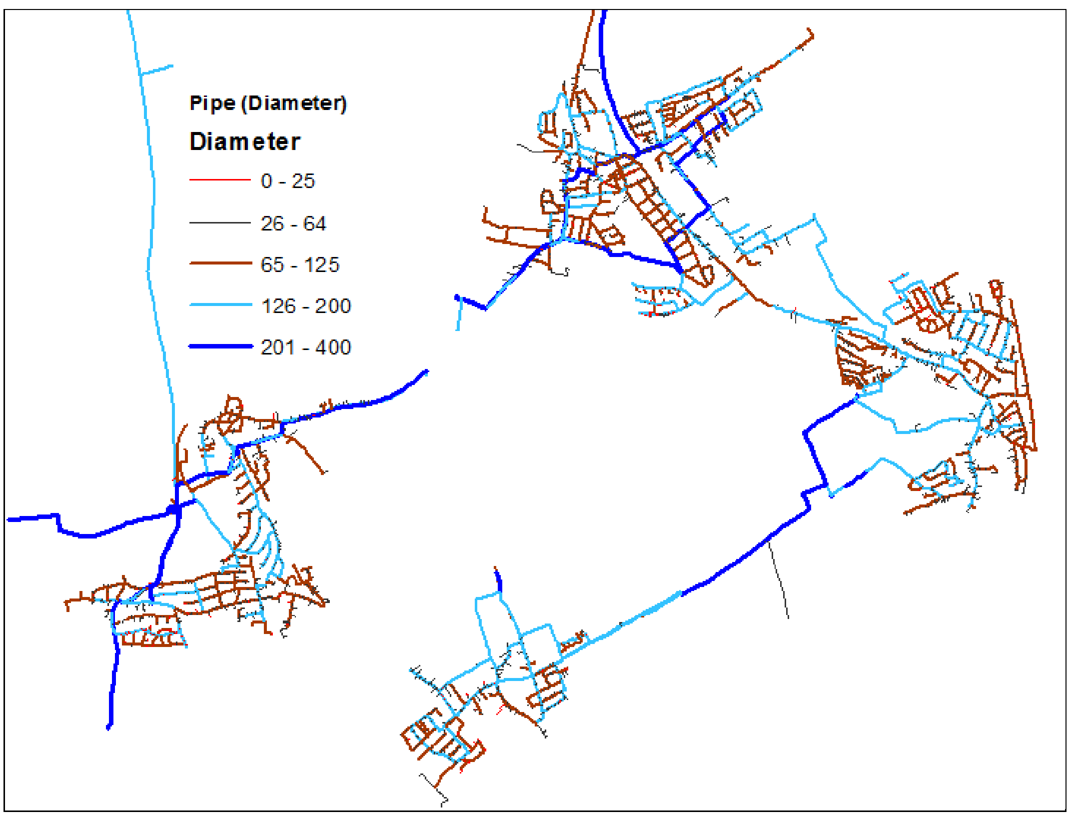


Figure (8-6) Bodenheim water network map classified by diameter groups

Failure types	Frequency	%
Connection Leakage	180	21,1
Crack	373	43,7
cross fracture	46	5,4
Fitting Leakage	28	3,3
Fracture	19	2,2
Hole	131	15,4
Plastic deformation	1	0,1
sleeve damage	3	0,4
Unknown	70	8,2
Valve break	1	0,1
Total	853	100

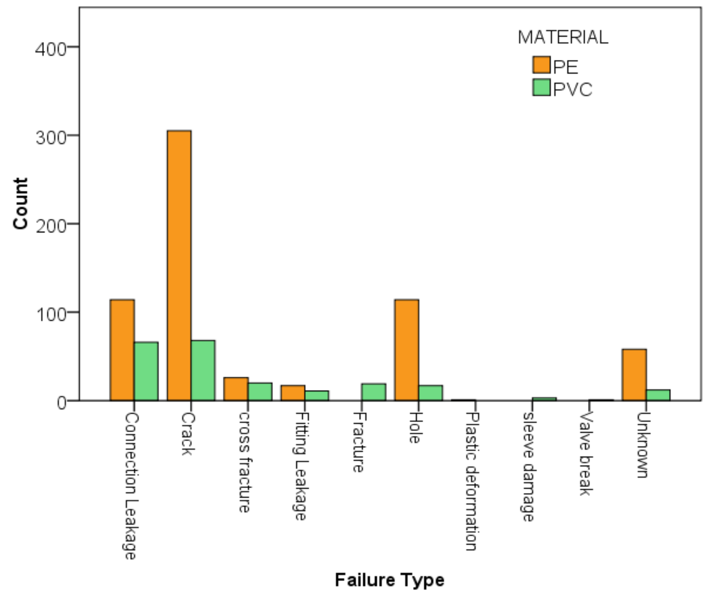


Figure (8-7) Burst counts based on failure types

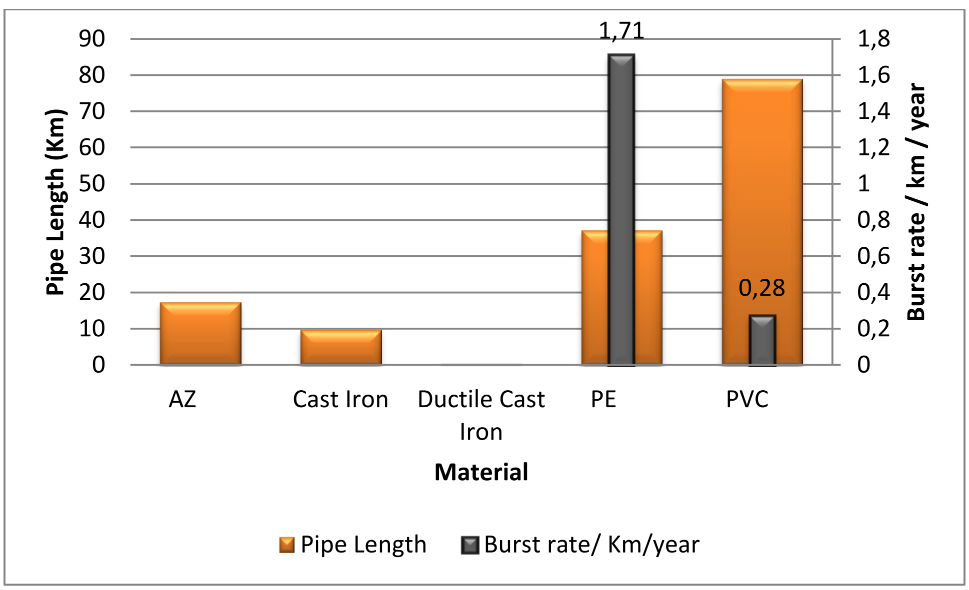


Figure (8-8) Total pipe length for each pipe material groups and burst rate / km /year

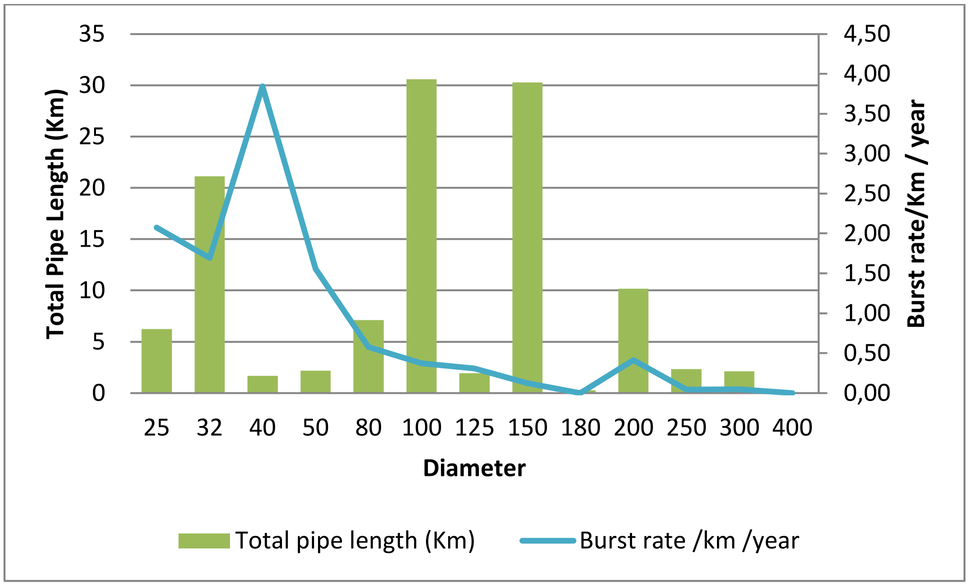
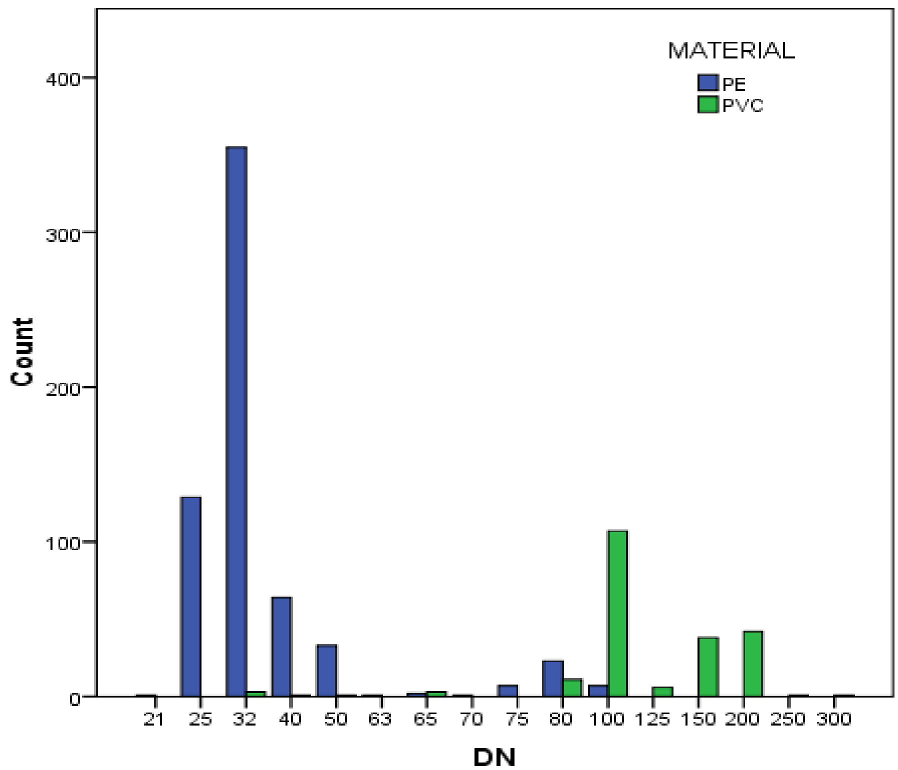


Figure (8-9a) Burst rate for each pipe diameter in water network



Diameter (mm)
Figure (8-9b) Burst counts based on diameter and material in water network

We can identify that crack is the main failure types in water network with about 44 % of the total failure. The next failure type is connection leakage (21%) due installation error, bonded socket joint defect and frost. Figure (8-7) shows burst counts based on failure types in Bodenheim water network. Annual pipe failures are shown in figure (8-10). The linear curve is plotted for pipe failures from 1998 -2010.

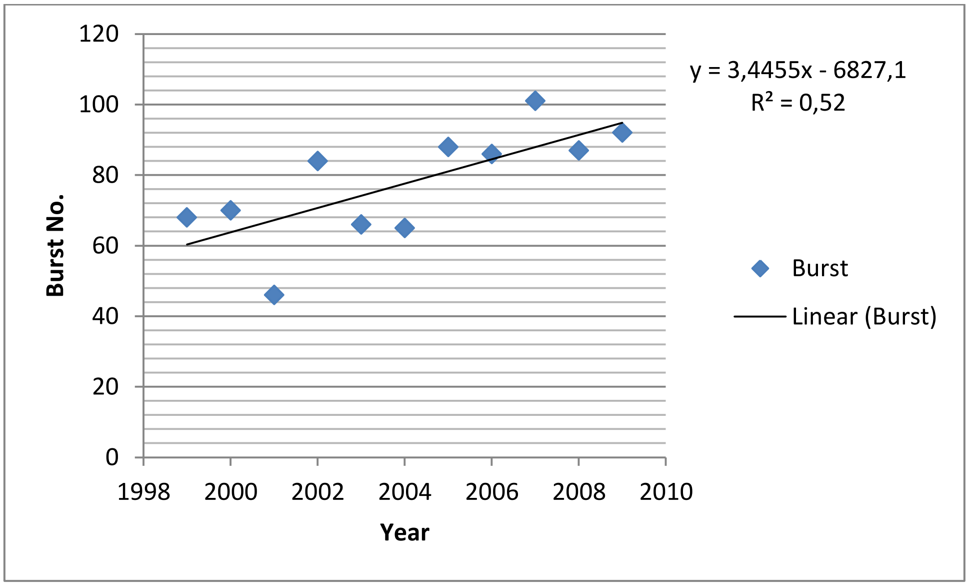


Figure (8-10) annual pipe failures in water network

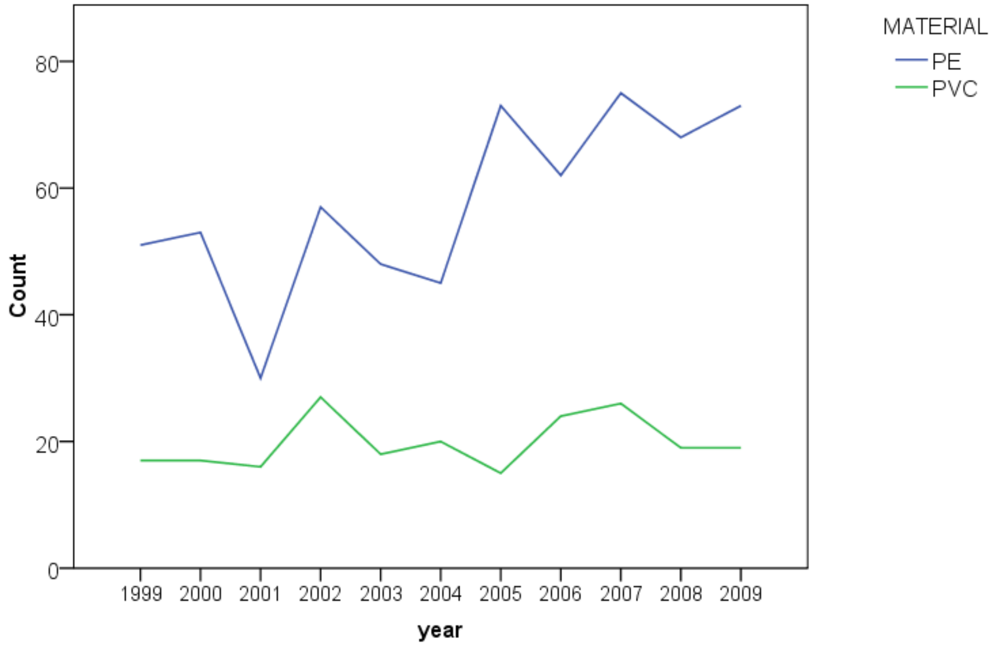
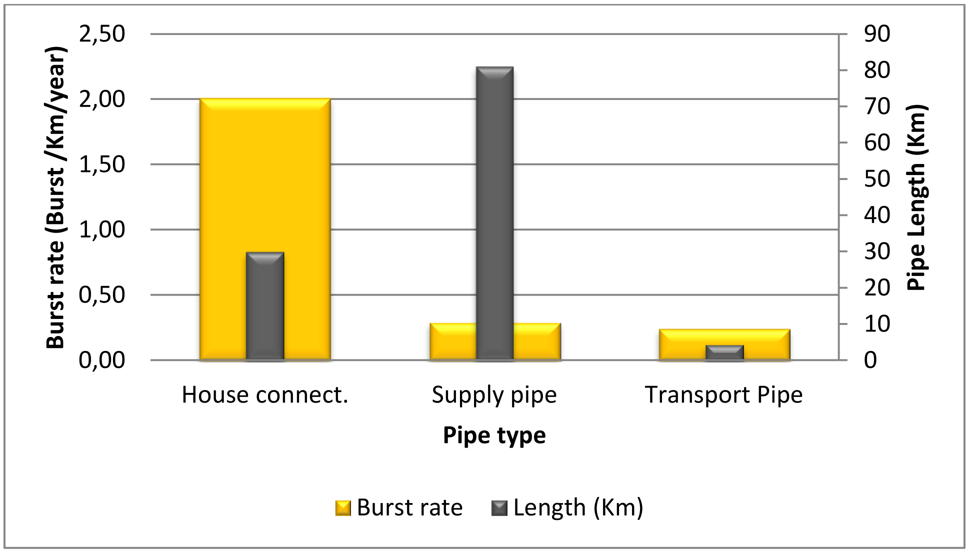


Figure (8-11) annual pipe failures for PVC and PE pipes



Pipe types	Frequency	%
House connection	603	70,7
Supply pipe	239	28,0
Transport Pipe	11	1,3
Total	853	100,0

Figure (8-12) Plastic pipe average burst rate based on pipe types

Also we can identify from Figure (8-11) that annual pipe failures for PE pipes are higher than PVC pipes since most of PE pipes. Most of The PE pipes have small diameter less than 80mm and high low strength against surrounding condition such as stones and frost weather. About 70% of pipe failures are in house connections and average burst rate is about 2 burst/Km/year as shown in Figure (8-12). Several cases have been described for plastic pipe failures in the following figures from (8-13) to (8-16).

Failure case H- 1	
Pipe material	HD-PE SDR 11 (S 5) PN 16
Dimensions	Outer diameter 90mm, inner diameter 72.6, thickness 8.2
Description of the system	Water distribution system
Failed part	Fitting connection
Failure description	Valve Movement
Environmental condition	
Pipe condition	bad
Dimension analysis	Shortest ID 64mm (64 / 72.6)x100 = 88.15 %
Deflection	100 - 88.15 = 11.84%
Time to failure	After 30 years
Tests performed	unknown

Failure cause	Material weakness , increasing the stress on the connection
Corrective actions	Replaced the connection part of the pipe
Photo documentation	Figure (8-13)

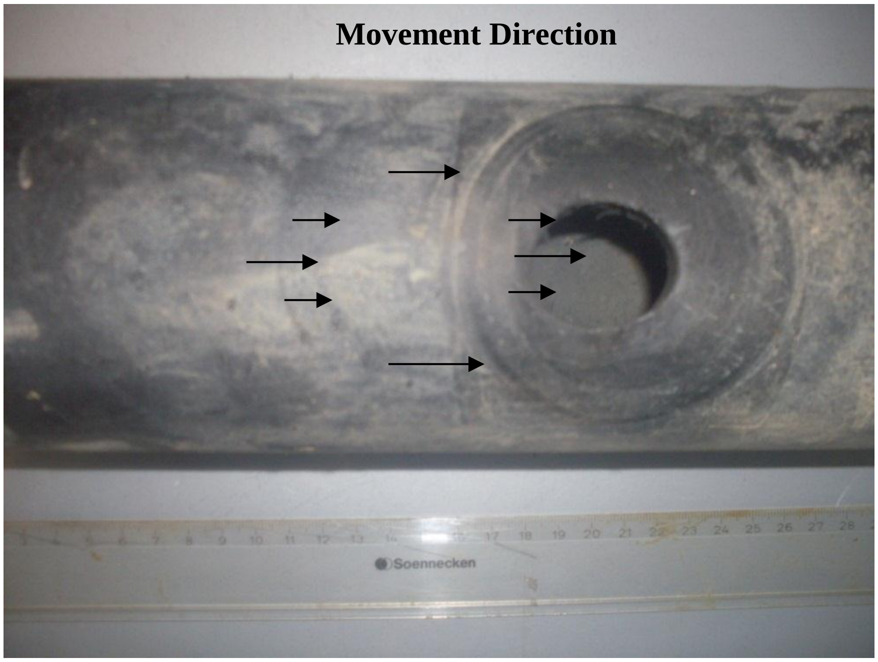


Figure (8-13) Failure case (H-1) for PE pipe connection failure

Failure case H- 2	
Pipe material	U-PVC PN 12.5
Dimensions	Outer diameter 225mm, inner diameter 203.4, thickness 10.8mm
Description of the system	Buried pipeline Water distribution system
Failed part	Pipeline
Failure description	the pipe was broken for 2 pieces
Environmental condition	
Pipe condition	Good
Dimension analysis	100%
Deflection	No deflection
Time to failure	30 Years
Tests performed	Unknown
Failure cause	Increasing the Internal hydrostatic pressure
Suggested Corrective actions	Redesign the pipe network, choose appropriate pipe material diameter taking into consideration internal pressure
Photo documentation	Figure (8-14)

Figure (8-14) Failure case (H-2) for UPVC pipe failure

Failure case H- 3	
Pipe material	U-PVC 12.5 PN
Dimensions	inner diameter 160
Description of the system	Water distribution system
Failed part	Gate Valve for 160mm upvc pipe
Failure description	Broken of the upper part of gate valve
Environmental condition	
Pipe condition	Good
Dimension analysis	100%
Deflection	No deflection
Time to failure	30 Years
Tests performed	Unknown
Failure cause	Increasing the stress on the disc due to corrosion of steel screw stem
Suggested Corrective actions	Redesign the pipe network, choose appropriate pipe material diameter taking into consideration internal pressure
Photo documentation	Figure (8-15)

Figure (8-15) Failure case (H-3) for UPVC pipe valve failure

Failure case H- 4	
Pipe material	PE
Dimensions	Outer diameter 40 mm, inner diameter 32.2, thickness 3.7mm
Description of the system	Water distribution system
Failed part	Pipe
Failure description	Cracking
Environmental condition	
Pipe condition	Bad
Dimension analysis	
Deflection	
Time to failure	25 years
Tests performed	Unknown
Failure cause	Material weakness, external loading, insufficient of pipe thickness
Suggested Corrective actions	
Photo documentation	Figure (8-16)

Figure (8-16) Failure case (H-4) for PE pipe crack failure

8.5 Case No.2

Quality assessment of plastic pipes in deposition concentration in comparison with Iron pipe of Water Network. Pipe samples were obtained for PVC and iron pipes because these constitute the majority of the infrastructure used for distribution systems. This study will show in general a view the amount of deposition based on pipe materials. When the flow in water network is not continuous concentration of deposition will be increased. Polyvinyl chloride (PVC) and iron pipe materials differentially affected by manganese deposition within a water network (Kriš, 2007).

Sediment settling in water networks causing deterioration in quality of water. This creating brown water, which can lead in many cases to complaints by customers (Kriš, 2007). (Thomson, 2003) also studied the possible deterioration of water quality once it enters a distribution system. Figure (8-17) shows the sediment settling in plastic and iron water pipe.

Figure (8-17) Corroded surface scales on the pipe

Figure (8-18) Corroded surface scales on the iron pipe

Figure (8-19) Sediment settling amount taken from iron pipe

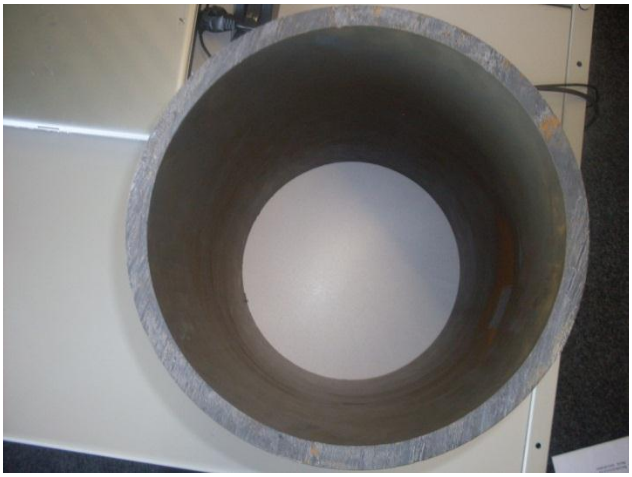
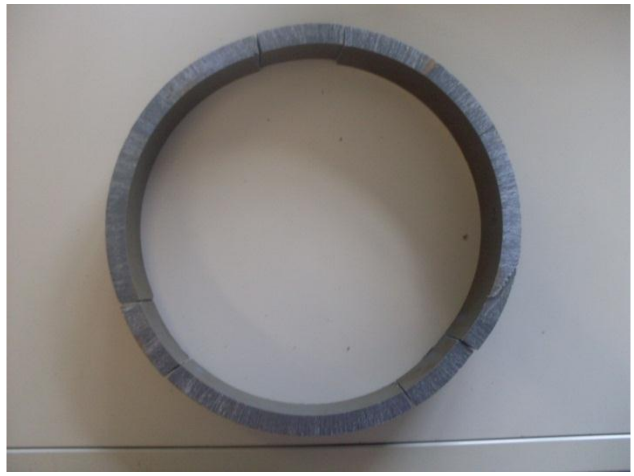



Figure (8-20) Pipe Diameter and Dimension Ratio (DR)

UPVC 315 mm pipe sample:

Settled mass in PVC has been measured by making square 4 x4 cm inside the PVC pipe measuring the amount of settled material.

Iron pipe

Settled mass in iron pipe has been measured by making square 10x10 cm inside iron pipe.

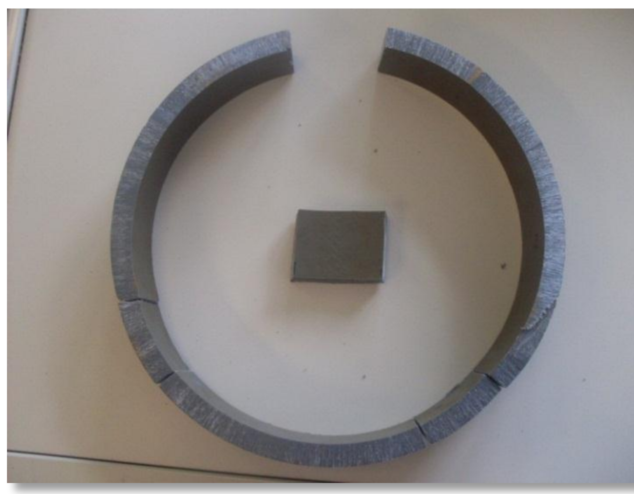



Figure (8-21) UPVC pipe sample preparation

Figure (8-22) Bottom view of the UPVC pipe after 30 years installation.

Figure (8-23) Settled mass in iron pipe and PVC pipe

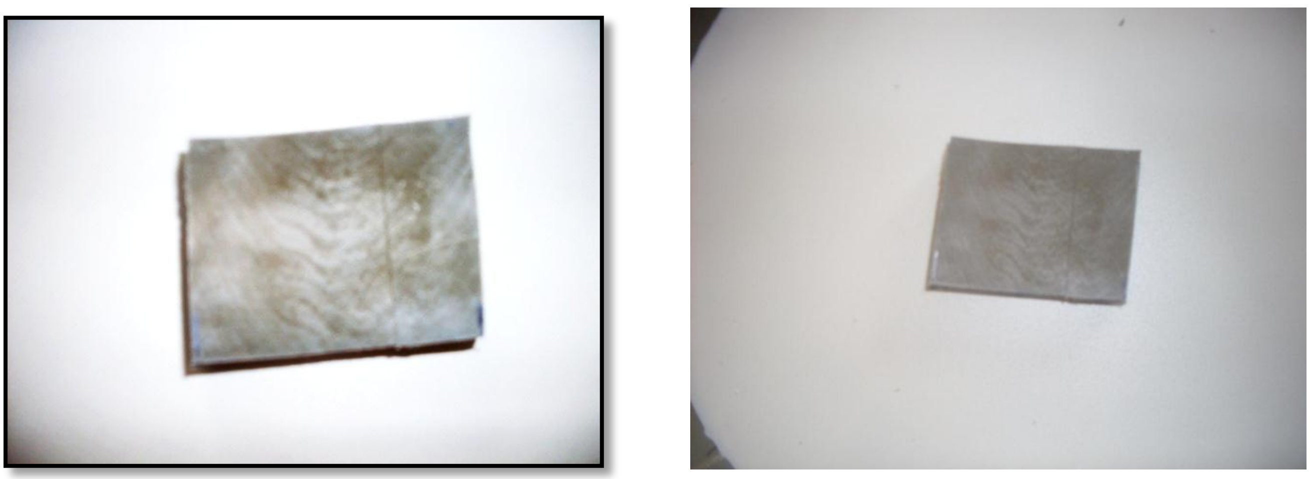


Figure (8-24) Deformation on the bottom side of UPVC pipe

Results of Comparison between deposited in UPVC pipe and Iron pipe:

We can identify by vision the big difference between deposition settled in Iron pipe since it is about 3,75 Kg/m^2 and 0,0125 Kg/m^2 in UPVC pipe as shown in table (8-1).

The UPVC pipe after 30 years under service has a good condition despite of small deformation in below of UPVC. However, the iron pipe has been corroded with high rate of deposited inside the pipe.

Table (8-1) Comparison between deposited in UPVC pipe and Iron pipe

pipe sample	Sample size		m^2	Deposited g	Deposited g/m^2	Deposited Kg/m^2
Iron Pipe	0,15	0,15	0,0225	84,3	3746,7	3,75
UPVC Pipe	0,04	0,04	0,0016	0,02	12,5	0,0125

The effect of main parameters on increasing the cracks in plastic pipe a comparison can be prepared between old and new pipe samples to identify real strength of plastic pipes. Table (8-2) shows some of suggested pipe tests for old and new samples to make a general comprehensive overview for plastic pipe assessment.

Table (8-2) pipe test for old and new samples

	Old Pipe Samples PVC & PE
1	**Growth Crack Rate Tests**
	Objectives: • Collect samples of plastic pipes from German companies and then test these samples in the labs to identify the reason of failure and assess the condition of the pipe samples according to Growth Crack Rate. • Comparing between PVC & PE Samples • Comparing between different producing Periods Ex.1980-1990 or 1990 -2000 • Comparing between different companies
	APPARATUS
	• Microtome • Microscope

	New & Old Pipe Samples
1	**Mechanical Tests**
	Objectives: • To determine the prediction life period for the Plastic Pipes (PE &PVC) under the Static Load (Soil) and Live loads (Traffic).
2	**Thermal Tests**
	Objectives: • To find which type of plastic pipe should be used according to the temperature changes • To determine the Plasticizing additives should be used in Plastic pipe depending on the environments
3	**Chemical Tests**
	Objectives • To determine the external effects of chemicals on the plastic pipe deterioration • To determine the Permeability of chemicals (Benzen & Oil) inside the Pipe.
4	**Hydraulic Tests**
	Objectives : • To determine the effects of water hammer on the plastic pipe and Fittings

8.6 Conclusions:

This research gives an overview about the plastic pipes failure. Comparison between old plastic pipe and Iron pipe has been done. Iron pipe tend to have high rate of deteriorated more than plastic pipes taking into the consideration the pipe age. These pipe samples for UPVC and Iron pipe were taken from the similar location and surrounding condition. Several plastic pipe failures have been studied in Bodenheim water network. Visual inspection of failed pipes has been done. Crack is the main failure type in plastic pipes due to high stress on the of the pipe and material defects.

This research presents a comparison between iron pipe and plastic pipes with similar surrounding conditions. Both pipes have been installed before about 30 years in same location. According to simple inspection, there is big difference between depositions settled in Iron pipe and plastic pipe.

Evaluation of crack growth is an important indicator for strength of plastic pipes in the future. This research can be used also by water utilities to take into consideration the factors of plastic pipe deterioration.

Chapter 9

9 Survival and Neural Network Analysis of Water Pipeline: Frankfurt am Main Case Study

9.1 Summary

Sustainable improvement of water network is required to understand the real condition of the system. Several methods are available for determining condition of the water pipe network such as prediction methods, deterministic methods and proactive methods. This research presents a framework overview for determining the condition of integrated water network based on survival and neural network analysis of the water network. Frankfurt am Main water network is the case study in this research. The approach presented combined between theoretical and practical tools to develop this framework. This framework is the basics for prioritizing the rehabilitation of water networks including the most important factors of pipe failures.
The results of this approach on Frankfurt water networks are very satisfying. In this research, two results have been achieved: survival analysis between pipe material and importance factor using ANN.
Keywords: Water networks · Risk analysis · Survival analysis, GIS

9.2 Introduction:

Prediction of sustainability of water network is an important issue in water network management. Pipelines renewal priorities are one of the factors determining the future condition of this pipeline.
Pipe failures have been studying from many researches since many years trying to achieve the new methods in reducing the failures or improvement of the water network. This research used survival analysis to build efficient strategies for pipe maintenance. By this analysis the impact of

renew pipe al rate on the percentage of reducing of failures numbers and increasing the improvement of water network.

The analysis presented in this research was performed using SPSS statistical software. Survival analysis has been used in distribution of the survival time for different pipes materials.

The pipe failure database have been collected for the period from 2001 – 2009. This research analysed the technical condition of water pipe network in Frankfurt am Main. Survival analysis and neural network analysis have been used to analyse the technical condition of the pipes using statistical software. The pre-processing for most of the data for this research has been done using in ArcGIS. The data is obtained from Mainova Water Company.

The pipes in the system are predominantly ductile iron, grey cast iron and plastic (PVC and PE) although there are smaller amounts of pipes made of asbestos, steel. Pipe diameter ranged from 20mm to 1200 mm. It is well worth noticing that the average length of a pipe is 30 m. The average pipe age for 25 % of water networks is 60 years and about 8% of pipes older than 100 years.

This makes high pressure to Water Company for increase the maintenance and rehabilitation efforts. According to that, two challenges faced Water Company in Frankfurt; the first is needs for water pipe rehabilitation expenditure, the second is decreasing the water price according to federal state of Hessen requirements. In this research, the future requirements for rehabilitation plans of water networks have been described. Strategic rehabilitation plans in this research aims for improving the level of the network performance in the long-term.

This research is important to identify and prioritize rehabilitation strategies of water pipes, and to assess the impact of various renewal strategies. Analyses have been achieved using survival analysis model and neural network analysis.

9.3 Methodologies

Work methodology for this research was based on three components; GIS analysis, Survival analysis and neural network analysis. Geographic Information System (GIS) has been used as a system for capturing, storing, checking, manipulating, analysing and displaying data collected from Mainova Company. We used survival analysis to estimate time distribution based on two factors; pipe material and pipe diameter. Artificial Neural Networks (ANNs) are used to recognize patterns in the data, train the network for calibration, and predict future conditions.

The factors considered in this research are the number of observed previous failures (NOPF), the material types (MAT) and pipe diameter (D), failure mode and pipe types.

Table (9-1) Material symbols definition

Material (German)	**Description**
GGG	Ductile cast iron
GGGZm	Ductile cast iron with Cement mortar lining for interior protection
GGGKaZm	Ductile cast iron with Cement mortar lining for interior protection and Plastic coating for external protection
GG	Cast iron
GGZm	Cast Iron with Cement mortar lining for interior protection
Pb	Polybutene
St	Steel
StBit	Steel with bitumen
StZm	Steel with Cement mortar lining for interior protection
Et	Asbestos
B	Concrete
PE	PE(Polyethylene **)**
PVC	PVC Polyvinyl Chloride
Spb	Prestressed concrete

9.4 State of Knowledge

Christodoulou (2011) developed a framework for proactive risk for water network based on a combination of artificial neural network, parametric and nonparametric survival analysis. Stavroula (2011) also presented a pipe networks risk assessment based on survival analysis. He used three pipe networks carrying different types of fluids (oil; gas; and water) to study risk assessment. (Ho CI et al, 2010) used GIS-based hybrid artificial neural network to prioritize pipe replacement in water network. (Al-Barqawi et al, 2008) also designed a model to predict the performance of water mains using an analytic hierarchy process (AHP) and artificial neural network (ANN). Also (Ardakani, 2004) used ANN to find water pipe failures due earthquake. In addition, some of researchers used ANN to predict the condition of pipes or sewer such as (Najafi et al, 2005).

9.5 Description of Frankfurt water network

The water distribution supply in this research is the network of the Frankfurt am Main, Germany. The water network in Frankfurt is over 120 years of age. The dataset used in the study spans a 10-year period (2000–2010) and about 6,000 pipe bursts (Mainova, 2010). Frankfurt city gives the operation of public water supply in the urban area to the Mainova Company. The company currently supplied daily around 662,000 inhabitants and around 305,000 commuters and around 31,000 guests. The Mainova Company operates water utilities in Frankfurt depending on water from the Hessenwasser GmbH & Co. KG (Hessenwasser) without extraction and treatment systems (Mainova, 2010). Mainova provides water for about 250 km^2 of urban area also the company has a supply network with approximately 1,380 km of pipelines and approximately 60,900 service connections. The water supplied by the Hessenwasser drinking water to some 180 transfer points in the supply network of Mainova to compensate for fluctuations in consumption and to keep water reserves for the case of fire and operate the Hessians water with six elevated tanks with a total storage volume of 146,000 m^3. The functional distinction between the transport network of Hessen and water supply network of Mainova is not possible due to the enormous number of transfer points. Because of that, the billing of water consumption between Hessenwasser and Mainova is particularly important (Mainova, 2010).

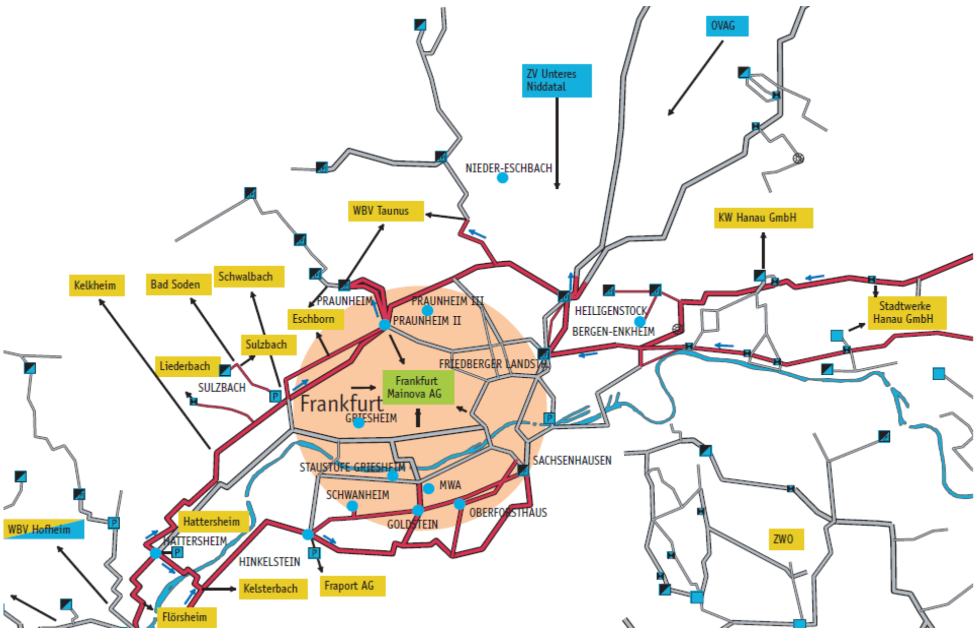


Figure (9-1) The water network considered in this study (Hessenwasser, 2011)

The Hessenwasser conducts drinking water through the supply system of the city of Frankfurt am Main to neighboring cities and communities. The water flow is carried out by the transport or main network of the Hessenwasser, as well as by the supply network of Mainova Company. Figure (9-1) shows the water network considered in this study. Due to the topography with geodetic height differences of up to 132 m 1st, the total area of the city of Frankfurt am Main, divided into 15 service areas, spread over six pressure zones. The coverage areas are supplied by one or more elevated tanks. In some service areas is a booster or a pressure reduction system interconnected. The inventory data of the supply system are stored digitally in a geographic information system (GIS) Mainova. The levels of consumption in urban areas are maintained digitally in an accounting system. A digital pipeline calculation in a complex supply system is based on any major planning task; the hydraulic, sanitary and economic aspects should be taken into account. Therefore, if the development of a computational model for the coverage area of the city of Frankfurt am Main is a right decision Mainova (Mainova, 2010). Mainova uses for establishing remediation strategies in the supply network a manually based on criteria. Here for each individual case has separately an assessment of pipe failure based on the following criteria;

pipe material, pipe age, soil type, groundwater level, development distance, traffic congestion, operating expenses (Mainova, 2010) .

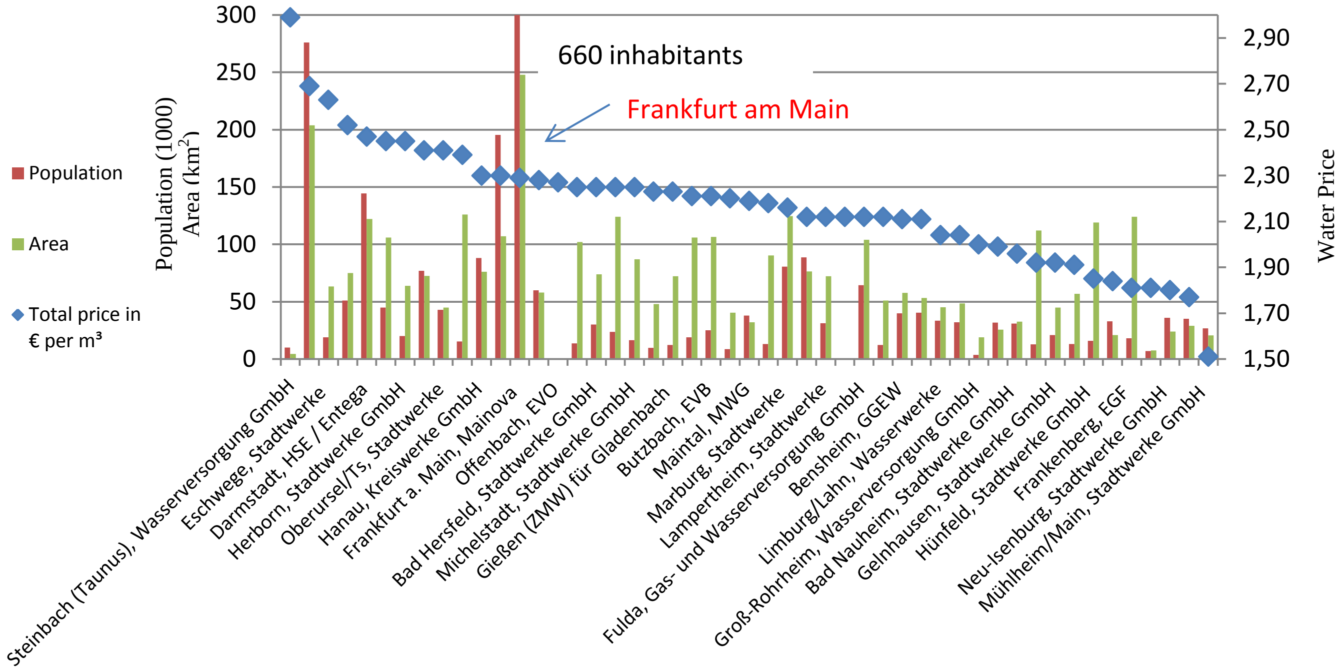


Figure (9-2) Comparison between water utilities in Hessen in water price, area and population (Hessen, 2011).

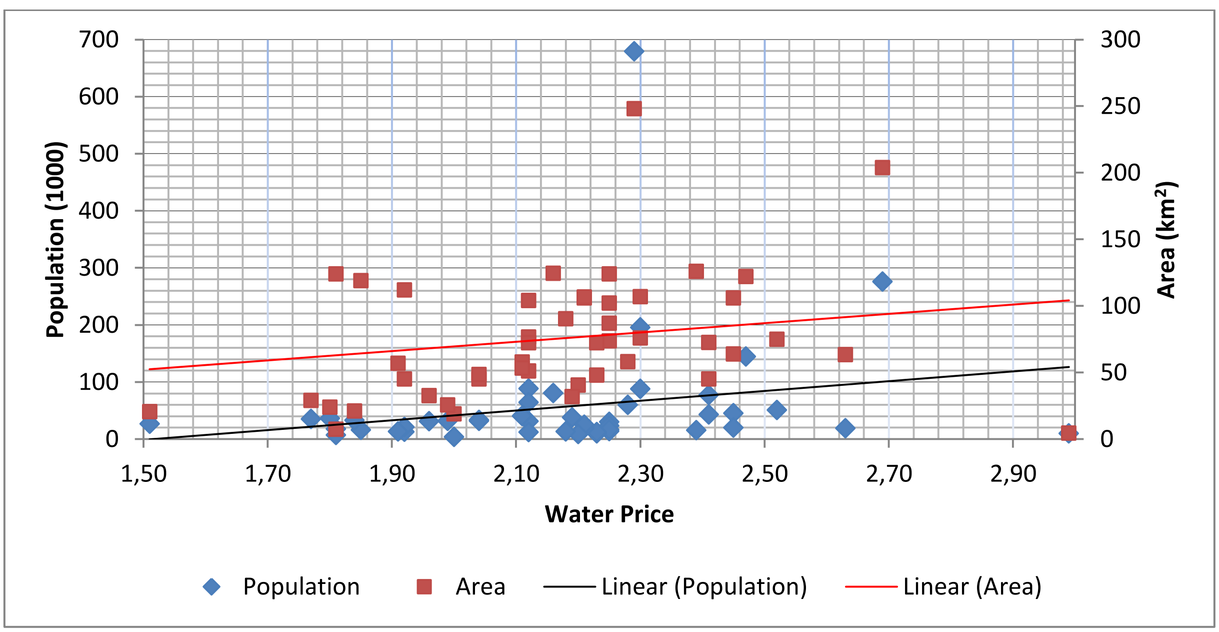


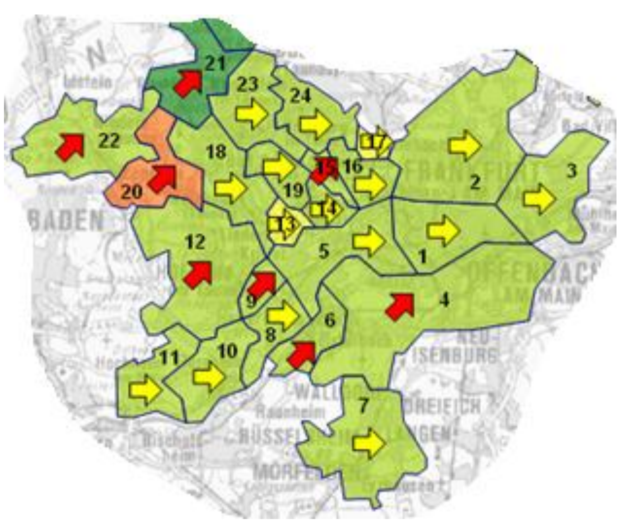
Figure (9-3) Relationship between water price, population and area for water utilities in Hessen State (Hessen, 2011).

Water price in Frankfurt City

The water supply industry typically is a candidate for natural monopoly. Currently, in Germany prices for water customers differ between 0.52 Euro and 3.95 Euro per cubic meter. This encourages the federal state of Hessen to undertake a number of trials to reduce the water prices in Frankfurt for about 37% by the federal cartel office, primarily because of the wide range observed throughout the country (Hessen, 2011). Figure (9-2) shows the comparison between water utilities in Hessen in water price, area and population. The water price in Frankfurt is 2,29Euro per cubic meter.

Also we can indicate that there are slight relation between increasing of water price with increasing service area and number of inhabitants. Figure (9-3) shows the relationship between water price, population and area for water utilities in Hessen State. However Frankfurt City has special case in increasing of water price more than average prices of cities in Hessen state due that there are about 20% of water pipes are older than 60 years under the service, which need more rehabilitation and renewal program. Also the number of population in Frankfurt is increasing through the day 50% more than the actual inhabitants in the City.

Figure (9-4) shows zones definition in Frankfurt am Main city



	Zones Definition
ID	**Name**
1	KG 1 (Stadtkern)
2	KG 2 (Westend / Bockenheim)
3	KG 3 (Nordend)
4	KG 4 (Ostend / Bornheim)
5	KG 5 (Sachsenhausen / Oberrad)
6	KG 6 (westliche Vororte)
7	KG 7 (Praunheim / Rödelheim / Hausen)
8	KG 8 (Heddernheim / Niederursel)
9	KG 9 (Ginnheim / Dornbusch / Eschersheim)
10	KG 10 (Preungesheim / Bonames / etc)
11	KG 11 (Riederwald / Seckbach / Fechenheim)
12	KG 12 (Kalbach-Riedberg)
13	KG 13 (Nieder-Erlenbach)
14	KG 14 (Harheim)
15	KG 15 (Nieder-Eschbach)
16	KG 16 (Bergen-Enkheim)
17	KG 17 (Flughafen)
18	KG 18 (Niederrad)
19	KG 19 (Sindlingen / Zeilsheim / Unterliederbach)
20	KG 20 (Bad Vilbel)
21	KG 21 (Camp-Phönix-Park)

Figure (9-4) Zones definition in Frankfurt am Main city (Mainova, 2010)

Data quality

Date quality of collected database was important point in our research. We used ArcGIS mapping and SPSS Statistical software to check the quality of data. Several records have been ignored to insure the analysis accuracy. We eliminated bad data records such as doubled records and wrong input data. In this study, about 5000 cases of water pipelines failures were considered to the analysis.

History of Pipe failures

Mainova water Company reports approximately 600 water pipelines bursts per year. Water pipelines breaks may temporarily suspend water supply to households and businesses in the surrounding areas in Frankfurt city. Pipe failures can also result in several damages, street and sidewalk closures, and traffic disruptions. Failure database is available from 2001 until 2010. The water pipelines failure database was recording the failures just happened in the night. However currently there are recording to all failure databases.

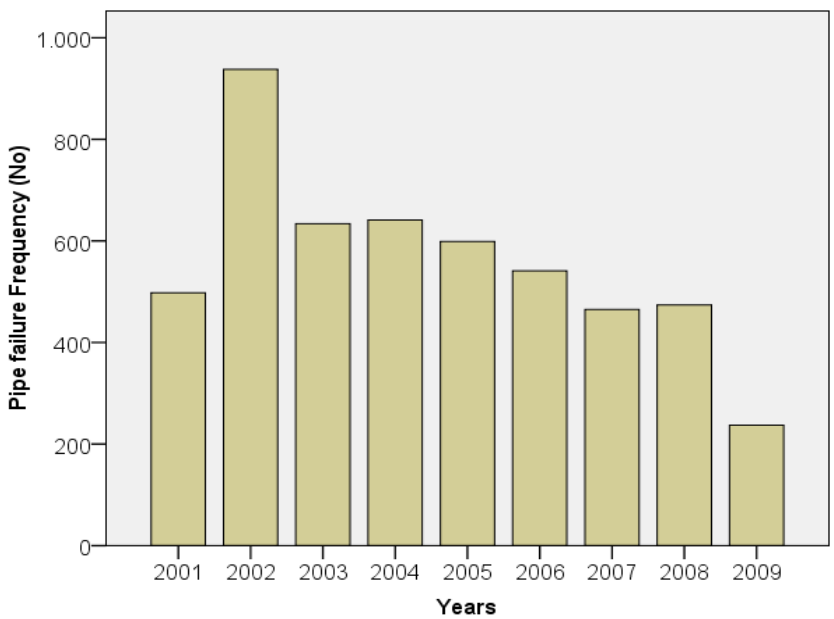


Figure (9-5) Annual Pipe Failure in Frankfurt City

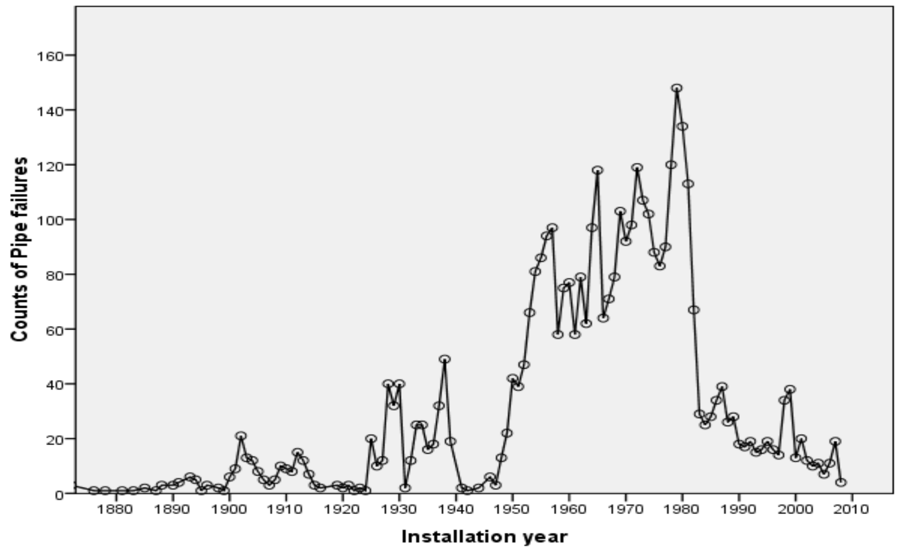


Figure (9-6) Pipe Failure counts based on the installation years of pipelines in Frankfurt City

Figure (9-5) shows the annual number of bust in Frankfurt city. Based on pipe installation years, we can identify that the number of bursts has been increasing with pipe installed between 1960 and 1980. Figure (9-6) shows pipe failure counts based on the installation years of pipelines in Frankfurt City. Figure (9-7) shows monthly failure counts. Distribution of pipe failure based on pipe diameter is shown in Figure (9-8). This figure shows that pipe failure are decreasing with increasing of pipe diameter. According the pipe burst based on material types, Steel pipes had a higher number of failures than other materials, which had 1,625 bursts in the whole period from 2001 to 2010 (6.58 Bursts/Km). Cast Iron had about 800 bursts in the whole period (1.65 burst/Km) then Ductile Cast Iron with 451 burst in the whole period (1,02 bursts/Km).
Figure (9-9) shows burst rate per Km, bursts accounts and total pipe length for each pipe material groups. This graph also indicate that Pb indicated highest burst rate as small diameter pipes since there are about 110 bursts within 7 km of total length of the Pb pipe.

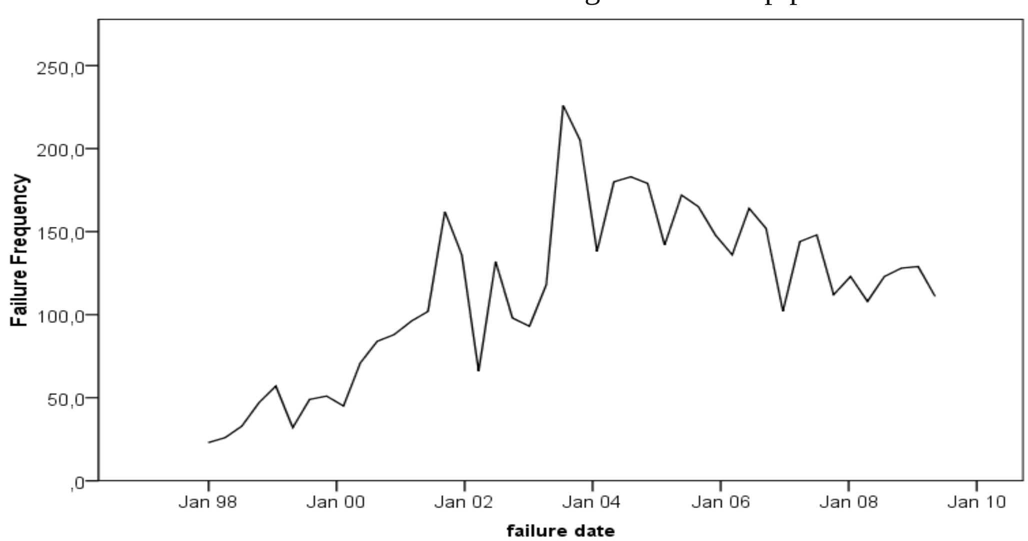


Figure (9-7) Monthly pipe failure frequencies for Frankfurt water network from 1998 to 2010

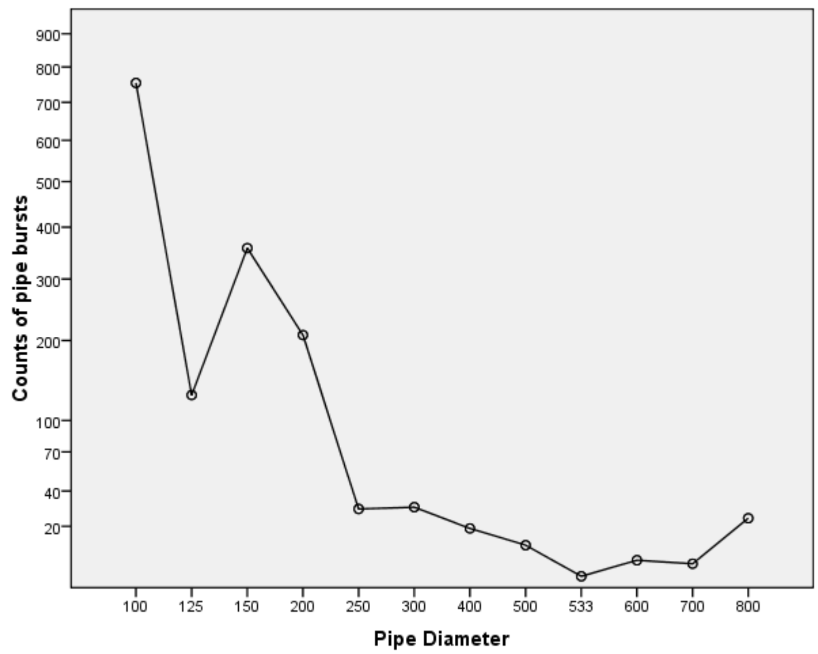


Figure (9-8) Pipe failures according to pipe diameter

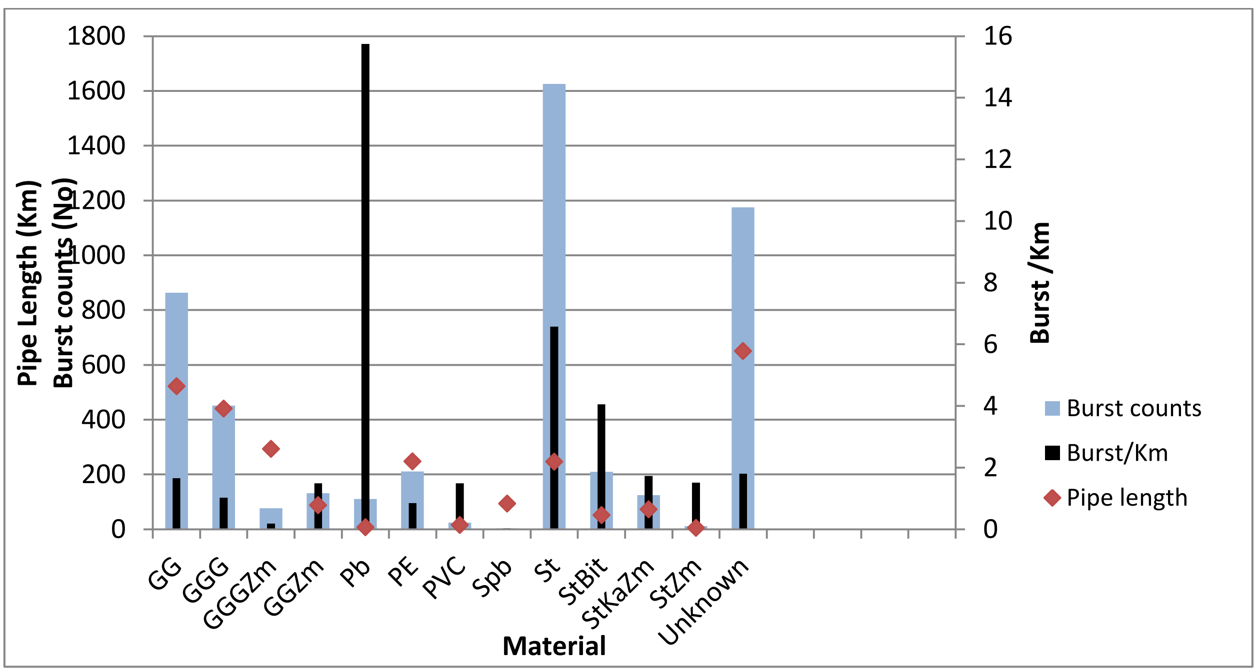


Figure (9-9) burst rate per Km, bursts accounts and total pipe length for each pipe material groups.

Spatial distributions have been created for pipe failure rate using ArcGIS 10. Figure (9-10) and Figure (9-11) show the Geo-referenced mapping (GIS) of water pipe failures in Frankfurt am Main and Failure analysis mapping at street level respectively. This map indicated several areas with high failure rate per Km^2. West-south zone has highest failure rate per Km^2. In addition, there are high concentrations of failure in the center of the city. Figure (9-12) shows pipe burst rate per Km for each district zone in Frankfurt City. This figure can be indicator for the pipe rehabilitation strategy focus in the future. This figure also shows that district No.6 and No. 19 have the highest failure rate in comparison with other districts. Also Figure (9-13) shows burst counts for each district zone and classified based on pipe material.

Failure counts have been prepared also for each street to identify the most critical streets with high number of failure. Figure (9-14) shows pipe burst accounts for each street in Frankfurt city. Number of streets in Frankfurt City is about 1430 streets. This figure identify that number of streets has really high failure rate such as königsteiner street (9 km) which has highest number of failures (78 failures) which means that failure rate is about 8,6 Burst/Km.

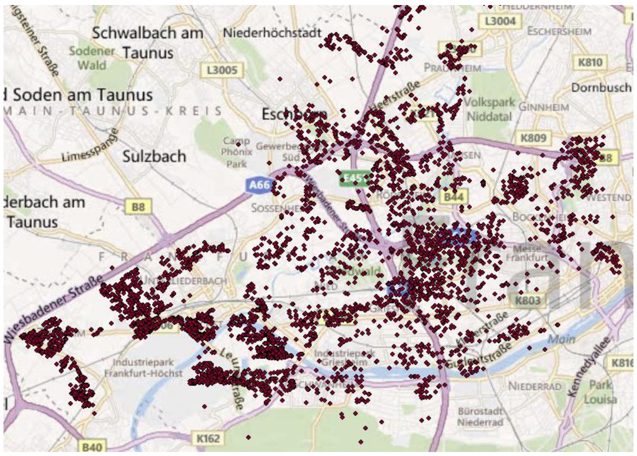


Figure (9-10) Geo-referenced mapping (GIS) of water pipe failures in Frankfurt am Main

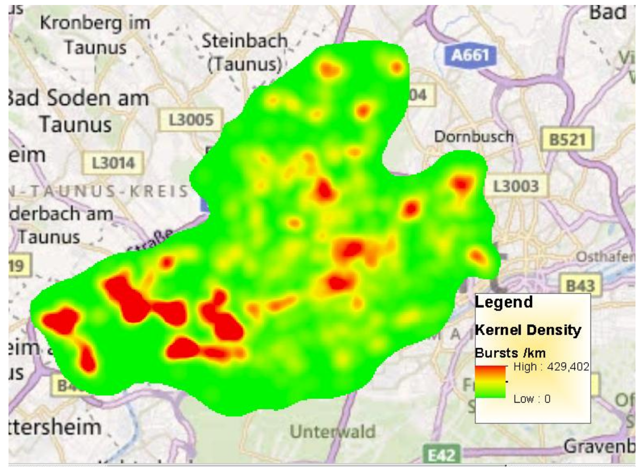


Figure (9-11) Failure analysis mapping at street level (color variations indicate varying degrees for of failure rate).

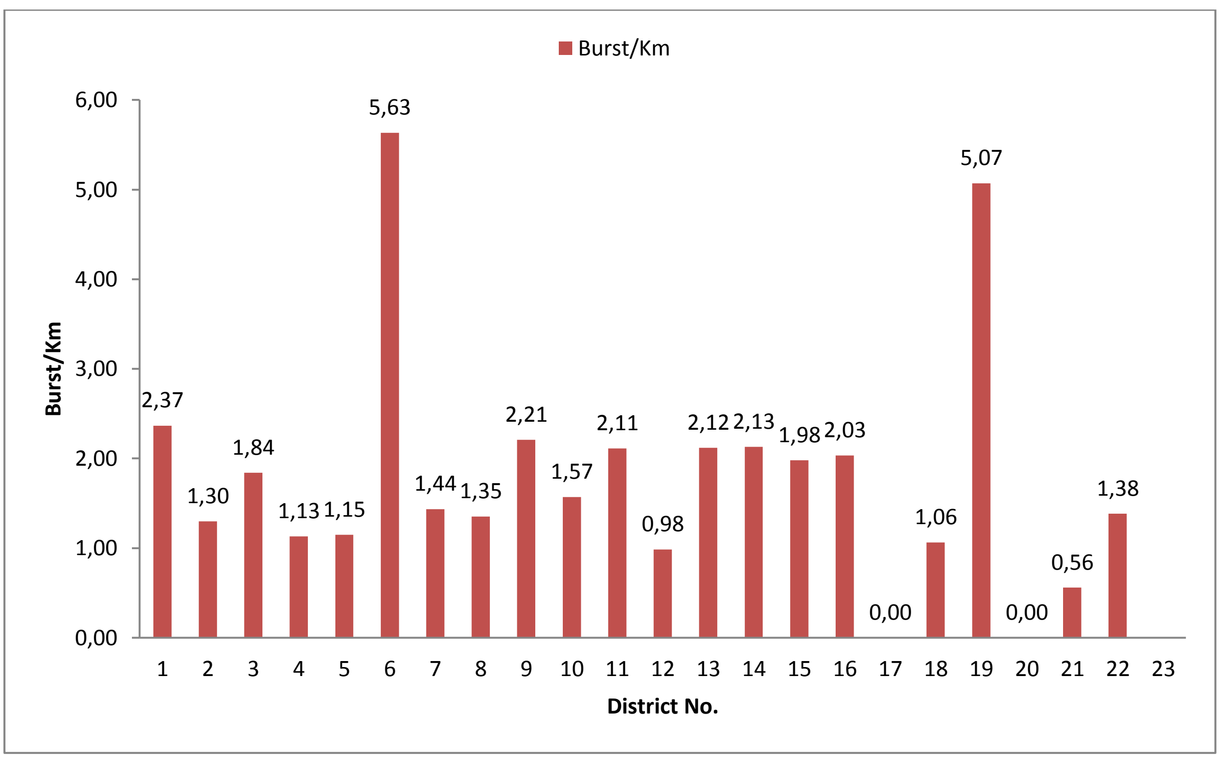


Figure (9-12) Pipe burst rate per Km for each district zone in Frankfurt City

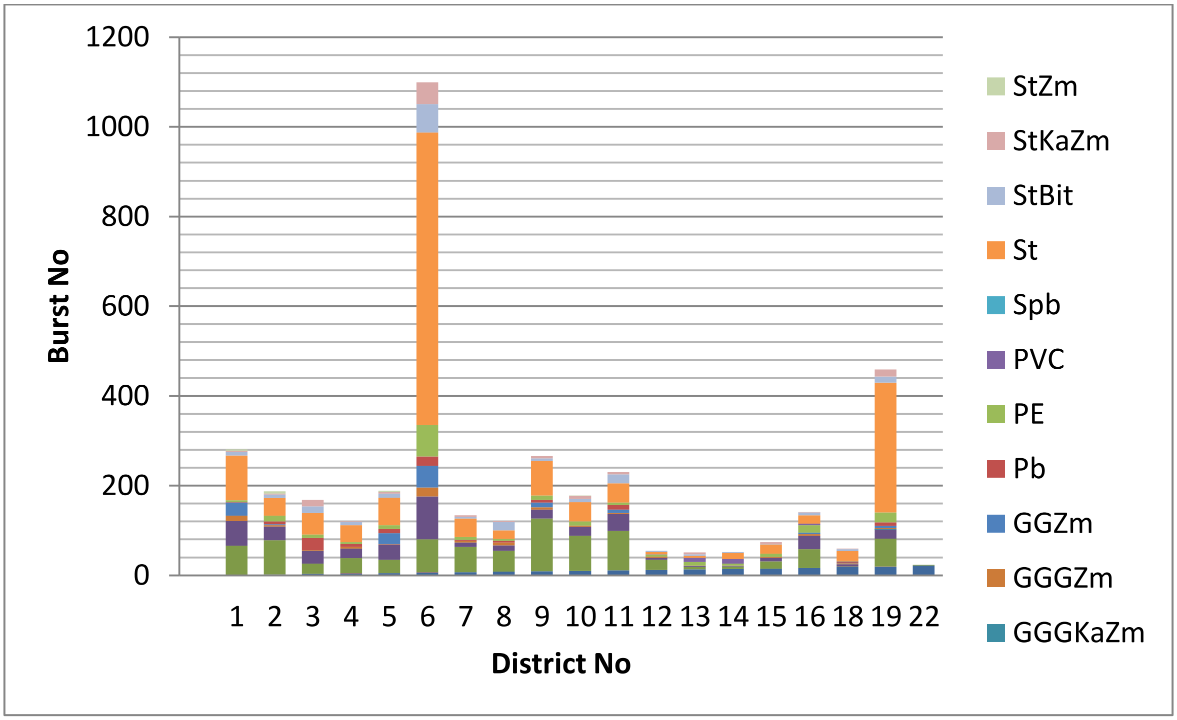


Figure (9-13) burst counts for each district zone and classified based on pipe material

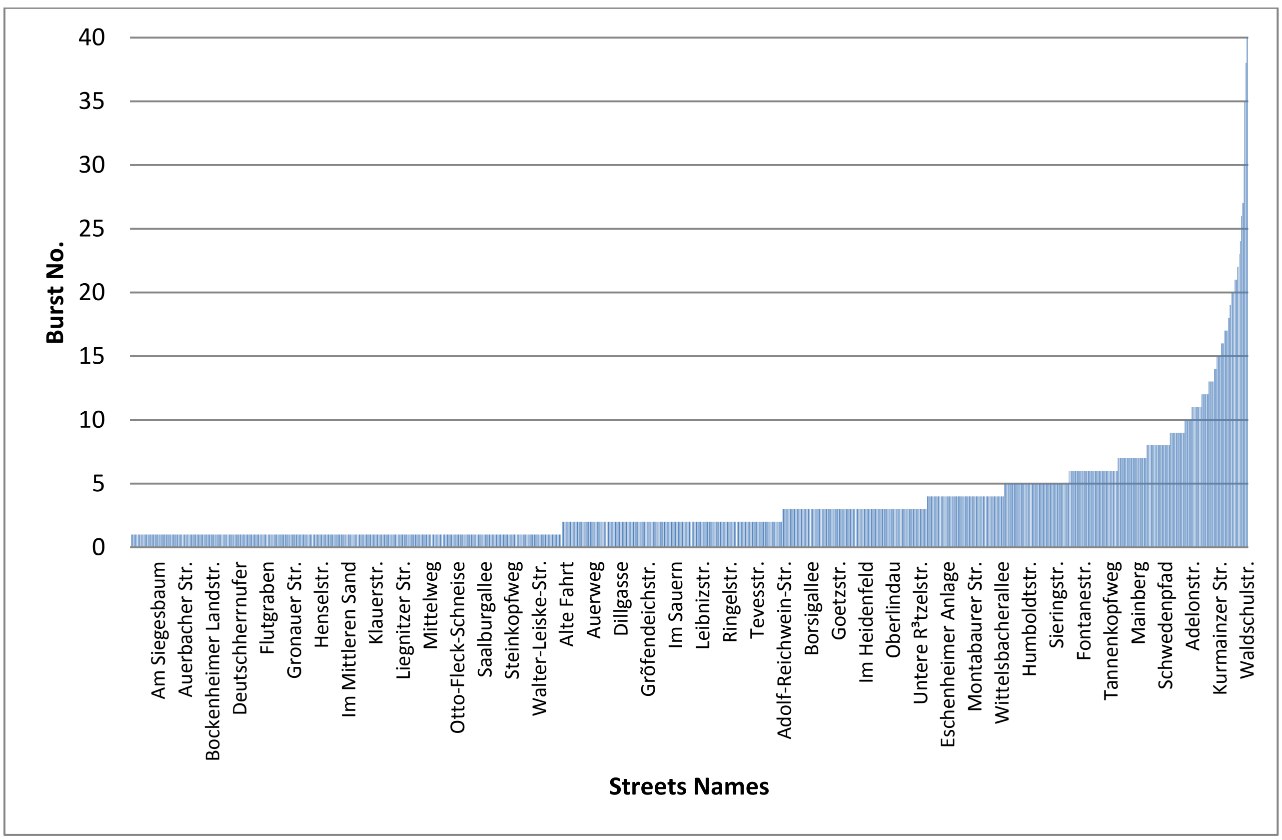


Figure (9-14) pipe burst accounts for each street in Frankfurt city

9.6 Survival analysis of water pipe network

9.6.1 Survival analysis concepts

Survival analysis can be used in water network sector to provide several estimation such as estimate the survival time between individual pipes and to provide an estimation and comparison between pipe groups as material factor. The concept of survival analysis of water network is based on that the lifetime of pipeline will be used as random variable then statistical distribution will be fitted to pipe from similar groups (Rostum,2000; Asnaashari, 2007). Several researchers have been analyzed water network using survival analysis. (Cox, 1972) introduced the Proportional Hazards Model in order to estimate the effects of different covariates on the time to failure of a system. Andreou (1986) used of proportional hazards model for analyzing failures in water supply networks.

This section comprises the survival analysis of water network in Frankfurt case study. Survival analysis is used in building rehabilitation scenarios taking into consideration lifetime of the pipe. We used in this research survival analysis to estimate time distribution based on two factors; pipe material and pipe diameter. Hazard analysis will be also estimated and compared based on pipe material and pipe diameter

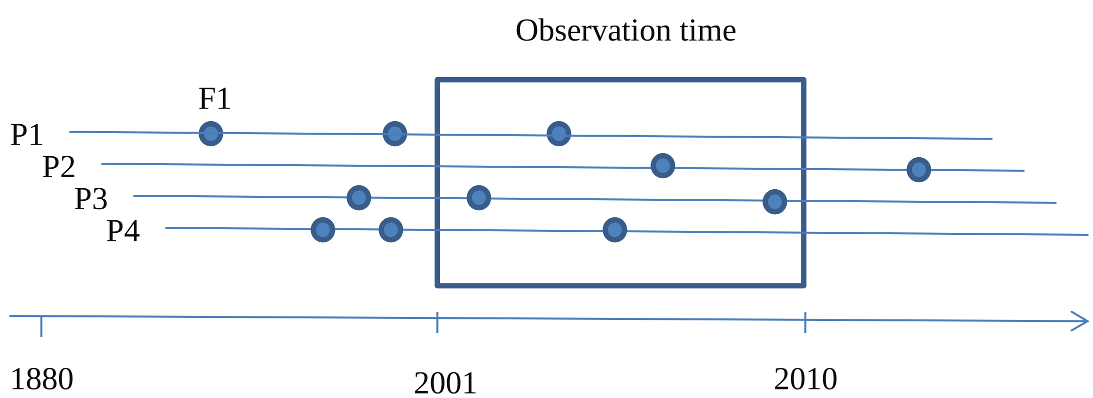


Figure (9-15) Pipe failure data availability in water network

Figure (9-15) shows the pipe failures in water pipe network, which is available between 2001 and 2010. We used censored method to overcome the missing data before 2001, which called left censored data whereas the future pipe failures are called right censored. Survival data are usually censored, as some data are incompletely observed (Rostum,2000; Asnaashari, 2007). (Rostum, 2000) used also the two types of censoring in water pipelines network: Left censoring and Right censoring. He described left censoring that a period after installation when no data is recorded. However in right censored, the dependent variable is known to be greater than a specific value, but it’s true value is not known (Rostum, 2000; Asnaashari, 2007). We used in this research (Rostum, 2000) methodology of definition the censoring values (CV). If the pipe failure has occurred the censoring value, CV is set equal to 1, else CV=0 (right censored).

Interval censoring pipe failure event occurred between two know time points. We do not observe exactly when failure occurred, but we know that it occurred between analysis times t and t+Δt (Rostum, 2000; Asnaashari, 2007). We used Kaplan-Meier method to estimate the survival curves based on pipe material and pipe diameter. Survival analysis discussed in this section was performed using SPSS statistical software.

9.6.2 Survival Models

Survival models have been described in this section by (Jenkins ,2005) and (Utah , 2009).
The cumulative distribution function (cdf) of t is denoted F(t) and the density function is
$f(t) = \frac{dF(t)}{dt}$ (Jenkins , 2005). Then the probability that the duration is less than t is

$$F(t) = \Pr[T \le t]$$
$$= \int_0^t f(s)ds$$

So survivor function (S) is the probability that duration equals or exceeds t, defined by (Jenkins , 2005).

$$S(t) = \Pr[T > t]$$
$$= 1 - F(t)$$

The survivor function indicates the probability that there is no failure event prior to t (Jenkins, 2005), (Utah, 2009).
The density function f(t) also can be obtained from S(t) as it can from F(t), (Jenkins , 2005)

$$f(t) = \frac{dF(t)}{dt} = \frac{d}{dt}[1 - S(t)] = -S'(t)$$

Hazard function (h (t)) is the probability that the failure event occurs in a given interval, conditional upon the subject having survived to the beginning of that interval, divided by the width of the interval (Utah , 2009).

$$h(t) = \lim_{\Delta t \to 0} \frac{\Pr(t + \Delta t > T \ge t \mid T \ge t)}{\Delta t} = \frac{f(t)}{S(t)} = \frac{\Pr obability\ of\ failing\ between\ times\ t\ and\ t + \Delta t}{\Pr obability\ of\ surviving by\ time\ t}$$

The hazard rate for failure at time t is defined also as the rate of failures at times t among those who have survived to time t (Jenkins ,2005; Utah , 2009).

In survival analysis, hazard rate (h(t)) in the dependent variable:

$$h(t) = f(h_0(t), \alpha + x\beta)$$

where f = functional form, $h_0(t)$ is = baseline hazard, α = intercept and β = coefficient of variables x (Jenkins ,2005; Utah , 2009).
A particularly popular way to parameterize these models is (Jenkins, 2005; Utah , 2009)

$$h(t) = h_0(t)\exp(\alpha + x\beta)$$

Survival data can be analyzed by 3 different ways; nonparametric, semi-parametric and parametric models. In this research we used nonparametric analysis which is very useful to estimate the survivor function and cumulative hazard function (Jenkins ,2005; Utah , 2009). We used in this research just Kaplan Meier to know the shape of the hazard or survival function.

9.6.3 Kaplan-Meier Survival Analysis

Kaplan-Meier (1958), is a descriptive procedure for examining used to estimate the survivor function and cumulative hazard function based on water pipelines failure data that were multi censored also it examining the distribution of time-to-event variables and can be used to compare the distribution by levels of a factor variable or produce separate analyses by levels of a stratification variable (SPSS, 2012). We used SPSS software to prepare the data into required format to apply the survival analysis.

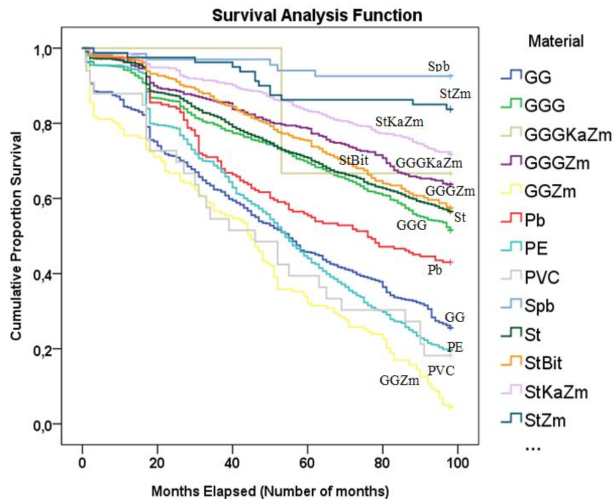


Figure (9-16) Survival curves of burst rats according to pipe materials

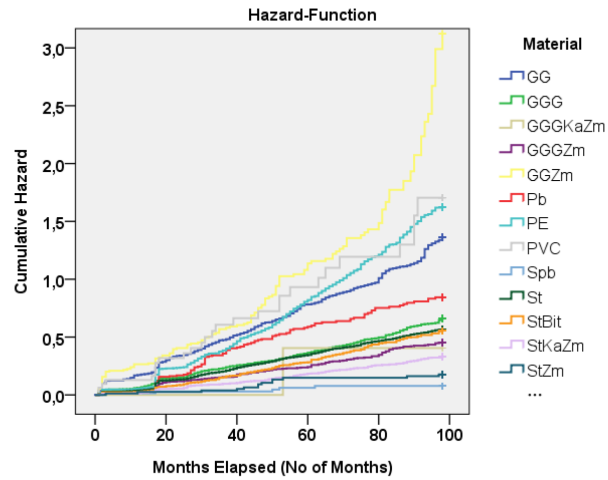


Figure (9-17) Hazard rate vs. pipe age (in days) for data stratification based on material type

The Kaplan Meier (KM) survival curves were plotted using SPSS software based on burst rate for the pipe materials. Jumping points are indicating the failure time. Figure (9-16) shows Survival curves of burst rats according to pipe materials. Plotted lines are showing the influence of the time factor on the respective breakage rates. Horizontal lines show the low deterioration failure rate in pipelines while the sharp curves shows high deterioration rate. Related to current Frankfurt case study we can identify that cast iron pipes (GG) have higher deterioration rate than ductile cast iron (GGG). Also plastic pipes (PE and PVC) have higher deterioration rate than metallic pipes. According to graph iron water pipelines have faster survival declines than steel pipes. The Kaplan-Meier method is useful for comparing survival curves according pipe materials. Based on comparison between each pipe group (Plastic pipes, ductile iron and Steel pipes) we found for plastic pipes that PE the survival lines is slightly over PVC. Hazard rate plots are also developed for pipe material types. The hazard rate for GGZm (Cast iron with cement mortar) is the highest hazard rate. Hazard rate for GGG (Ductile cast iron) and steel pipe are relatively similar. Figure (9- 17) shows hazard rate vs. presumed pipe age (in days) for data stratification based on material type. Survival curves have been developed also for water pipeline based on pipe diameter. The KM curve for pipe diameter of 125 mm has lowest survival distribution then pipe diameter with 100mm. this indicating that pipes ranging from 100 to 150 has highest deterioration rate. Also there is big gap between pipe diameter 150 mm (Brown line) and pipe diameter 200 (red line). Pipelines with diameter 200 mm and above have a greater possibility for survival. Figure (9-18) shows Survival analysis based on pipe diameter.

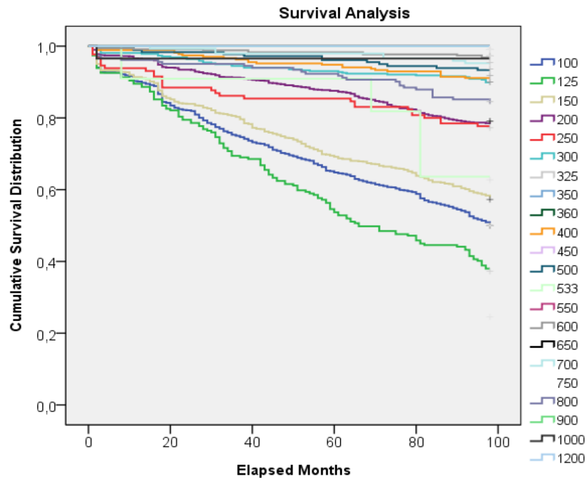


Figure (9-18) Survival analysis based on pipe diameter

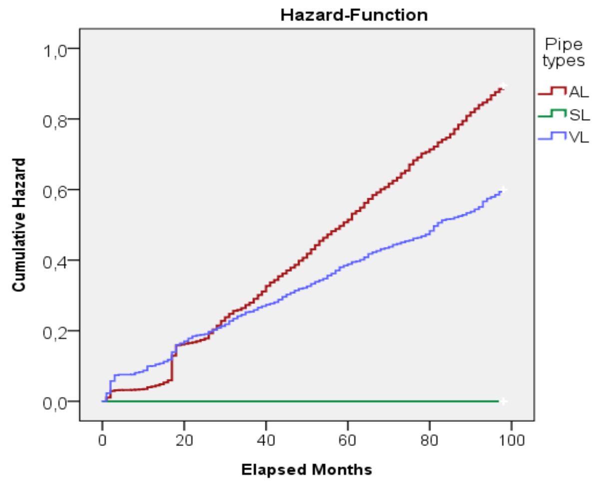


Figure (9-19) Hazard rate for pipeline deterioration based on pipe types

VL= distribution lines, AL= Connection pipelines, SL= Stand Pipes

Hazard rate have been developed also based on pipe types. We found that Hazard rate for connection pipelines (AL) are higher than distribution lines (VL) and standpipes (SL). This caused due to low depth of connection pipelines and small of pipe diameters. Figure (9-19) shows Hazard rate for pipeline deterioration based on pipe types.

9.7 Neural Network analysis

Artificial Neural Networks (ANNs) are forms of mathematical models that simulate the structure and/or function of biological neural networks. It consists of interconnected neurons and processes. ANN is adaptive during the learning phase by changing the structure based on the information flow. ANN are used to recognize patterns in the data, train the network for calibration, and predict future conditions Asnaashari, (2007). ANN has been used by several researchers in water network sector such as Al Barqawi and Zayed, (2006), Asnaashari, (2007) and Rajani and Kleiner, (2001). Ahn et al. (2005) also developed an ANN model for predicting pipe failures. He provided a relationship between pipe failures and several factors such as historical pipe breaks and soil temperatures. Artificial neural networks are capable of generating models fitted to the empirical reliability values, more accurately than existing probabilistic models (Hertz et al. 1991). ANNs consist of a number of artificial neurons variously known as processing elements, nodes or "neurons". Processing elements in ANNs are usually arranged in layers: an input layer, an output layer and intermediate layer called hidden layer (Asnaashari, 2007). ANN model structure is developed by fixing the number of layers and choosing the number of nodes in each layer (Hornik et al. 1989). We used one hidden layer to estimate any continuous function (Hornik et al. 1989). The relationship has been developed between pipe failures and input variables, using neural network with one hidden layer. This will be used to find importance variable contributing in increasing of pipe failures. The ANN architecture model for this study is shown in Figure (9-20). The ANNs software used in this work is SPSS Version 2012. We used in this study five input variables; Material, Pipe types, Pipe diameter, Age and pipe length. The dependent variable is number of pipe failures. ANNs model have been applied for all failures on the total water pipelines in study area. Total case in this dataset contains about 2,300 water pipelines, which have been divided into three subsets: a training set: testing set and holdout. Table (9-2) shows summary of ANN case Processing using SPSS software. The dataset have been split into three parts to overcome the problem of data over fitting through cross- validation technique. The training data connection weights are provided using training data, the test data are used to find the best configuration and optimal network, a validation data is required to test the true generalization ability of the model (Gavin et al, 2002). Also the testing data are used to determine the best number of hidden layer (SPSS, 2012).

Table (9-2) Case processing summary

	N	%
Training	1184	50,7%
Test	670	28,7%
Holdout	482	20,6%
Total	2336	100,0%

The case processing summary shows that 1184 (50%) cases were assigned to the training sample, 670 (30%) to the testing sample, and 482 (20%) to the holdout sample as shown in Table (9-2).

Table (9-3) Network Information

Input Layer	Factors	1	Material
		2	Pipe types
	covariates	1	Length
		2	Pipe Age
		3	Diameter
	Number of units:[a]		17
	Rescaling method for covariates		Normalized
Hidden Layers:	Number of Hidden Layers		1
	Number of units in Hidden Layers 1[a]		8
	Activation Function		Sigmoid
Output Layers	Dependent Variables	1	Status
	Number of units:		1

a. Excluding the bias unit. This table is generated from SPSS Software.

The network information Table (9-5) shows information about the neural network. This table is used to check the correction of specifications. Input layer is including the number of covariates and factor; two factors; Material and pipe types, three covariates; Length, diameter and pipe age. 8 units in the hidden layer have been automatically produced in architecture selection (SPSS, 2012).

Table (9-4) Parameter Estimates

Predictor		Predicted								
		Hidden Layer 1								Output Layer
		H(1:1)	H(1:2)	H(1:3)	H(1:4)	H(1:5)	H(1:6)	H(1:7)	H(1:8)	Condition
Input Layer	(Bias)	,036	,159	-,012	-,277	-,525	-,301	,135	,647	
	[Type=AL]	1,421	-,364	,355	,246	,121	,394	-,238	1,433	
	[Type=IW]	-,407	-,100	,281	,228	-,172	,375	,279	,766	
	[Type=VL]	-,743	,165	,091	,237	-,500	-1,125	-,096	-,355	
	[Material=GG]	,382	-1,069	,908	-1,368	,375	,978	,261	-2,324	
	[Material=GGG]	,584	,179	,327	-,443	,466	,384	-,214	-,530	
	[Material=GGGZm]	,315	,129	,314	,164	,269	,289	,293	,094	
	[Material=GGZm]	-,247	-,304	,493	-,374	-,290	-,216	-,433	-1,318	
	[Material=PE]	,134	-,091	-,103	,029	,510	-,455	,358	-,558	
	[Material=PVC]	,618	-,038	-,367	,530	-,093	,336	-,319	,234	
	[Material=Spb]	-,202	-,163	,152	,170	,173	-,261	,249	,300	
	[Material=St]	-1,338	1,082	-,980	1,099	,062	-2,394	-,769	3,999	
	[Material=StBit]	,310	,486	,369	-,632	-,440	,286	,266	,652	
	[Material=StKaZm]	-,447	,144	,328	,083	,025	-,176	,340	,513	
	[Material=StZm]	-,695	,253	,099	,019	-,454	,052	,055	,288	
	Length	1,168	-,430	,930	1,606	,637	-,664	-,825	-1,019	
	Pipe_Age	,334	-,394	,190	-,386	,383	,039	,302	-,217	
	Diameter	-2,038	,399	,099	,618	-,643	,286	-,187	1,702	
Hidden Layer 1	(Bias)									-,504
	H(1:1)									2,914
	H(1:2)									-,292
	H(1:3)									,992
	H(1:4)									3,030
	H(1:5)									1,260
	H(1:6)									-1,874
	H(1:7)									-1,003
	H(1:8)									-2,915

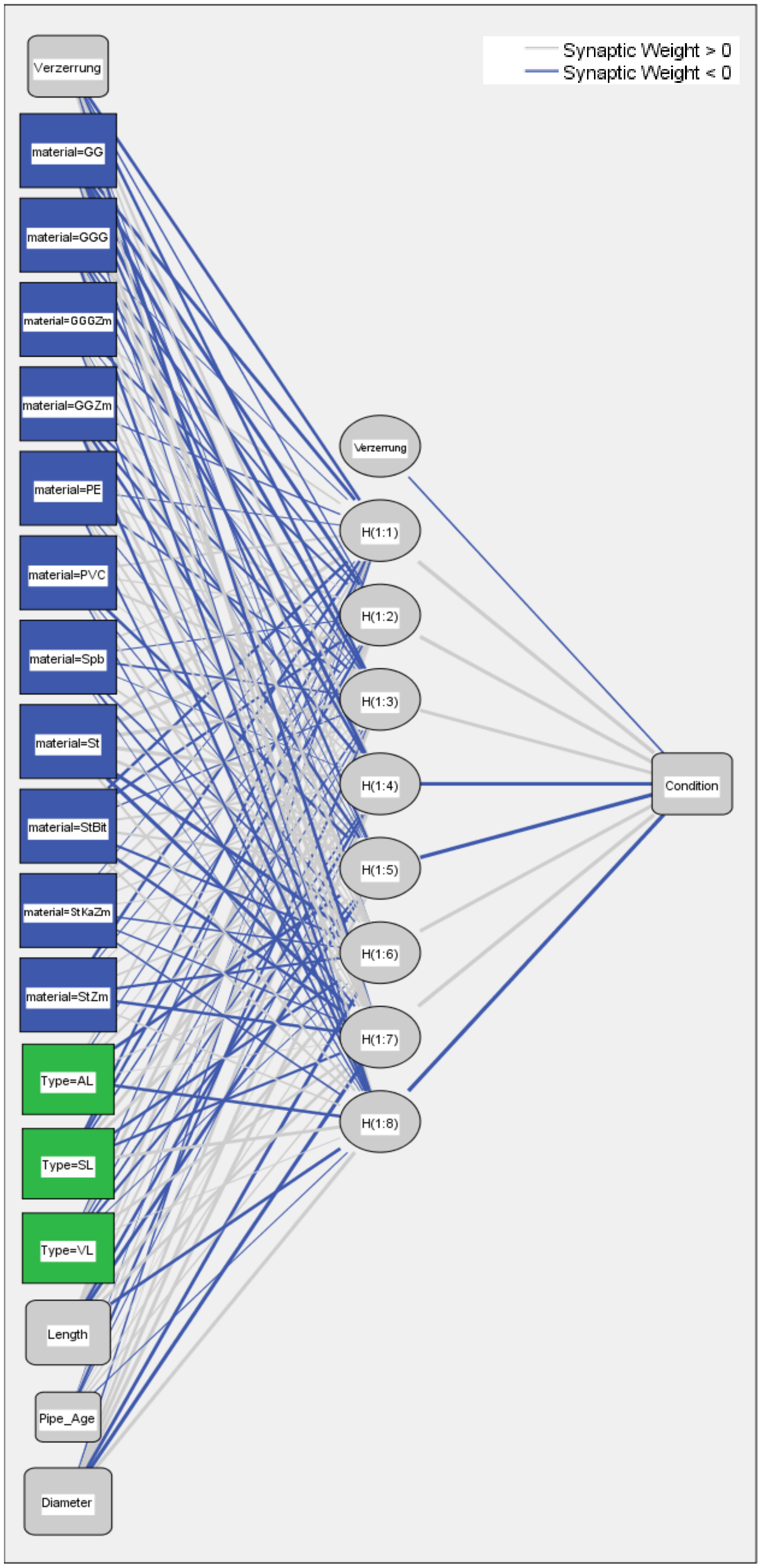


Figure (9-20) neural network Architecture.

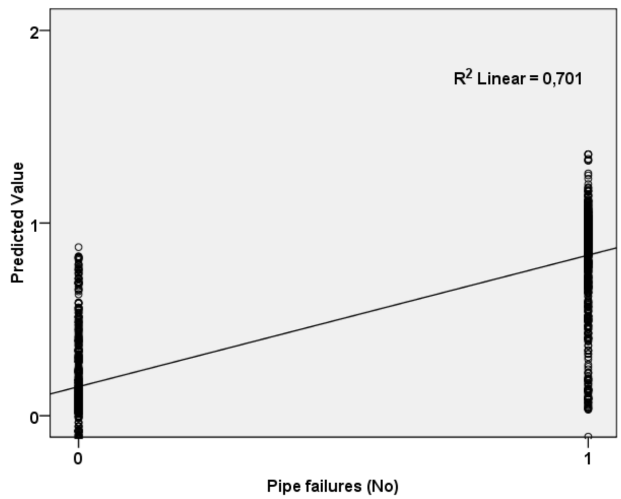


Figure (9-21) Comparison of predicted and observed values of pipe failures

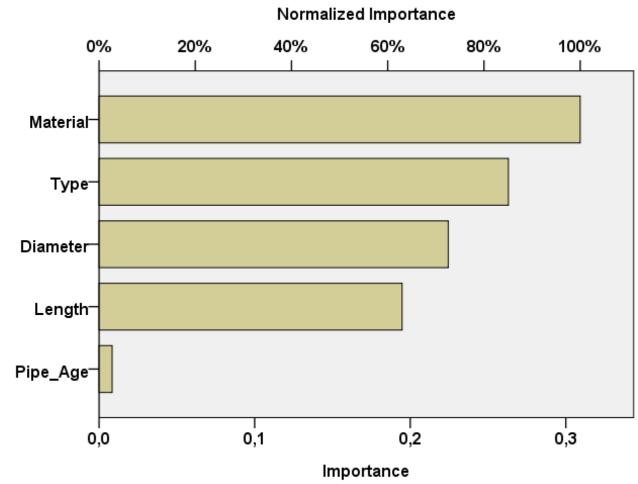


Figure (9-22) Normalized importance of independent variables

Number of failures was limited between (No failure =0) and (there is failure =1). Figure (9- 21) shows the correlation between the predicted and observed values of water pipe failure for all material. The correlation is R^2=0.70, which used just for 0 or 1 failure in pipe based on SPSS analysis.

We can identify that pipes with no observed failures have big chances to have failures in future taking into consideration the contributing factors.

The importance chart of Figure (9-22) is simply a bar chart of the values in the importance table, sorted based on value of importance. Variables of pipe material and pipe types have the greatest effect on increasing of pipe failures. Table (9-5) shows the importance for each factor, which also shows the rank order for each input.

Table (9-5) Importance of the independent variables

	Rank	Importance	Normalized Importance
Material	1	,309	100,0%
Pipe types	2	,263	85,1%
Diameter	3	,224	72,6%
Length	4	,195	63,0%
Pipe Age	5	,008	2,7%

9.8 Water Main renewal strategies

9.8.1 Introduction

Water Main Replacement Prioritization strategies is one of the most important tool to improve the overall water networks. This section shows several scenarios for water pipe line renewal taking in to consideration the renewal scenarios on reducing pipe failure rates. Decision of pipe replacement or rehabilitated depends on the existing quality condition of water pipes, serious risk on the reliability of network service, cost of repairing and insufficient of pipe capacity DVGW W 403 (2010).

In this section, we applied the DVGW strategies to use minimum available data to find the best rehabilitation strategies. Approaches for determining the rehabilitation rate are discussed for the entire water distribution system with different data availability. We used two simplified methods according to DVGW. The different approaches are described consistent with a record of a drinking water network.

Method 1: Direct, system group specific derivation of the technical useful life accordance to DVGW W 403. With this method it is assumed that no information about individual pipes is available for the entire water network DVGW W 403 (2010).

The age of the pipes groups was estimated and pipe failures data are not available. This means that the useful life can only be estimated, based on empirical values within the company or the technical literature *DVGW W 403*. If water network for medium technical useful life of 100 years, a long term strategic rehabilitation rate was 1% per year, and for 50 years of useful life a required rehabilitation rate was 2% per year.

Figure (9-23) shows the margins of pipe ages (years) for each pipe material used in Frankfurt water network.

In general, the rehabilitation rate is determined using the following formula:

% rehab rate = 1 / useful life in years

Table (9-6) shows the individual rehabilitation rates of the pipe groups based on the technical useful life of the pipes. According the calculations for Frankfurt case, ductile cast iron (GGG) pipes need the highest rehabilitation scale of (5,51 km / year) for rehabilitation rate of (1,25 %). The total amount of required rehabilitation length is about 27 km/year.

On the other hands, water network needs to be assessed, whether in the past was a regular rehabilitation of the network has been rehabilitated or not. If it was not rehabilitated, it must be used instead of the total technical life of the pipe, the residual service life (RSL) to determine the rehabilitation rate. The remaining useful life is determined as the difference between useful life of the pipe and current of pipe age. The formula for determining the rehabilitation rate is then: *(DVGW W 403)*

Rehabilitation rate % = 1 / remaining useful life = 1 / (useful life - pipe age) in years

For the Frankfurt network, the estimated useful lives and the rehabilitation rate of main pipe groups are shown in table (9-7). By using this method, the rehabilitation rate is higher than the last method. The total of required rehabilitation length is about 58 Km/year.

Table (9-6) Individual rehabilitation rates of the pipe groups of the remaining useful life

Material*	Total Length (Km)	Length %	Useful life (years)	Rehabilitation rate in% / year	Reha-scale in km / year
GG	521,69	23,54	105	0,95%	4,97
GGG	440,83	19,89	80	1,25%	5,51
GGGKaZm	3,23	0,15	80	1,25%	0,04
GGGZm	417,43	18,84	80	1,25%	5,22
GGZm	88,23	3,98	105	0,95%	0,84
Pb	7,05	0,32	105	0,95%	0,07
PE	247,34	11,16	70	1,43%	3,53
PVC	16,07	0,73	50	2,00%	0,32
Spb	93,43	4,22	70	1,43%	1,33
St	246,98	11,15	70	1,43%	3,53
StBit	51,86	2,34	70	1,43%	0,74
StKaZm	72,21	3,26	70	1,43%	1,03
StZm	9,74	0,44	70	1,43%	0,14
Total	**2216,1**	**100**		**1,23%**	**27,27**

*see Table (9-1) for abbreviations explain

Table (9-7) Estimated useful lives and the rehabilitation rate of main pipe groups

Material*	Total Length (Km)	Length %	Useful life (years)	Mean Pipe Age (years)	Remaining useful life in years	Rehabilitation rate in % / year	Reha- scale in km / year
GG	521,69	23,54	105	65	40	2,50%	13,04
GGG	440,83	19,89	80	43	37	2,70%	11,91
GGGKaZm	3,23	0,15	80	25	55	1,82%	0,06
GGGZm	417,43	18,84	80	19	61	1,64%	6,84
GGZm	88,23	3,98	105	71	34	2,94%	2,60
Pb	7,05	0,32	105	97	8	12,50%	0,88
PE	247,34	11,16	70	10	60	1,67%	4,12
PVC	16,07	0,73	50	35	15	6,67%	1,07
Spb	93,43	4,22	70	52	18	5,56%	5,19
St	246,98	11,15	70	44	26	3,85%	9,50
StBit	51,86	2,34	70	40	30	3,33%	1,73
StKaZm	72,21	3,26	70	24	46	2,17%	1,57
StZm	9,74	0,44	70	25	45	2,22%	0,22
Total	**2216,1**	**100**					**58,73**

*see Table (9-1) for abbreviations explain

A major disadvantage of this approach to determine the rehabilitation rate is that the rehabilitation rates based on estimated useful lives and an estimated ages have been determined without taking into account the individual age and individual pipe conditions. Due to the large uncertainty in such estimates, the actual rehabilitation requirements for each pipe are not accurate. However, this method leads in general to know investment needs for rehabilitation DVGW W 403 (2010).

Method 2: Derivation of technical useful lives and age based on pipe lengths accordance to DVGW W 403 (2010).

The rehabilitation method for present water pipeline is based on the useful life of the pipes and pipe ages taking into consideration last pipe installation lengths. Figure (9-24) shows the distribution of the installed pipe lengths for each pipe group per years and Figure (9-25) shows the cumulative sum of pipe length based on pipe installation year. The determination of the rehabilitation rates are based on the age cohort of each pipe and compared with the pipe group for each specific period of use. If the pipe reaches the age of a useful life, this line will be renewed (DVGW W 403, 2010). Results are shown in Figure (9-26) the rehabilitation rate for the entire water distribution system taking into account the pipe age In this approach to determine the rehabilitation rates for the renewal of the pipeline network of 1:1 followed installed lines in the past. There will be increasing in the need for renewal, as periods of low or high installation activity in the past at the same time come up for renewal.

Rehabilitation rate = annual sum of all pipelines, which must be renewed at the end of their technical life (DVGW W 403, 2010).

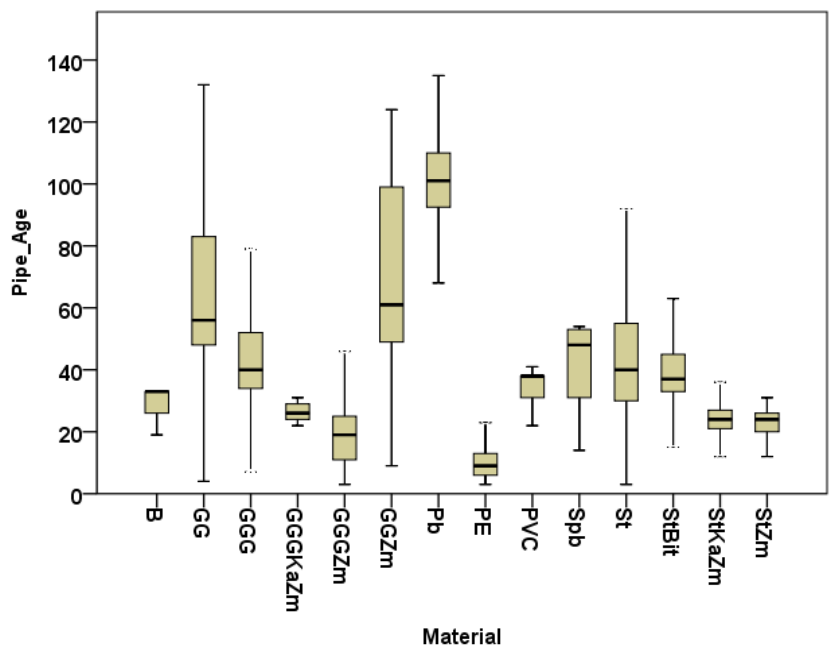


Figure (9-23) Margins of pipe ages (years) for each pipe material used in Frankfurt water network

Required Pipes rehabilitation has been also grouped based on pipe age life as shown in Figure (9-27). This graph shows that the entire pipe rehabilitation range for pipe ages from 75 and 110 years old.

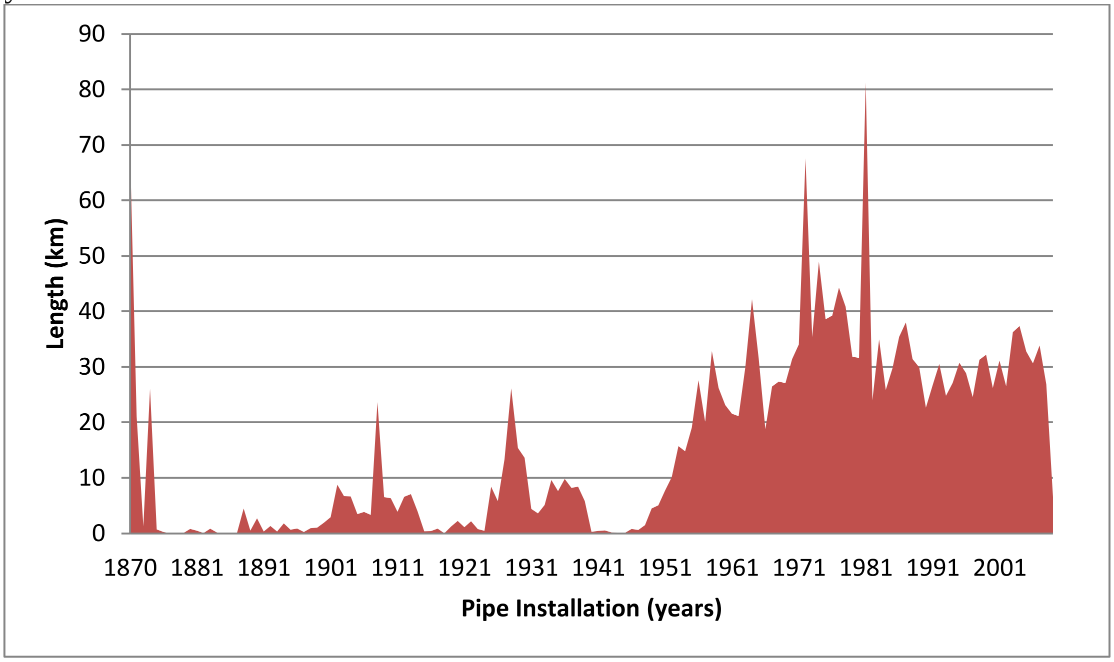


Figure (9-24) Distribution of the installed lengths of the pipeline groups by year of manufacture

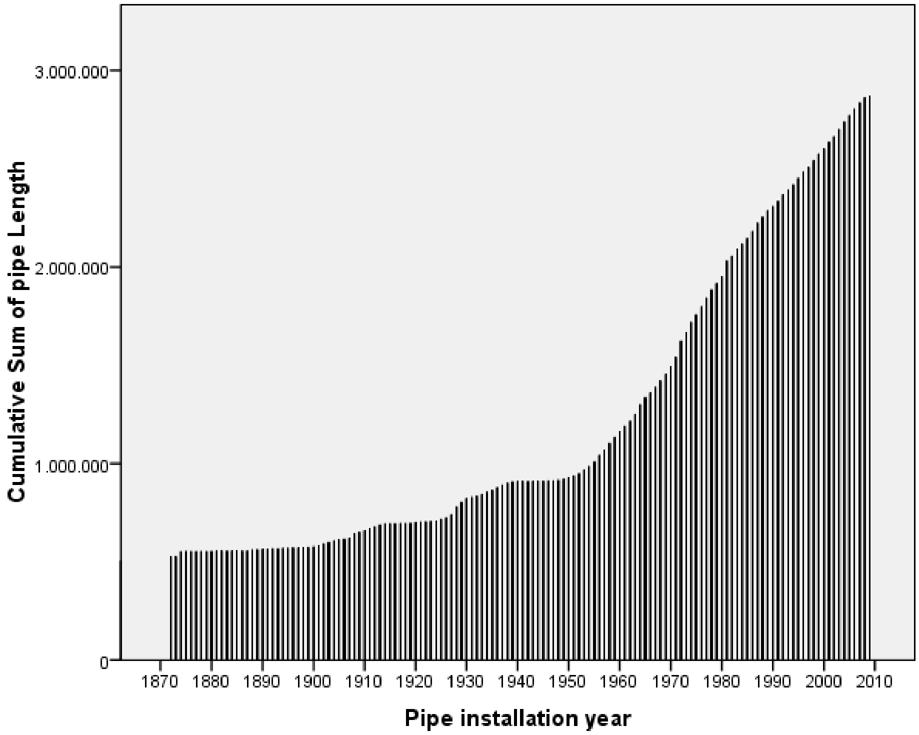


Figure (9-25) Cumulative sum of pipe length based on pipe installation year.

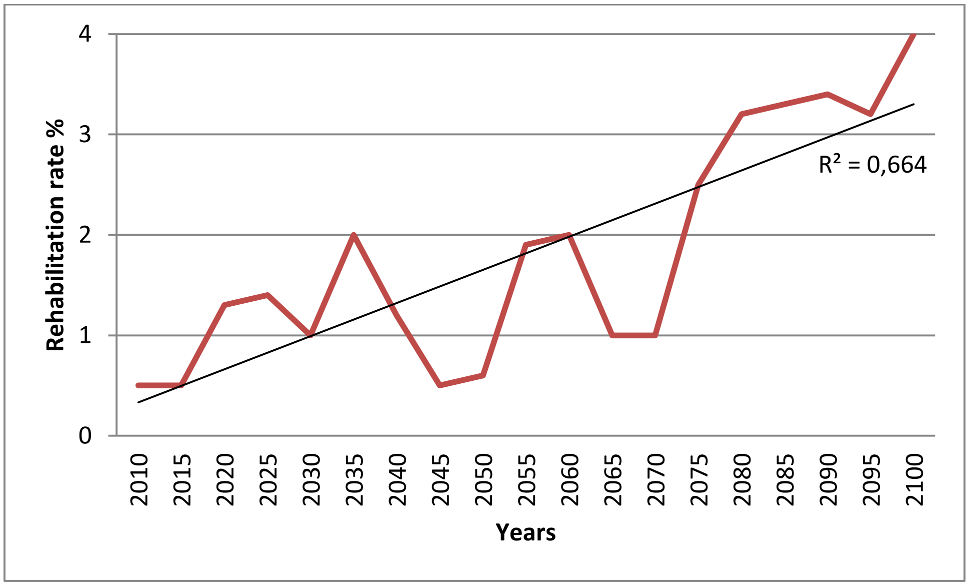


Figure (9-26) The rehabilitation rate for the entire water distribution system taking into account the pipe age

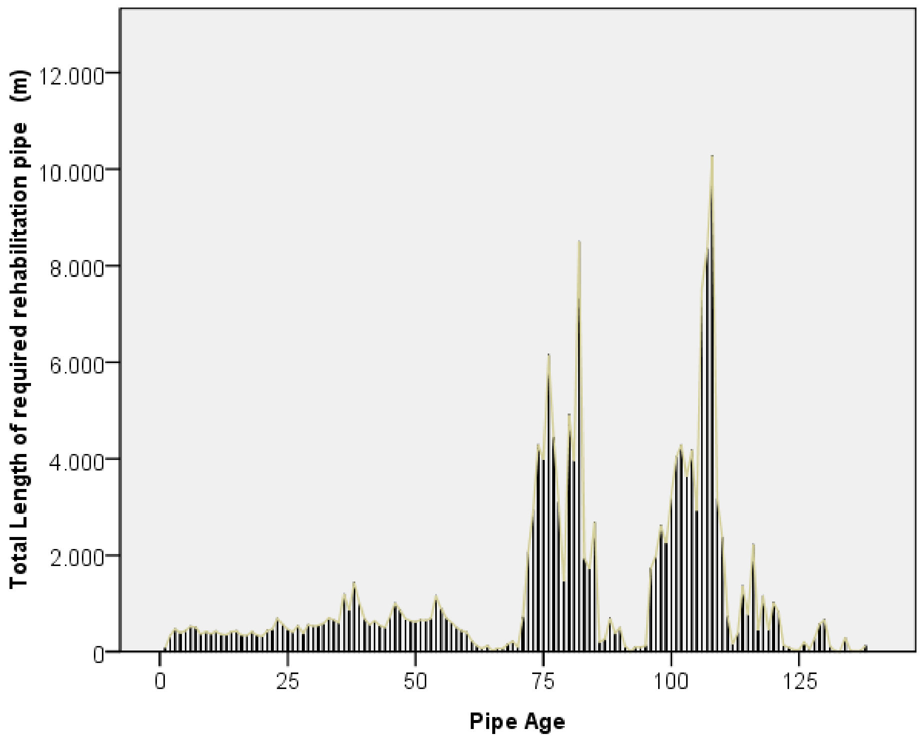


Figure (9-27) Total length of required pipe rehabilitation according to pipe age

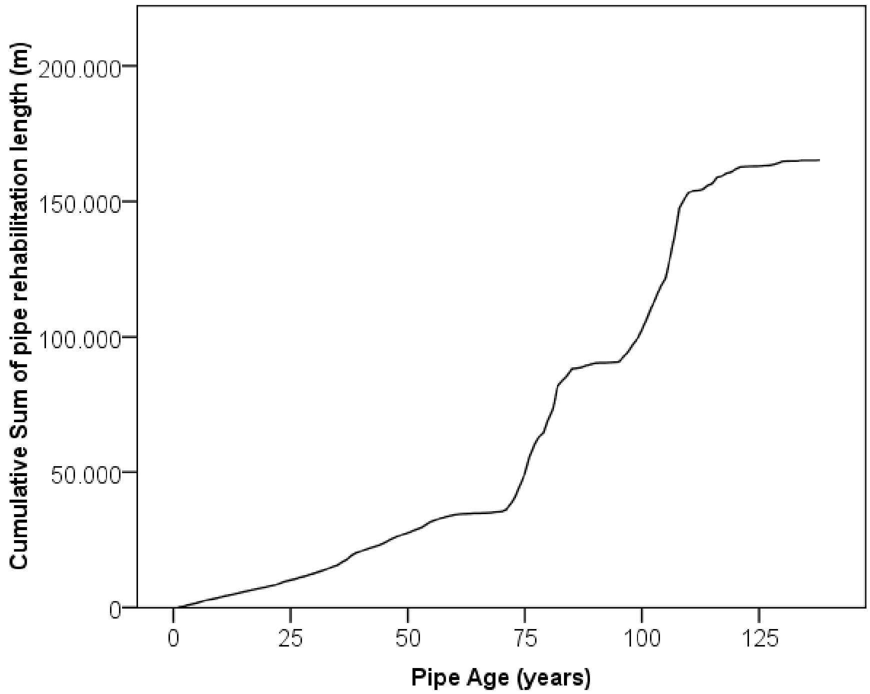


Figure (9-28) cumulative sum of pipe length required rehabilitation

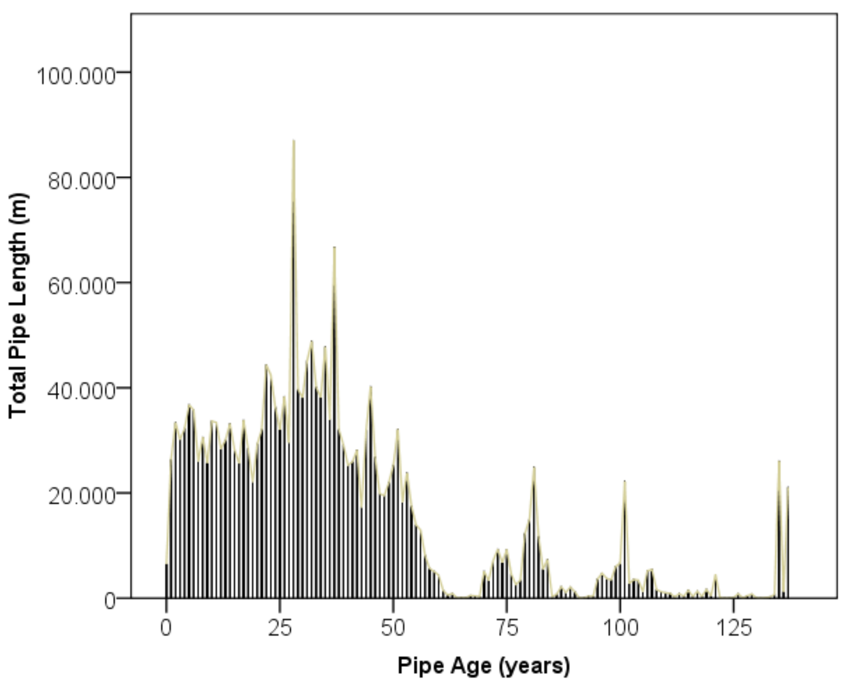


Figure (9-29) Total pipe length for each group of pipe ages

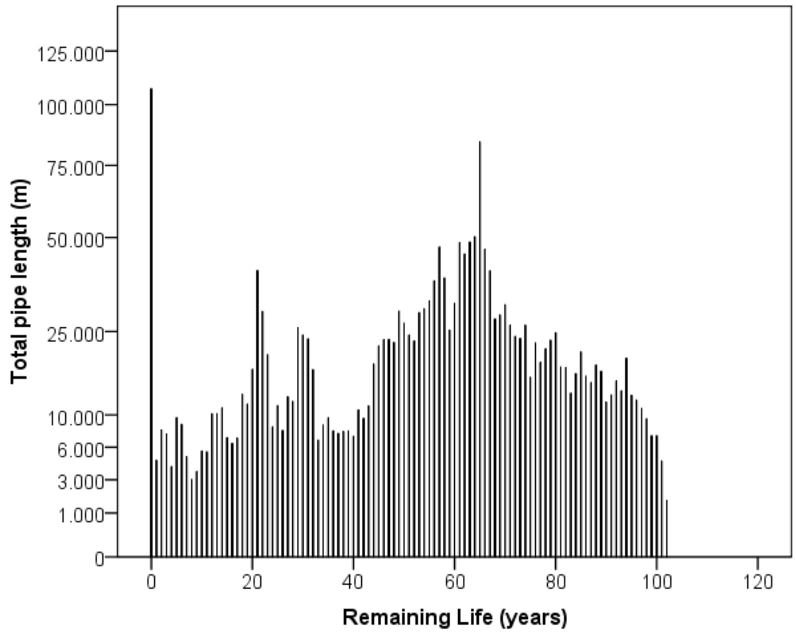


Figure (9-30) total amount of pipe length based on remaining life of water pipe

Figure (9-29) shows the total pipe length for each group of pipe ages. Pipeline classifications based on pipe age groups are shown in Table (9-8). This table shows that about 25% of total pipe lengths are more than 50 years old. Total amount of pipe length based on remaining life of water pipe are shown in Figure (9-30). More than 100 km of water pipeline are under service with remaining life = 0. Related to the relation between pipe failures and pipe ages, Figure (9-31) shows that total pipe failure amounts in water network are high in pipe age between 25 to 50 years.

Table (9-8) Pipeline classification based on pipe age groups

Age	Total Length	Percentage	rank
< 10	288	13	10
10 to 20	279	13	9
20 to 30	362	17	8
30 to 40	412	19	6
40 to 50	268	12	4
50 to 60	179	8	2
> 60	400	18	0

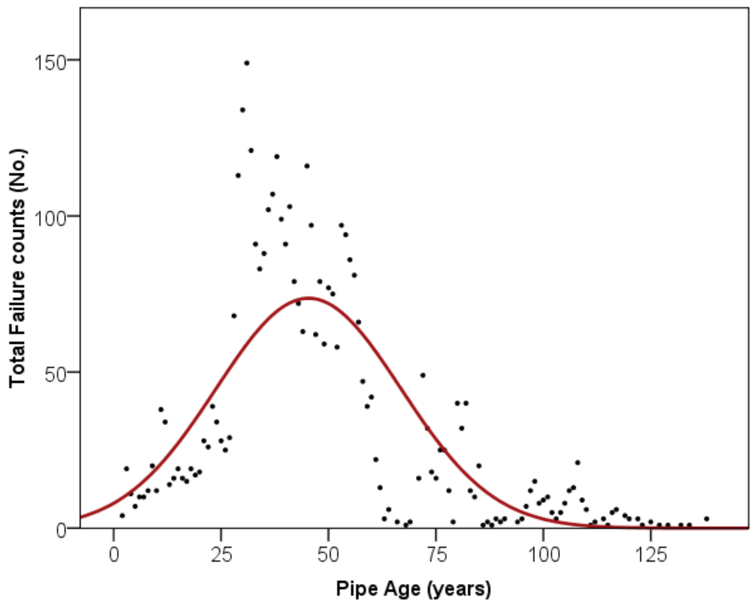


Figure (9-31) Total pipe failure amounts in water network

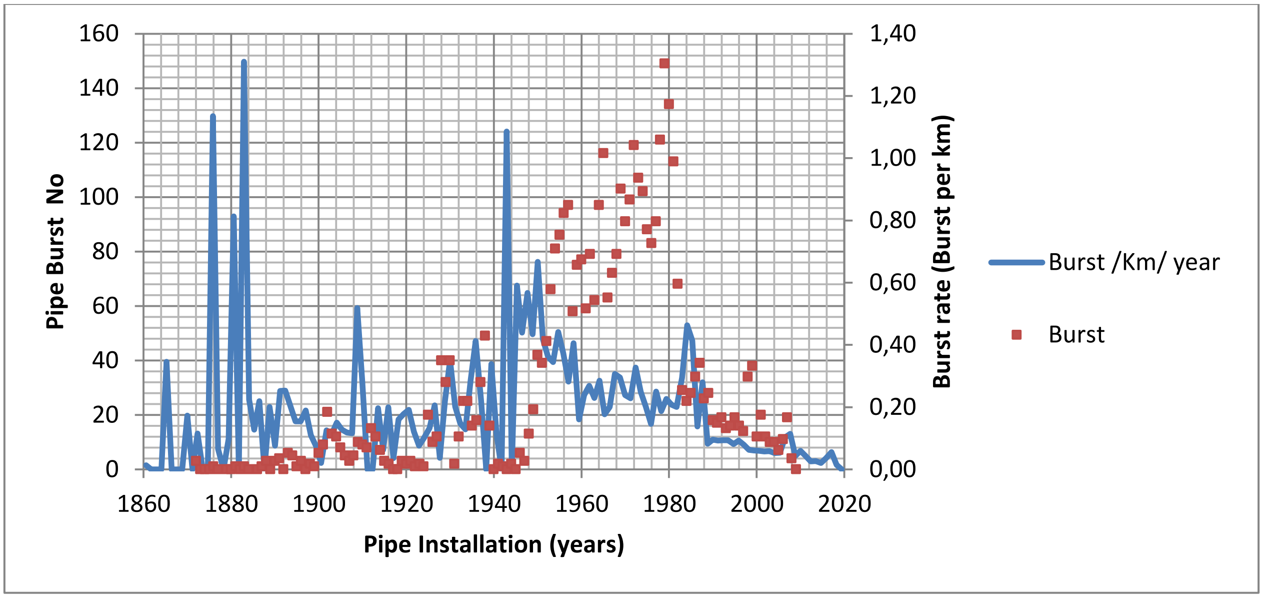


Figure (9-32) Pipe installation years, burst number and burst rate for entire water network in Frankfurt am Main city

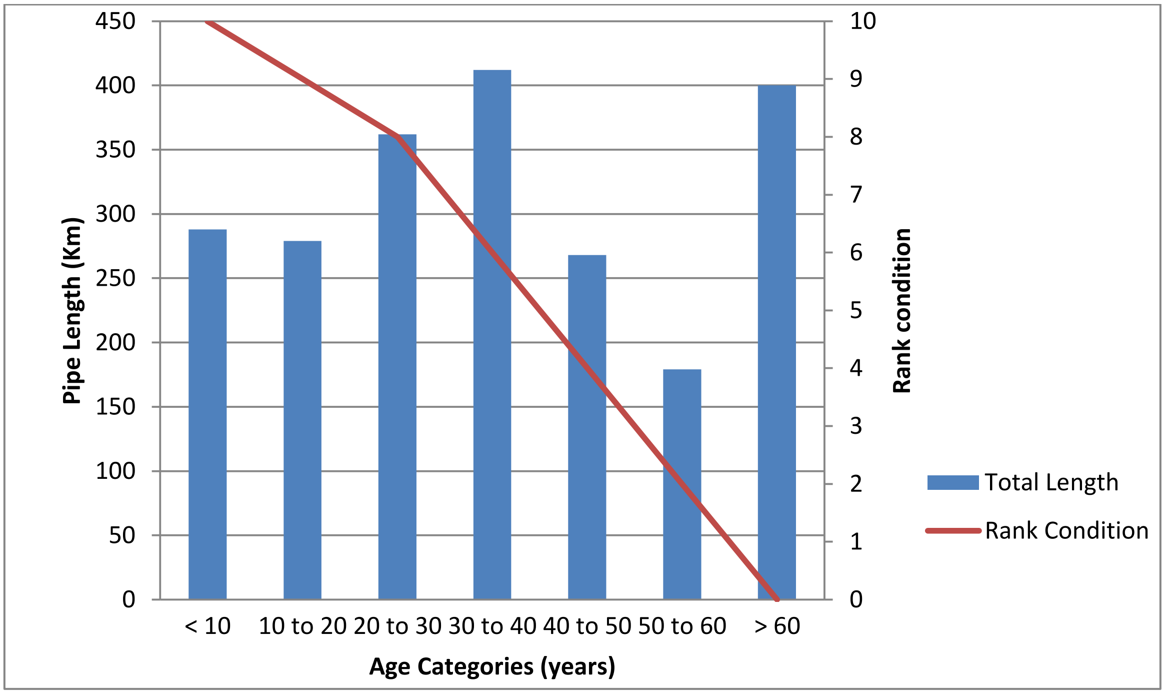


Figure (9-33) Total pipe length and ranking condition based on pipe age category

Figure (9-32) shows pipe installation years, burst number and burst rate for entire water network in Frankfurt am Main city.
The analysis for these pipe groups has been done considering the failure statistics to calculate trends for different groups. In the future, this group classification shall be supported by statistical analysis and preset by the software. The principles for planning the rehabilitation of water distribution systems were comprehensive defined in 2006 in the DVGW worksheet W 400-3. Specific requirements and targets set by which the effectiveness and sustainability of rehabilitation can be assessed.

The structured methodology is applicable regardless of the structure of the water distribution system and data availability and this allows water utilities working on plans for rehabilitation strategies (DVGW W 403, 2010).

This research shows the basis of rehabilitation needs for the planning and establishment of long-term rehabilitation programs for water pipe networks. DVGW notice clearly that pipeline age not a primary reason for a renewal, but this can be a basic condition assessment of the rehabilitation taking into focus. Figure (9-33) shows an overview for total pipe length and ranking condition based on pipe age category (DVGW W 403, 2010).

9.8.2 Water Pipe Rehabilitation scenarios

Generally, rehabilitation processes are composed from three phases; rehabilitation strategy, rehabilitation planning and rehabilitation operations. Figure (9-34) shows these rehabilitation processes (DVGW W 403, 2010).
For the next 100 years (2012 – 2100), rehabilitation scenarios have been estimated to renew the main water network in Frankfurt City. Three Scenarios have been developed based on different

rehabilitation rates. Also the relationships between rehabilitation rate and failure rate have been created. Figure (9-35) shows the water pipe renewal scenarios. First scenario was for next 50 years and Scenario No 2 and 3 for next 100 years and 60 years respectively. Each scenario taking into consideration the effects of renewal pipes onto failure rates. Table (9-9) shows comparison between rehabilitation strategies (DVGW W 403, 2010).

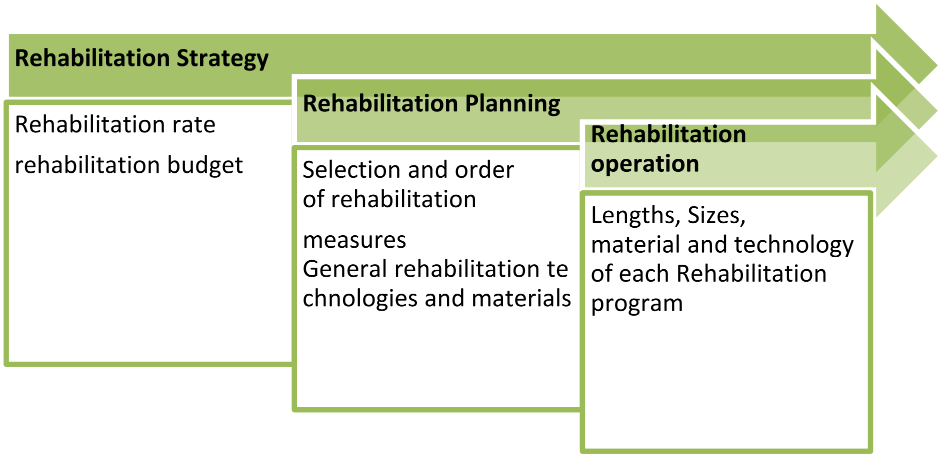
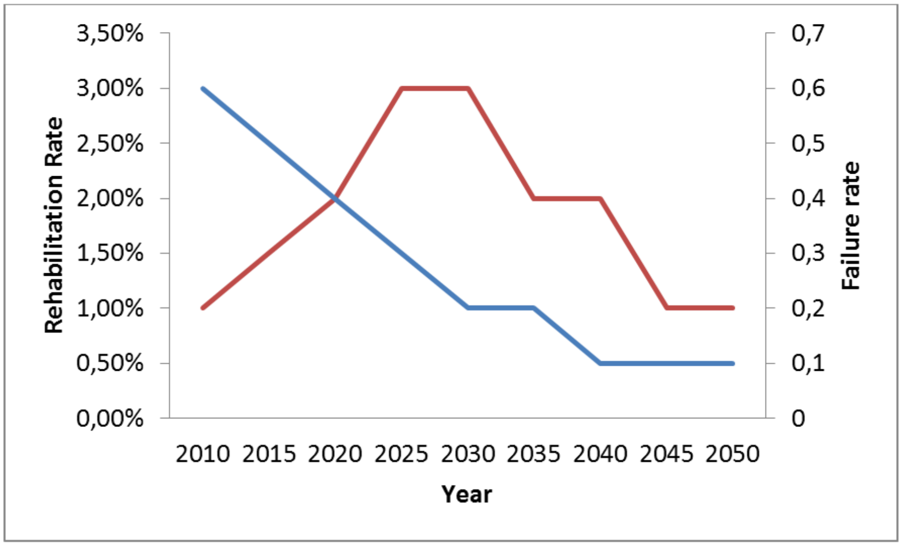


Figure (9-34) Rehabilitation process

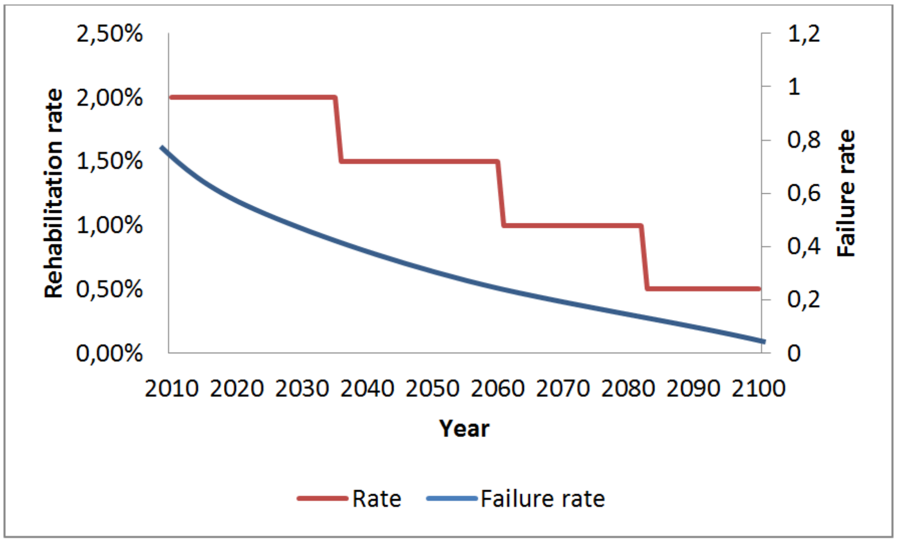
Table (9-9) Comparison between rehabilitation strategies

Criteria	**Strategy 1**		**Strategy 2**		**Strategy 3**	
	2010	**2050**	**2010**	**2100**	**2010**	**2060**
Mains renewal rate	1,0 %	1,0 %	2 %	0,5 %	0,5%	2%
Accumulated net length renewed	25 km	1650 km	50 km	2500 km	12Km	1800
Cumulative investment cost in € million	9	660	17	825	4	630
Net loss rate in (Damage / (km × year)	0,6	0,1	0,6	0,02	0,7	0,09

Scenario 1



Scenario 2



Scenario 3

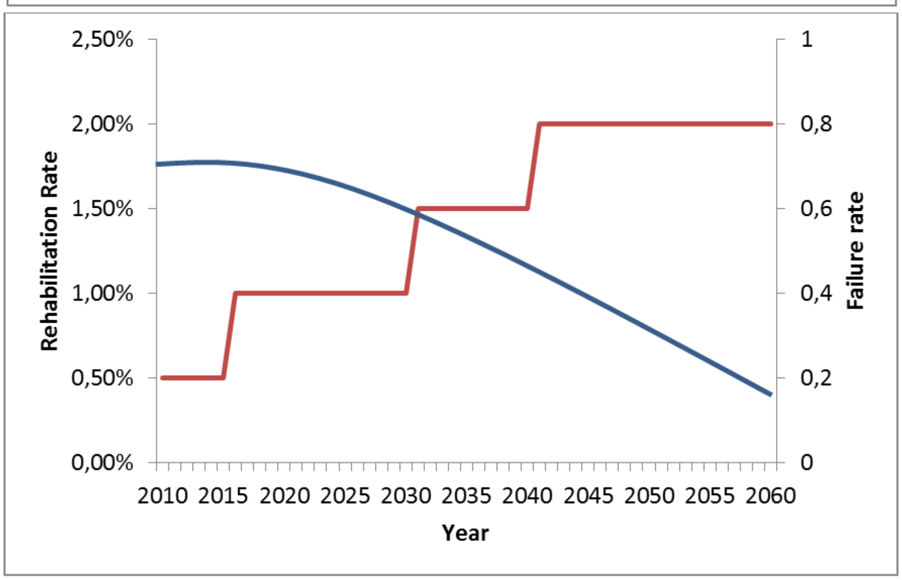


Figure (9-35) water pipe renewal scenarios

9.8.3 Asset management roles of owner and operator

asset management consists from five components; asset inventory, level of service, critical assets, life cycle costing and long-term funding strategy. Each component has an important role to have a sustainable water network and to know how the network can be managed and operated in the right direction.

Actually, there are different thinking between asset owner and network operator regarding to Asset management. Related to the role, the asset owner focuses to preserving the value of the asset Profit expectations. Also asset owner focuses on the business mission statements, network lengths, Budget limits and etc. taking in to consideration maximize Returns, maximize net value.

However, the network operator focuses to preserving the network operation to be continuous and functional. In addition, network operator taking in to consider the failures rates / water losses, supply quality and rehabilitation costs (Mainova, 2010).

Table (9-10) shows the different roles of asset management between asset owner and network operator

Table (9-10) the different roles of asset management between asset owner and network operator (adapted from Mainova 2010)

Role: Asset Owner (preserving the asset value)	Role: network operator (preserving the functional and technical condition)
1. Targets	
▪ profit expectations	♣ target network concepts, such as
▪ business mission statements	♣ failures rates / water losses
▪ target network concepts, such as	♣ supply quality
▪ network Value (Fixed Assets)	♣ rehabilitation costs
▪ Network length	♣ Rehabilitation Technology (Materials, techniques, ...)
2. Restrictions / conditions	
Governing business risks	Limited to
Budget limits / budget path /	♣ damage rates / water losses
max. budget variations	♣ operational resources
	competition law reviews
3. Optimization criteria	
e.g maximize returns and net value	e.g. minimum cost network

Figure (9-36) sample for pipe failure disruption in the center of Frankfurt am Main city

9.9 Conclusion

The study identifies several analysis concepts. Survival analysis for water pipes has been used to determine the deterioration rate for each pipe material for the whole life of the pipes. We identified that cast iron pipes have higher deterioration rate than ductile cast iron (GGG). In addition, plastic pipes (PE and PVC) have higher deterioration rate than metallic pipes. The Kaplan-Meier method is useful and simple tool for comparing survival curves based on pipe materials. Neural network analysis has been used to determine the importance factors affecting of failure rates in water network. We identify using neural analysis that material factor is the most important factor for deterioration of factors, in addition of expecting the number of failures. Several rehabilitation strategies also have been applied for Frankfurt water network taking in to consideration the failure rates and required rehabilitation rates.

This research helps the water utilities with the most important decisions, tools and strategies in water distribution networks.

10 Conclusions and Recommendations:

Conclusions

This research made significant contributions to improve the sustainability of water network. This research mainly focuses on three case studies from different locations. First case study is water network of Gaza city representing developing countries.

Recent researches in optimal rehabilitation strategies have been studied. Contributions of pipe failure for different material have been reached for our different cases.

This work included the use of several Statistical techniques based on GIS application.

For Gaza city water network case we used hydraulic model (WaterCAD) based on GIS to develop a simplified deterioration models can be used easily in water utility with limited data available. Water pressure and water velocity have been an output of the hydraulic model to be used as an indicator for pipe deterioration ranking model. A GIS-based hydraulic analysis model was developed to evaluate the condition assessment of the pipe. The model was fairly accurate in identify the critical pipes in water networks.

Bodenheim water network has been selected to analyze the plastic pipes failures since about 55% of total water network made from UPVC material. Several plastic pipe failures have been inspected and described. Comparison has been made also between UPVC pipe sample with Iron pipe have similar location and surrounding condition. The iron pipe has been deteriorated from inside more than plastic pipe, which was in good condition in spite of small deformation at the bottom.

Kuala Lumpur water network was the main case study. Several statistical analyses have been applied on the Kuala Lumpur water network. Generalized linear model has been used to predict the failures in the individual pipes and in district meter zones based on available data. Pipe deterioration model in individual pipes and DMZ has been derived from the GLM model and the methodology on how to use such a model to support asset management decision-making is presented. Contributing factors of pipe deterioration has been discussed.

Geo-statistical and Spatial Analysis techniques play an important role in the analysis of water mains failure. These methods help in obtaining significant concentration about exploratory settings and prediction tasks. We used spatial and time intervals relationship between failures as a new indicator for prediction of failures. A close correlation was observed between the spatial distributions of pipeline damage and temporal interval. The research reports on the development of an integrated GIS based decision support system for asset management of urban water distribution networks. Cluster analysis has been used for understanding the failures in each cluster zone.

Results provided a clear picture of main patterns in the Kuala Lumpur with a reasonable interpretation of the identified clusters of pipe failures, especially with AC pipes.

This research includes ranking model for AC pipe renewal based on a combination of chemical pipe inspections and statistical analysis of pipe condition. The model is developed using ArcGIS.

In order to estimate the water distribution condition-state probabilities, using the following methodologies: Geo-statistical Analysis of pipe failures to build the ranking model for pipe condition and renewal plans and simple test to verify of AC pipe condition using phenolphthalein to determine the leaching grade. The resulting integrated system can be deployed as a decision support system for the management of water distribution networks, prioritizing pipes based on its condition.

Also this research includes Artificial Neural Networks and Survival analysis for the prediction of water pipelines failure for Frankfurt am Main case study. This case study provides several rehabilitation strategies for decision makers with tools for an effective rehabilitation and maintenance programs.

Research questions which have been mentioned in chapter one have been answered in this research. Several water utilities used GIS just as achieving system. This research addressed the importance of GIS in developing models can be used simply in building pipe condition assessment models. GIS model have built using limited data available in water companies. Statistical analysis methods also have been used to estimate numbers of pipe failure using limited data available based on GIS and generalized linear model. Important deterioration factors have been addressed using survival analysis and ANN network analysis.

Generally, this research can be used in different water utilities in the world taking into consideration budget and data availability. This research applied models and statistical tools among different cities with high non-revenue water (NRW) such as Gaza-Palestine and Kuala Lumpur- Malaysia. In addition, Frankfurt city, that has low NRW rates and old pipes network.

The objectives of this research have been achieved by:

- Building a condition assessment model based on hydraulic parameters as addressed for Gaza Strip case in chapter 3.
- Finding the relationship between failures based on spatial and temporal intervals between

pipe failures as in chapter 7.

- Analysis of pipe failures using advanced statistical model based on generalized linear model and GIS as in chapter 6.
- Developing pipe rehabilitation scenarios based on economic plans as in chapter 9.
- Finding the important factors effects in pipe deteriorations using survival analysis and ANN methods.
- Establishment of simple condition assessment model for AC pipes based on chemical test in comparison with developed assessment model using different variables and parameters as in chapter 8.

This work constitutes a starting point for future research for more comprehensive improvement assessment for water network and provides tools for improving rehabilitation strategies based on quantitative and predictive models.

Finally, one of the important point in this research that it has been applied on different case study from different countries taking of economic budgets and percentage of NRW. This makes research applicable in whole water utilities in the world through developing countries to developed countries.

Recommendations

ANN has been used in this research to provide importance factors in pipe deterioration. Further work needs to be done on the ANN model to develop prediction model based on Geographic Information system. Also comprehensive and unique database system including the most important factors is required to improve the water network database quality.

11 References

Abu Shaaban S (1999) Infrastructure Projects in Gaza Strip Upgrading and Rehabilitation of Water, Sewage Systems and Municipal Infrastructure in Northern Gaza

Advanced Engineering Solutions (2007), Cementitious pipe condition report, http://www.aesengs.co.uk/.

Ahn J.C., Lee S.W., Lee G.S. and Koo J.Y. (2005). Predicting water pipe breaks using neural network. Water Supply. Vol. 5, No. 3-4, pp. 159–172 c IWA Publishing 2005.

Akaike, H. (1974), "A New Look at the Statistical Model Identification," IEEE Transactions on Automatic Control, AC-19 (6) 716-723.

Al-Barqawi Hassan and Tarek Zayed, (2006), Condition rating model for underground infrastructure sustainable water mains. Journal of Performance on constructed facilities. Journal of Performance of Constructed Facilities, Vol. 20, Issue 2, pp. 126-135.

Al-Barqawi H and Zayed T (2008) "Infrastructure Management: Integrated AHP/ANN Model to Evaluate Municipal Water Mains' Performance" JOURNAL OF INFRASTRUCTURE SYSTEMS © ASCE / DECEMBER 2008

Al-Barqawi, H., Zayed, T., (2006a). Condition rating model for underground infrastructure sustainable water mains. Journal of Performance of Constructed Facilities, 20(2):126-135. [doi:10.1061/(ASCE)0887-3828(2006)20: 2(126)]

Al-Barqawi, H., Zayed, T., (2006b). Assessment Model of Water Main Conditions. The Pipeline Division Specialty Conference, Chicago, USA. [doi:10.1061/40854(211)27]

Ambrose. M, Burn. S, DeSilva. S (2011) Life cycle analysis of water network , available on , http://www.pepipe.org/uploads/pdfs/Life_Cycle_Cost_Study.pdf

American Water Works Association (AWWA). (1986). Introduction to Water Distribution Principles and Practices of Water Supply Operations. Denver, CO: AWWA.

American Water Works Association AWWA, (2002) PVC Pipe-Design and Installation (Awwa Manual, M23)

American Water Works Association Research Foundation AWWARF , DVGW-Technologiezentrum Wasser (1996), Internal corrosion of water distribution systems /. 2nd ed. ISBN 0-89867-759-9.

Ana E, Jr. and Bauwens (2007) SEWER NETWORK ASSET MANAGEMENT DECISION-SUPPORT, International Symposium on New Directions in Urban Water Management, 12-14 September 2007, UNESCO Paris .

Andreou, S. A., D. H. Marks, and R. M. Clark (1987a). A new methodology for modeling break failure patterns in deteriorating water distribution systems: Theory, Adv. Water Resour., 10, 2-10, 1987a.

Andreou, S. A., D. H. Marks, and R. M. Clark (1987b). A new methodology for modeling break failure patterns in deteriorating water distribution systems: Applications, Adv. Water Resour., 10, 11-20,1987b.

Andreou, S. A., Marks, D.H., and Clark, R. M. (1987). "A new methodology for modelling break failure patterns in deteriorating water distribution systems: Applications." Advance in Water Resources, 10, 11-20.

Andreou, S.A., (1986). "Predictive models for pipe break failures and their implications on maintenance planning strategies for water distribution systems," unpublished PhD Thesis, Department of Civil Engineering, Massachusetts Institute of Technology, Cambridge, MA, 1985.

Applus, (2011) interview with technical expert in applus company. http://www.applusrtd.com

ArcGIS (2010), ArcGIS help tutorials available on website on 1/1/2011 http://resources.arcgis.com/en/help/arcgisonline/index.html#//010q00000002000000.

Ardakani, R. (2004), "Earthquake damage detection in water distribution system." Conf. Proc., Pipeline Engineering and Construction: What's on the Horizon? ASCE, New York, 1–4.

Asnaashari (2007), Water Pipelines Failure Modeling, Statistical, Artificial Neural Networks and Survival Modeling, PhD thesis.

Becker A, (2011), "Technical assessment report for AC pipes" IWW water center.

Berenson, M., Levine, D., & Krehbiel, T. (2002). 8th edn Basics Business Statistics: Concepts and Applications. New Jersey: Prentice Hall 488-490.

Bernal-Lara T, et al (2006), Stepwise Fatigue Crack Propagation in Poly(vinyl Chloride), Journal of Vinyl & Additive Technology, 10(1),5-10 (2006).

Boxall, J. B., O'Hagan, A., Pooladsaz, S., Saul, A. J., Unwin, D. M. (2007). Estimation of burst rates in water distribution mains. Water Management, Vol. 160, Issue: 2, pp. 73-82.

Brad C (2004), Transient and Surge Related Pipe Bursts, Water Loss and Damage Prevention, Singer Valve Inc.: Surrey, B.C., Canada. p. 19.

CAMP (Coastal Aquifer Management Program), 2000 "Integrated Aquifer Management Plan" , Palestinian water authority, Gaza Strip- Palestine.

Christodoulou S (2009) Water network assessment and reliability analysis by use of survival analysis. EWRA 7th Conference, Limassol, Cyprus, pp 503–510.

Christodoulou S, Aslani P, Vanrenterghem A (2003) A risk analysis framework for evaluating structural degradation of water mains in urban settings, using neurofuzzy systems

Christodoulou S, Charalambous B, Adamou A (2007) Managing the ‘repair or replace’ dilemma on water leakages. In: Proc. international water association’s (IWA) third specialty conference on water loss reduction (Water loss 2007), Bucharest, Romania.

Christodoulou S, Deligianni A (2010) A neurofuzzy decision framework for the management of water distribution networks. Water Resour Manag 24(1):139–156. doi:10.1007/s1126900994412.

Christodoulou S, Deligianni A, Aslani P, Agathokleous A (2009) Risk-based asset management of water piping networks using neurofuzzy systems. Comput Env Urban Syst 33(2):138–149. doi:10.1016/j. compenvurbsys.2008.12.001.

Christodoulou SE (2011) Water network assessment and reliability analysis by use of survival analysis. Water Resour Manag 25(4):1229–1238

Clark, R. M., Stafford, C. L. and Goodrich, J. A. (1982), “Water distribution systems: a spatial cost evaluation.” Journal of Water Resources Planning and Management Division ASCE, 108 (WR3), 243-255.

Cox, D. R. (1972), Regression models and life tables. J. R. Statist. Soc. 34(Series B), 187–220.

Crabtree, Oliphant, (2012) , “Residence of PE4710 piping to pressure surge events in force main application” available on website http://plasticpipe.org/pdf/resistance-of-pe4710-piping-to-pressure-surge-evnets-in-force-main-applications.pdf.

CSIRO Manufacturing and infrastructure technology, Pipe life times (2012). Available at http://www.csiro.au/org/CMSE access 1.1 2012

Date, C. J., (1995), An Introduction to Database Systems, 6th edition (Reading: Addison-Wesley Publishing Company).

Dehghan A, (2009) “Failure Prediction for Water Pipes” PhD thesis,

Dorn, R., Houseman, P., Hyde, R. A., and Jarvis, M. G. (1996), Water Mains: Guidance on Assessment and Inspection Techniques. London, UK. Construction Industry Research and Information Association.

Dridi L, Mailhot A, Parizeau M, Villeneuve JP (2009) Multi-objective approach for pipe replacement based on bayesian inference of break model parameters. J Water Resour Plann Manag 135(5):344–354

DVGW W 392 (2003), DVGW W 392 Deutsche Vereinigung des Gas- und Wasserfaches e.V., Technische Mitteilung: Rohrnetzinspektion und Wasserverluste – Maßnahmen, Verfahren und Bewertungen, 2003.

DVGW W 400-3 (2006), DVGW W 400-3 Deutsche Vereinigung des Gas- und Wasserfaches e.V., Technische Regel: Wasserverteilungsanlagen (TRWV), Teil 3: Betrieb und Instandhaltung, 2006.

DVGW W 403 (M) (2010), “Entscheidungshilfen für die Rehabilitation von Wasserverteilungsanlagen“ Technischer Hinweis – Merkblatt April 2010

Francis, C. (1994). “Sieving the evidence on leakage.” Water and Waste Treatment, DR Publications, London

Gavin J. Bowden, Holger R. Maier, and Graeme C. Dandy (2002) Optimal division of data for neural network models in water resources applications WATER RESOURCES RESEARCH, VOL. 38, NO. 2, 1010, 10.1029/2001WR000266, 2002

Germanopoulos, G., and Jowitt, P. W. (1989), “Leakage reduction by excess pressure minimisation in a water supply network.” Proc. Inst. Civ. Eng., Part 2. Res. Theory, 87, 195–214

GETIS, A., and J.K. ORD. (1992). The analysis of spatial association by use of distance statistics. Geogr. Anal. 24(3):189–206.

Goulter, I. C. and Kazemi, A. (1988). “Spatial and temporal groupings of water main pipe breakage in Winnipeg.” Canadian Journal of Civil Engineering, 15, 91-97.

Hadzilacos, T., Kalles, D., Preston, N., Melbourne, P., Camarinopoulos, L., Eimermacher, M., and Kallidromitis, V. (2001) “UTILNETS: A Water Mains Rehabilitation Decision Support System” Computers, Environment and Urban Systems, special issue on Urban Knowledge Engineering.

Han J, Kamber M, A.K.H. Tung,(2001) Spatial Clustering methods in data mining: a survey, in: J. Han, M. Kamber (Eds.), Geographic Data Mining and Knowledge Discovery, CRC Press, 2001, p. 338.

Harlow K (2010), THE MYTH OF DEEP PIPES: CRITICALITY AND PIPE REHABILITATION STRATEGIES, http://www.bcwaternews.com/AssetMgt/AM19_deep_pipes.pdf.

Hawth's (2011) “Hawth's Analysis Tools for ArcGIS” http://www.spatialecology.com/htools/tooldesc.php

Hertz J, Krogh A, Palmer RG, (1991), Introduction to the theory of neural computation. Reading, Massachusetts: Addison-Wesley Publishing

Herz, R. K. (1996). Ageing processes and rehabilitation needs of drinking water distribution networks. Journal of Water Supply Research and Technology – Aqua, 45(5), 221-231.

Hessen, (2011), available on website http://www.wirtschaft.hessen.de/irj/HMWVL_Internet?cid=5108cc51bcc241ce5b4d378fc7c00c88.

Hessenwasser, (2011), technical paper available on www.Hessenwasser.de.

Ho CI, Lin MD, Lo SL. (2010), "Use of a GIS-based hybrid artificial neural network to prioritize the order of pipe replacement in a water distribution network." Environ Monit Assess. 2010 Jul;166(1-4):177-89. Epub 2009 May 26.

Hornik, K., Stinchcombe, M., and White, H. (1989). "Multilayer feedforward networks are universal approximators." Neural Networks, 2, pp. 359–366.

Hu, Y. and Hubble, D. (2007). Factors contributing to the failure of AC water mains. Canadian Journal of Civil Engineering, 34:1-14.

Hu, Y.; Wang, D.L.; Cossitt, K.; Chowdhury, R. (2010) AC pipe in North America: inventory, breakage and working environments , International Journal of Pipeline Systems Engineering and Practice, 1, (4), pp. 156-172, November 01, 2010, DOI: 10.1061/(ASCE)PS.l949-1204.0000064

Hu,Y. and Hubble,D. (2009). AC pipe in North America: rehabilitation/replacement methods and current practices. Canadian Journal of Civil Engineering

Hunaidi (2010), "Condition assessment of water pipes" , www.nrc-cnrc.gc.ca.

IMQS, (2010) available online at website:
http://imqs.co.za/pdf/Company%20Profile%202010.pdf

International Water Association IWA, (2006), performance indicators for water supply services , second edition , ISBN: 1843390515.

Istt (International society for trenchless technology) , (2005) "Condition Assessment Inspection Technique" available on
http://www.astt.com.au/images/uploads/05_Condition_Assessment_Inspection_Technique.pdf

Jenkins P (2005) Survival Analysis , available on website 1/3/2011
(https://www.iser.essex.ac.uk/files/teaching/stephenj/ec968/pdfs/ec968lnotesv6.pdf)

Kettler, A. J. and Goulter, I. C. (1985). "An analysis of pipe breakage in urban water distribution networks." Canadian Journal of Civil Engineering, 12, 286-293.

Kingdom B, Liemberger R, Marin P, (2006), The Challenge of Reducing Non-Revenue Water (NRW) in Developing Countries, Paper No. 8 available on website
http://siteresources.worldbank.org/INTWSS/Resources/WSS8fin4.pdf

Kleiner Y, Rajani B (1999) Using limited data to assess future needs. J Am Water Works Assoc 91:47–61.

Kleiner, Y. and Rajani, B. B. (2001). "Comprehensive review of structural deterioration of water mains: statistical models." Urban Water, 3 (3), 131-150.

Kleiner, Yehuda, (1997). Water distribution network rehabilitation: selection and scheduling of pipe rehabilitation alternatives. A thesis submitted in conformity with the requirements for the degree of Doctor of Philosophy. Graduate Department of Civil engineering. University of Toronto.

Kuo C-L, Hsu N-S (2011) An optimization model for crucial key pipes and mechanical reliability: a case study on a water distribution system in Taiwan. Water Resour Manag 25(2):763–775.

Lee ET, Wang JW (2003) Statistical methods for survival data analysis. Wiley, Hoboken

Lei, J. and Sægrov, S. (1998). “Statistical approach for describing failures and lifetimes of water mains.” Water Science and Technology, 38 (6), 209-217

Levelton (2011) “Class 150 Asbestos cement (AC) watermain pipe condition evaluation” Deep bay water district”. Available on http://www.levelton.com/

Lindsey (2007) Applying Generalized Linear Models, Limburgs Universitair Centrum, Diepenbeek, October 29, 2007

Liu Z, Kleiner Y, and Rajani (2012) Condition Assessment Technologies for Water Transmission and Distribution Systems

Longinu M (1999), Risk Management in the Gold Mining Industry, thesis, Coventry University.

Mainova, (2010) ‘Technical report for Frankfurt water network’ Mainova Water Company, 2010.

Makar, J. and Kleiner, Y. (2000). Maintaining water pipeline integrity, AWWA Infrastructure Conference and Exibition, Baltimore, Maryland, USA, March 12-15, 2000.

Makar, J., Desnoyers, R. and McDonald, S. (2001). Failure modes and mechanisms in gray cast iron pipe, Underground Infrastructure Research; Municipal, Industrial and Environmental Applications, Kitchener, Ontario.

Malandain, J., Le Gauffre, P. and Miramond, M. (1999). Modeling the aging of water infrastructure. In: Proceedings of the 13th EJSW, 8 September – 12 September, Dresden University of Technology. ISBN: 3-86005-238-1.

Misiunas. D (2004) Failure Monitoring and Asset Condition Assessment in Water Supply Systems, Doctoral Dissertation in Industrial Automation, ISBN 91-88934-40-3

Moran, P.A.P. (1950). Notes on continuous stochastic phenomena, Biometrika 37, pp17-23.

Mordak, J . , and Wheeler, J. 1988. Deterioration of asbestos cement water mains. Final report to the Department of the Environment, Water Research Center, Wiltshire, U K .

Mu sigma, (2012) “The Generalized Linear Model” . Available on website http://www.mu-sigma.com/analytics/delivery-framework/cafe-cerebral-generalized-linear-model.html.

Najafi, M., and Kulandaivel, G. (2005). “Pipeline condition predicting using neural network models.” Conf. Proc., Pipelines 2005: Optimizing Pipeline Design, Operations, and Maintenance in Today’s Economy, ASCE, New York, 767–781.

Nicolini M, Giacomello C, Deb K (2011), Calibration and Optimal Leakage Management for a Real Water Distribution Network. / JOURNAL OF WATER RESOURCES PLANNING AND MANAGEMENT © ASCE / JANUARY/FEBRUARY 2011.

NKU Website Northern Kentucky University website(http://www.nku.edu/~longa/geomed/ppa/doc/NNA/NN)

NRC, 2003, Federation of Canadian Municipalities and National Research Council 2003 Deterioration and Inspection of Water Distribution Systems Issue No. 1.1 .

O'Day, D.K. (1982) Organizing and Analyzing Leak and Break Data for Making Main Replacement Decisions. Jour. AWWA, 108:5:243 (1982).

O'Day, D.K., Weiss,R., Chiavari, S., and Blair, D. (1986), Guidance Manual: Water Main Evaluation for Rehabilitation / Replacement, AWWA Research Foundation, Denver, CO, 1986.

O'Day, K. (1989). "External corrosion in distribution systems." AWWA Journal, 81 (10), 45-52.

Ohmer R (2009) „Betriebswirtschaftlich optimierte Instandsetzungsplanung" Wiesbaden.

Oliphant. K, Conrad. M, Bryce. W (2012) Fatigue of Plastic Water Pipe: A Technical Review with Recommendations for PE4710 Pipe Design Fatigue.

Oliveira D.P. de., (2010), A density-based spatial clustering approach for defining local indicators of drinking water distribution pipe breakage, Adv. Eng. Informat. doi:10.1016/j.aei. 2010.09.001

Oliveira D.P.d. , Soibelman L., J.H. Garrett Jr. (2009), Spatial clustering analysis of water main break events, in: 2009 ASCE International Workshop on Computing in Civil Engineering, ASCE, Austin, Texas, 2009.

Olson, H.L. (1974), Asbestos in Potable-Water Supplies. Jour. AWWA, 66:515.

Palermo (2010) , How to Design Against Long Running Cracks in Plastic Pipe for Water Applications, Palermo Plastics Pipe Consulting . Available on www.plasticspipe.com.

Park S (2008) Identifying the hazard characteristics of pipes in water distribution systems by using the proportional hazards model: theory. KSCE J Civ Eng 8(6):663–668

Park S, Jun H, Kim BJ, Im GC (2008) Modelling of water main failure rates using the log-linear ROCOF and the power law process. Water Resour Manag 22(9):1311–1324. doi :10.1007/s11269-007-9227-3.

Park, S. (2000), An Optimal Pipeline Replacement Scheduling Model for Water Distribution Systems, Ph.D dissertation, Virginia Tech, Blacksburg, VA, 2000.

Pascal, O. and Revol, D. (1994). "Renovation of water supply systems." Water Supply Congress, International Water Supply Association, 12 ((1/2) Budapest), 6-3, 6-7.

PCBS (2009). Palestinian Central Bureau of Statistics. http://pcbs.gov.ps/DesktopDefault.aspx?lang=en

PCBS (2011) Palestinian Central Bureau of Statistics report.

PIPA (2003) 'METHOD FOR ASSESSING THE RESIN DISPERSION IN PVC PIPES' Plastics Industry Pipe Association of Australia Limited

PlumbingMart, (2012) Water Hammer Information. Available on website http://www.plumbingmart.com/water-hammer-information.html

Preston, N., Melbourne, P., Eimermacher, M., Hadzilacos, T. and Kalidromitis, V. (1999). UtilNets: A Water Mains Rehabilitation Decision Support System. In: Proceeding of NO-DIG 1999, North American Society of Trenchless Technology, Orlando May 1999.

PWA (2006) Hydraulic analysis of Gaza water transmission system and design option for allocation merkorot bulk fresh water supply

Rajani, B.; Kleiner, Y. (2001). Comprehensive review of structural deterioration of water mains: physically based models, Urban Water, v. 3, no. 3, Oct. 2001, pp. 151-164

Rajani, B.B., Zhan, C. and Kuraoka, S., (1996). Pipe-soil interaction analysis of jointed water mains., Canadian Geotechnical Journal, Vol. 33, No. 3.

Røstum J (2000), "Statistical modelling of pipe failures in water networks" Dissertation Trondheim, Norway, February 2000.

Røstum, J., Baur, R., Sægrov, S., Hörold, S. and Schilling, W. (1999), Predictive service-life models for urban water infrastructure management. In: Proceedings of 8th International Conference on Urban Storm Drainage, Sydney, Australia, 30 August - 3 September, ISBN 0 85825 718 1, pp. 594-601.

Sægrov, S., Melo Baptista, J.F., Conroy, P., Herz, R.K., LeGauffre, P., Moss, G., Oddevald, J.E., Rajani, B. and Schiatti, M. (1999). Rehabilitation of water networks: Survey of research needs and on-going efforts. Journal of Urban Water

Sfsu, (2002), Generalized Linear Models (GLZ) available on web http://userwww.sfsu.edu/efc/classes/biol710/Glz/Generalized%20Linear%20Models.htm

Shamir U, Howard C (1979) An analytical approach to scheduling pipe replacement. J Am Water Works Assoc 71:248–258

Skipworth, P. Engelhardt, M. Cashman, A. Savic, D. Saul, A. Walters, G. (2002). "Whole life costing for water distribution network management." Thomas Telford Publishing, London, ISBN 0727731661

Smartball (2012) available on website http://www.puretechltd.com/products/smartball/smartball_leak_detection.shtml.

Smith, E.P. (1994). An Optimal replacement- Design Model for a Reliable Water Distribution.

Sorge C. (2007): Technical condition assessment of metallic water supply pipes as part of their rehabilitation planning, LESAM– 2nd Leading Edge Conference on Strategic Asset Management, Lisbon, Portugal 17.–19. October 2007.

Sorge. C (2009) Materialtechnische Zustandsbewertungen Grundlage für Rohrnetzbewertung und Instandhaltungsplanung , available on website http://www.hessenwasser.de/www/dnl/public/Rohrnetzbewertung_und_Instandhaltungsplanung.pdf.

Spatial Analyst (2010), ArcGIS10 tutorial.

SPSS (2012) IBM tutorial 2012.

Stavroula T & Vasilis K & Ioannis B (2011) "Pipe Networks Risk Assessment Based on Survival Analysis" Water Resour Manage (2011) 25:3729–3746 DOI 10.1007/s11269-011-9881-3.

Sterling, M. J. H., and Bargiela, A. (1984). "Leakage reduction by optimised control of valves in water networks." Trans. Inst. Meas. Control (London), 66, 293–298.

Stewart, R. (2005), Plastic pipe: corrosion resistance, ease of installation stimulate demand for plastic pipe. http://plasticpipe.org/pdf/plastic_pipe_corrosion_resistant.pdf

Stone, S,et al (2002) Decision-Support Tools for Predicting the Performance of Water Distribution and Wastewater Collection Systems EPA/600/R-02/029.

Sugihara K, Okabe A, Satoh T, (2009). Computational method for the point cluster analysis on networks, GeoInformatica.

SWAN Research, 2011, Stated NRW (Non-Revenue Water) Rates in Urban Networks

Syabas (2010) Annual technical report of Syabas Company, Kuala Lumpur, Malaysia.

Tabesh, M.; Delkhah, A.; Delavar, M. R., (2010). Use of geographic information system based tool for renovation and rehabilitation of water distribution systems. Int. J. Environ. Sci. Tech., 7 (1), 47-58.

Thomson, D. J. (2003): Dispersion of particle pairs and decay of scalar fields in isotropic turbulence. Physics of Fluids, 15, 801-813.

UK Water Industry Research UKWIR (2002) Plastic pipes http://www.ukwir.org/site/web/content/home.

Utah (2009) Survival Analysis, website: www.econ.utah.edu.

V.-M. V. a. M. C. Institute (2009), Surge Control in Pumping Systems., Val-Matic Valve and Manufacturing Corp: Elmhurst, IL. p. 21.

Vickridge and Lau (2010) Lessons Learnt from Pipeline Condition Assessment in Hong Kong. http://204.118.135.81/downloads/Resources/Reports/lessons_learnt_from_pipeline_condition.pdf

Walski, T. M., and A. Pelliccia (1982), "Economic Analysis of Water Main Breaks." J. American Water Works Assoc., 74(3), 140 – 147, 1982.

Walski, T. M., Wade , R., Sharp, W. W., Sjostrom, J. W. and Schlessinger, D. (1986). "Conducting a pipe break analysis for a large city." AWWA Conference Symposium, 387-402.

Water Science and Technology Board (WSTB) (2006) *Drinking Water Distribution Systems: Assessing and Reducing Risks*. Washington, DC: The National Academies Press.

Watson TG, Christian CD, Mason AJ, Smith MH, Meyer R (2004) Bayesian-based pipe failure model. J Hydroinformatics 6(4):259–264.

Wayman, M. (2003) Life Prediction and Condition Assessment for Large Diameter Water Mains Risk Assessment in the Pipeline Industry. Cramlington, U.K.

Wengström, T.R. (1993a). Comparative analysis of pipebreak rates: a literature review. Institutionen för vattenförsörjnings- och avloppsteknik, Chalmers tekniska högskola.

Wengström, T.R. (1993b). Drinking water pipe breakage records : a tool for evaluating pipe and system reliability. Institutionen för vattenförsörjnings- och avloppsteknik, Chalmers tekniska högskola.

World Bank (2009) Assessment of Restrictions on Palestinian Water Sector Development Report No. 47657-GZ

Yamada, Ikuho and Thill, Jean-Claude (2010) 'Local Indicators of Network-Constrained Clusters in Spatial Patterns Represented by a Link Attribute', Annals of the Association of American Geographers, 100: 2, 269 — 285.

Yamada, J.-C. Thill, (2006) Local indicators of network-constrained clusters in spatial point patterns, Geographical Analysis 39 268–292.

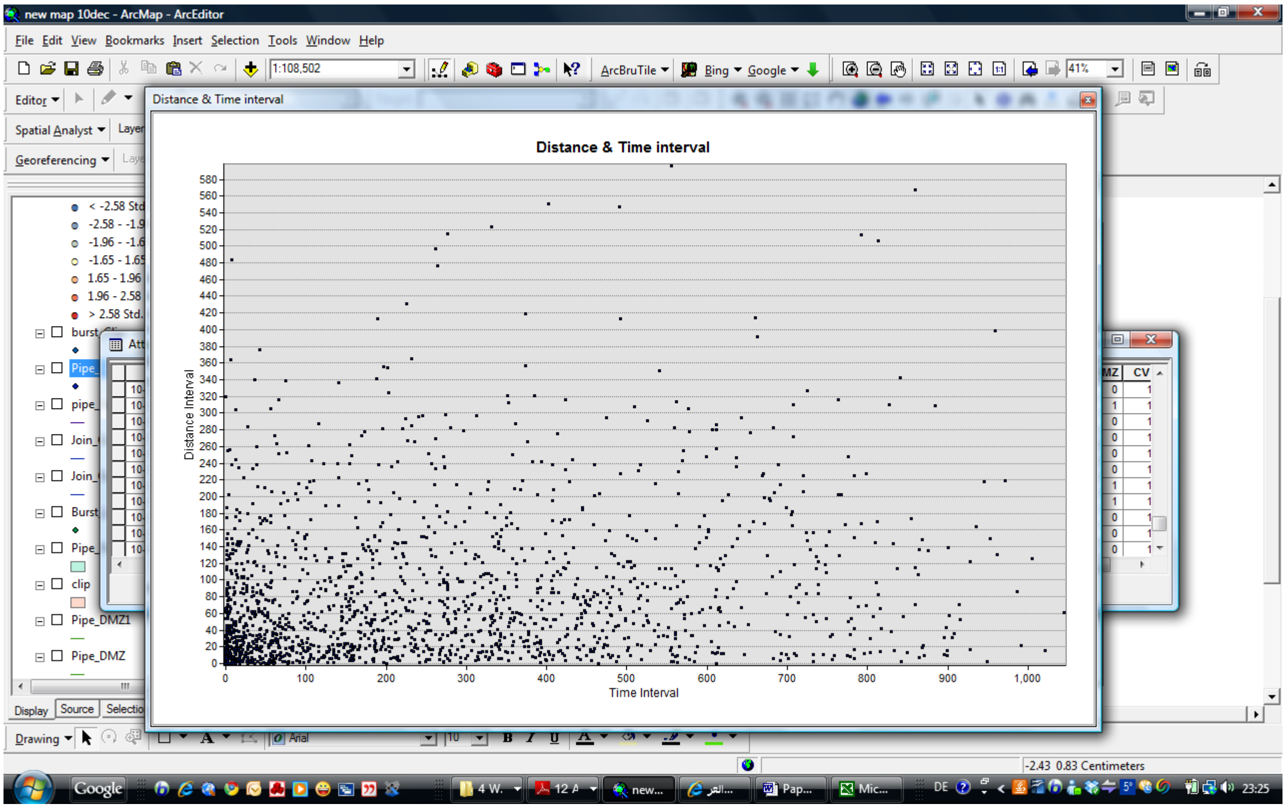
YAMIJALA S (2007), STATISTICAL ESTIMATION OF WATER DISTRIBUTION SYSTEM PIPE BREAK RISK , Thesis

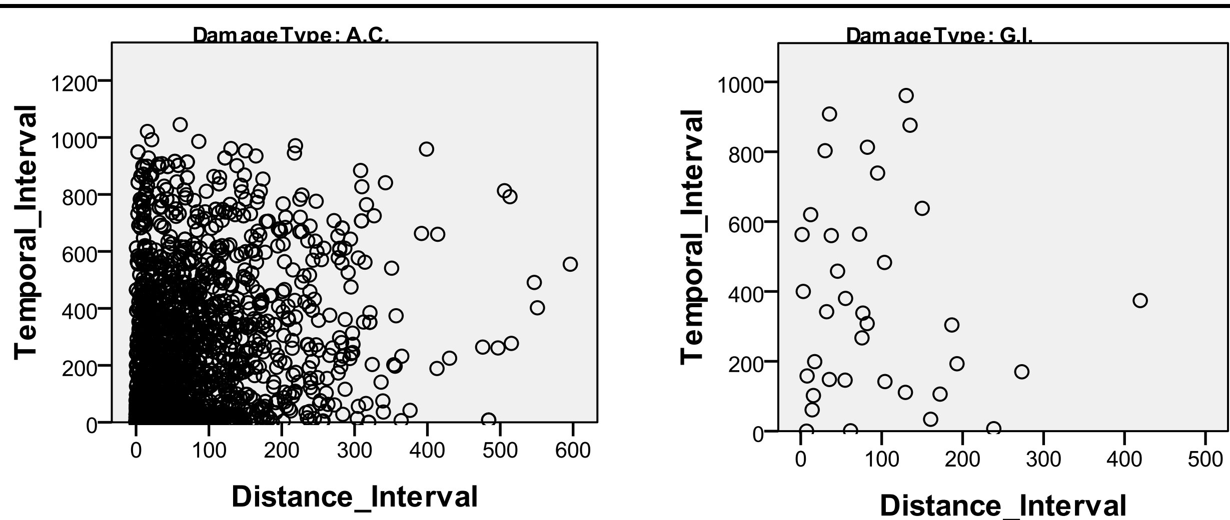
Yiu M, Mamoulis N (2004), Clustering objects on a spatial network, in: Proceedings of the 2004 ACM SIGMOD International Conference on Management of data, 2004, pp. 443–454.

Zeitouni K (2010) "A Survey of Spatial Data Mining Methods Databases and Statistics Point of Views" available on website http://www.prism.uvsq.fr/~karima/papers/IRMA_02.pdf.

12 APPENDIXES

12.1 Appendix I





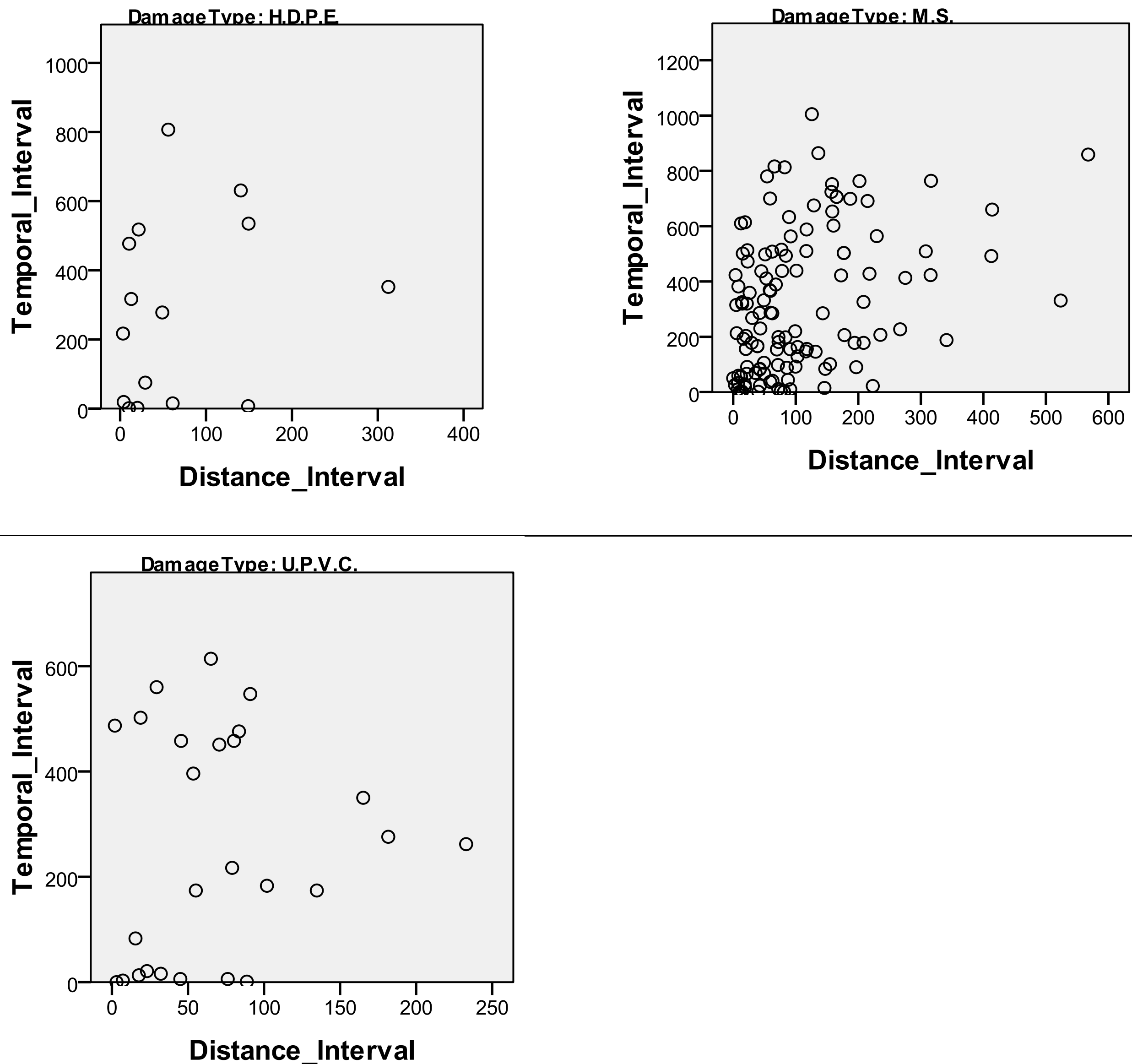
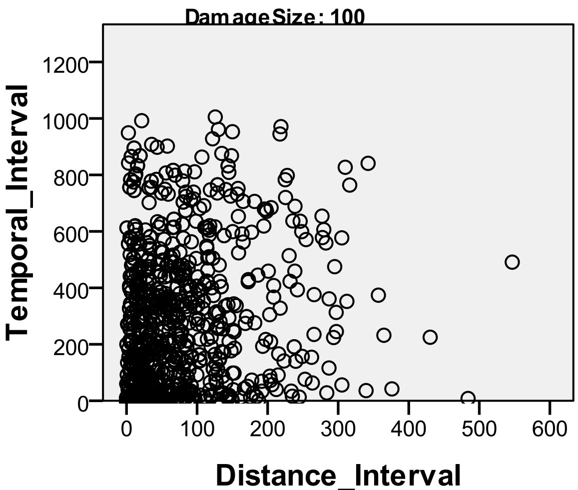
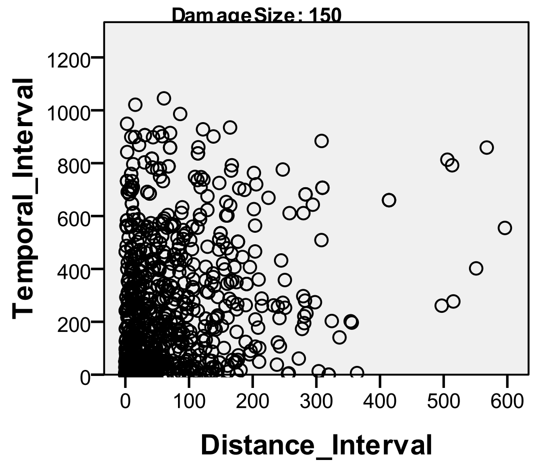
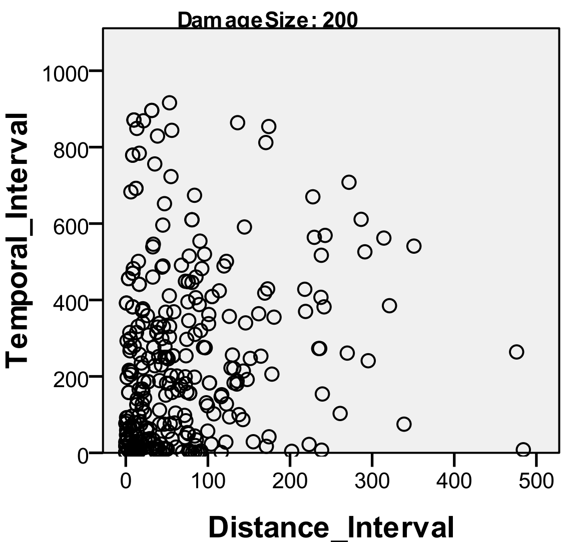
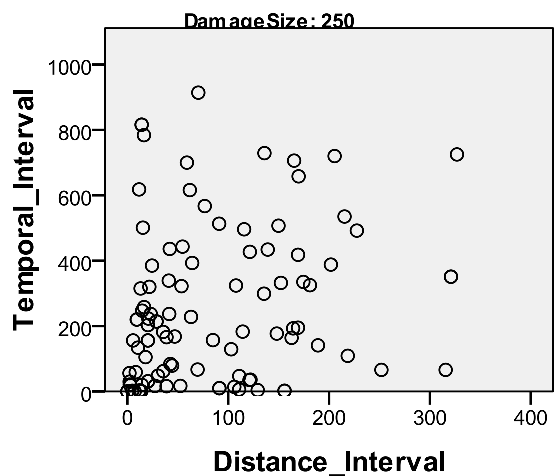


Figure (A1) relationship between distance and temporal intervals between failures based on pipe material


DamageSize: 100
Temporal_Interval
0
200
400
600
800
1000
1200
Distance_Interval
0
100
200
300
400
500
600


DamageSize: 150
Temporal_Interval
0
200
400
600
800
1000
1200
Distance_Interval
0
100
200
300
400
500
600


DamageSize: 200
Temporal_Interval
0
200
400
600
800
1000
Distance_Interval
0
100
200
300
400
500


DamageSize: 250
Temporal_Interval
0
200
400
600
800
1000
Distance_Interval
0
100
200
300
400

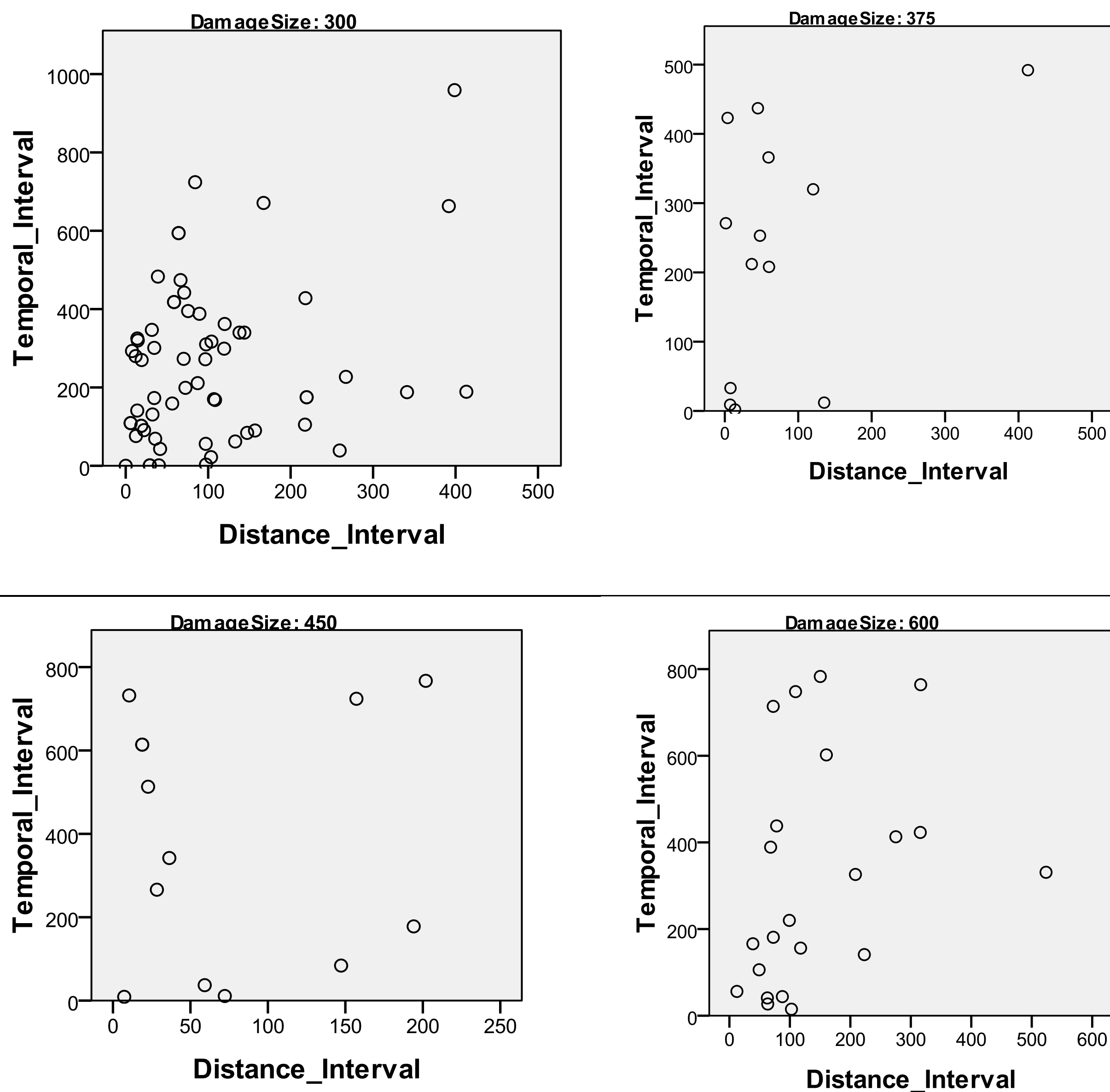


Figure (A2) relationship between distance and temporal intervals between failures based on pipe diameter

Histogram for distance interval

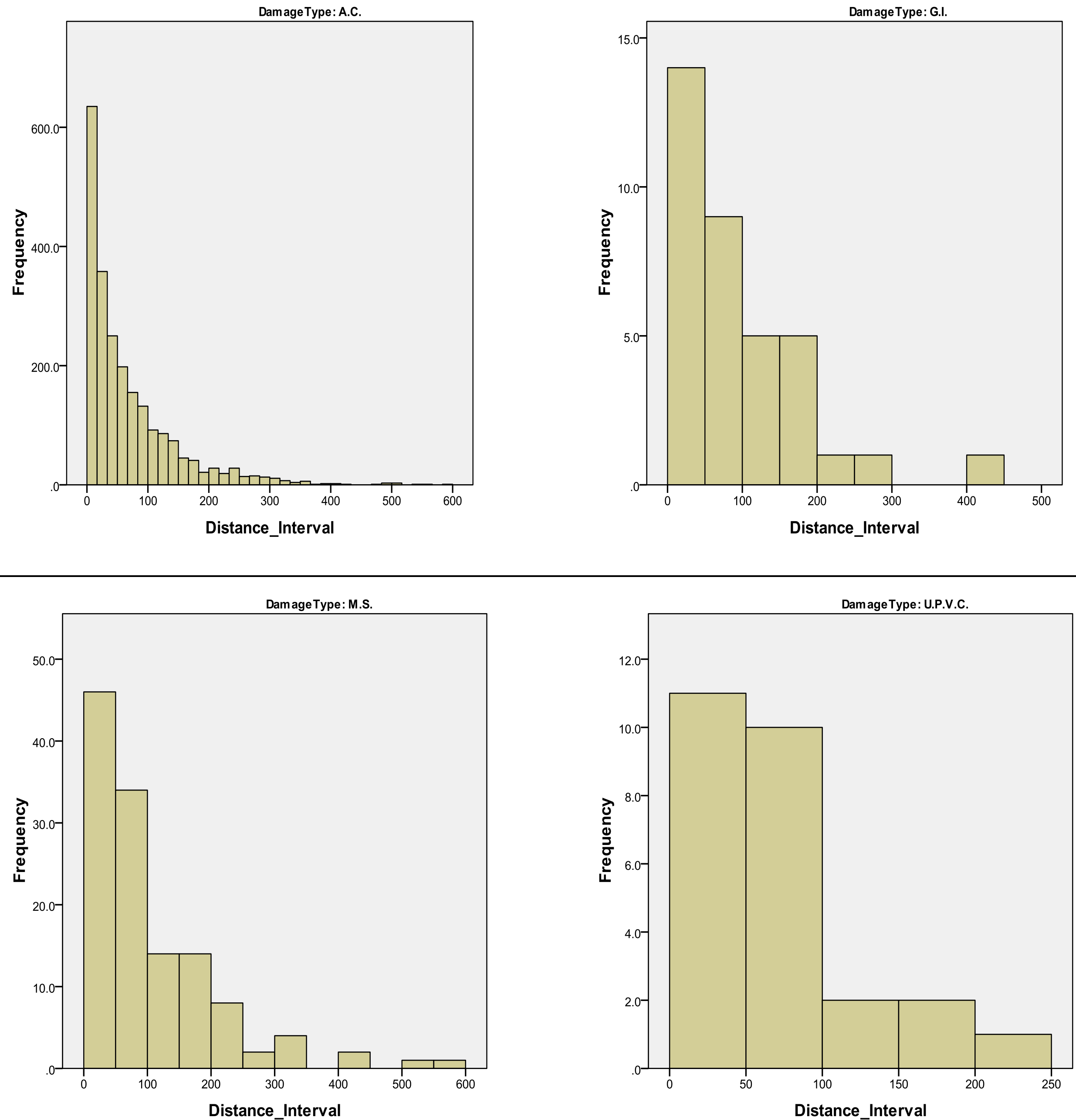
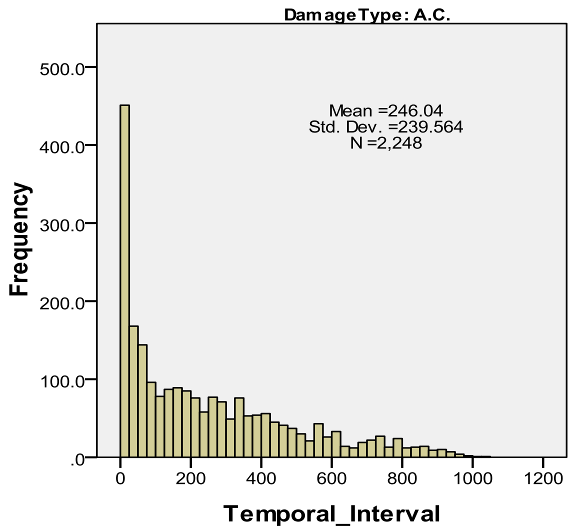
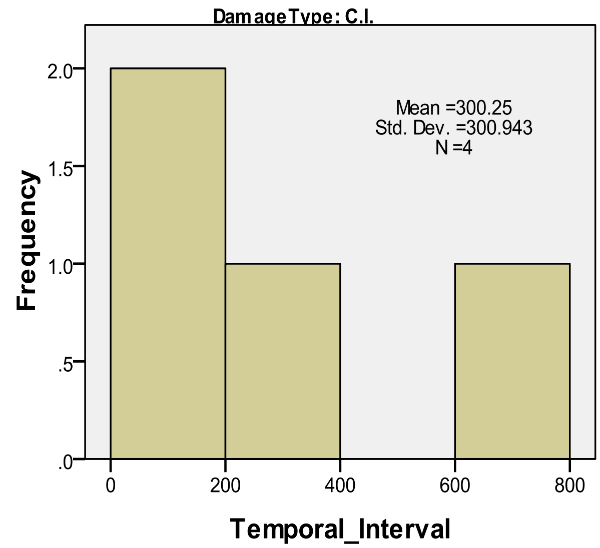
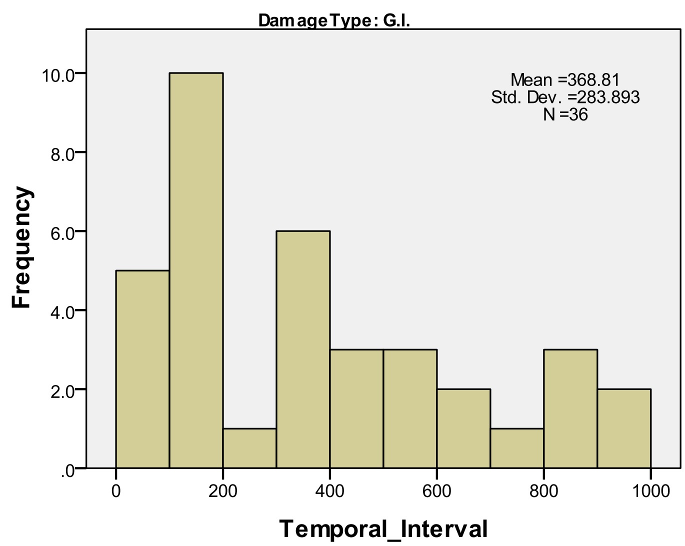
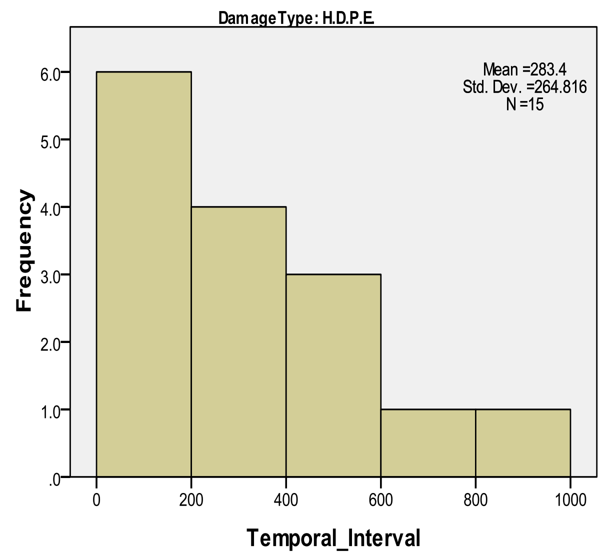


Figure (A3) Histogram for distance interval


DamageType: A.C.
Mean =246.04
Std. Dev. =239.564
N =2,248
Frequency
Temporal_Interval
500.0
400.0
300.0
200.0
100.0
.0
0
200
400
600
800
1000
1200


DamageType: C.I.
Mean =300.25
Std. Dev. =300.943
N =4
Frequency
Temporal_Interval
2.0
1.5
1.0
.5
.0
0
200
400
600
800


DamageType: G.I.
Mean =368.81
Std. Dev. =283.893
N =36
Frequency
Temporal_Interval
10.0
8.0
6.0
4.0
2.0
.0
0
200
400
600
800
1000


DamageType: H.D.P.E.
Mean =283.4
Std. Dev. =264.816
N =15
Frequency
Temporal_Interval
6.0
5.0
4.0
3.0
2.0
1.0
.0
0
200
400
600
800
1000

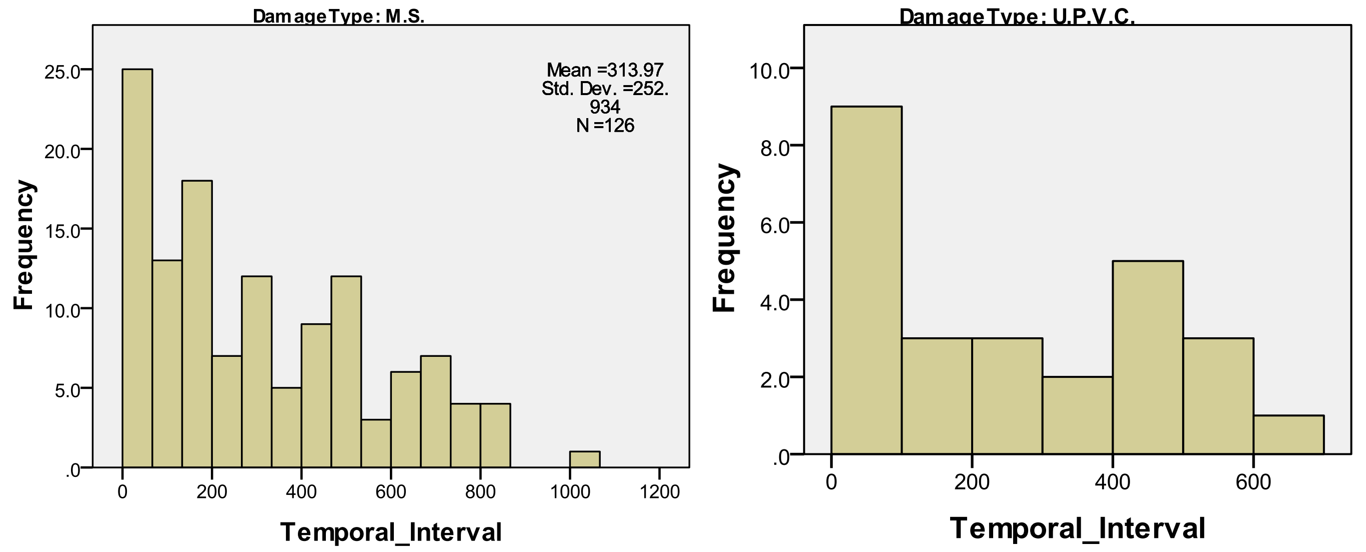


Figure (A4) Histogram for Temporal Interval between failures based on pipe material

12.2 Appendix II: Model Code

Criteria	Condition Index	Classification

Material	15	AC = 0 , DI=12, SS=15 , CI=10, HDPE=5, UPVC=7, MS=13
		if [Mat_Code]=1 then
		[Material_Index] =0
		elseif [Mat_Code]=2 then
		[Material_Index] =13
		elseif [Mat_Code]=3 then
		[Material_Index] =7
		elseif [Mat_Code]=4 then
		[Material_Index] =5
		elseif [Mat_Code]=5 then
		[Material_Index] =10
		elseif [Mat_Code]=6 then
		[Material_Index] =12
		elseif [Mat_Code]=7 then
		[Material_Index] =15
		end if

Diameter	13	if [OUTERDIAME] =100 then
		[Dia_Index]= 4
		elseif [OUTERDIAME]=150 then
		[Dia_Index]= 8
		elseif [OUTERDIAME]=200 then
		[Dia_Index]= 10
		elseif [OUTERDIAME]=250 then
		[Dia_Index]= 11
		elseif [OUTERDIAME]=300 then
		[Dia_Index]= 12
		else
		[Dia_Index]= 13
		End if

Pipe Length	6	if [Length_Pip]< 5 then
		[Length_Index]=6
		elseif [Length_Pip]< 10 and [Length_Pip] > 5 then
		[Length_Index]=5
		elseif [Length_Pip]< 20 and [Length_Pip] > 10 then
		[Length_Index]=4
		elseif [Length_Pip]< 30 and [Length_Pip] > 20 then
		[Length_Index]=3
		elseif [Length_Pip]< 40 and [Length_Pip] > 30 then
		[Length_Index]=2
		else
		[Length_Index]=0
		end if

Failure Mode	8	LF = 8 , CF =10 ,

		if [Failure_Mod]=0 then
		 [Mode_Index] = 8
		elseif [Failure_Mod] = 1 then
		 [Mode_Index] = 4
		elseif [Failure_Mod] = 2 then
		 [Mode_Index] = 2
		else
		 [Mode_Index] = 0
		end if

Pipe age	20	(age< 5) =20, (age5-10)= 15, (age 10-30)=10 , (age >30) =5
		if [Pipe_age] < 5 then
		 [Age_Index] = 20
		elseif [Pipe_age] > 5 and [Pipe_age] <10then
		 [Age_Index] = 17
		elseif [Pipe_age] > 10 and [Pipe_age] <20then
		 [Age_Index] = 12
		elseif [Pipe_age] > 20 and [Pipe_age] <30then
		 [Age_Index] = 7
		elseif [Pipe_age] > 30 and [Pipe_age] < 40then
		 [Age_Index] = 5
		else
		[Age_Index] = 2
		end if

NPF/km (FpK)	12	if [Failure_Km] = 0 then
		[FpK_Index]= 12
		elseif [Failure_Km] < 0.5 and [Failure_Km]> 0 then
		 [FpK_Index] = 8
		elseif [Failure_Km] < 1 and [Failure_Km]> 0.5 then
		 [FpK_Index] = 6
		elseif [Failure_Km] <2 and [Failure_Km]> 1 then
		 [FpK_Index] = 4
		elseif [Failure_Km] <3 and [Failure_Km]> 2 then
		 [FpK_Index] = 2
		elseif [Failure_Km] <5 and [Failure_Km]> 3 then
		 [FpK_Index] = 1
		else
		 [FpK_Index]=0
		end if

NPL	7	0 Leak= 7, 1 Leaks=5, 3 Leaks =3, 4 Leaks =2, Leaks > 4 = 0 if [Leak_Km]< 1 then [Leak_Index] = 7 elseif [Leak_Km]< 5 and [Leak_Km]>1 then [Leak_Index] = 6 elseif [Leak_Km]< 10 and [Leak_Km]>5 then [Leak_Index] = 5

		elseif [Leak_Km]< 20 and [Leak_Km]>10 then
		[Leak_Index] = 4
		else
		[Leak_Index] = 0
		end if

Pressure	6	Inside DMZ =10 , outside DMZ =0
		if [DMZ]=0 then
		[Pressure_Index] =0
		elseif [DMZ]=1 then
		[Pressure_Index] =7
		end if

Soil	8	if [Soil_Type]=1 then
		[Soil_Index]=0
		elseif [Soil_Type] =2 then
		[Soil_Index]=4
		else
		[Soil_Index]=7
		end if

Traffic	5	if [Traffic_Type]=1 then
		[Traffic_Index]=0
		else
		[Traffic_Index]=5
		end if

Concept of ranking system classification

```
========================================================================================
If [CInde*x] < 20 then
 [Class]= 0
elseif [CIndex]>20 and [CIndex]<40 the
[Class]= 1
elseif [CIndex]>40 and [CIndex]<60 the
[Class]= 2
elseif [CIndex]>60 and [CIndex]<80 the
[Class]= 3
elseif [CIndex]> 80 then
[Class]= 4
End if
============================================================================
```