A COMPARATIVE STUDY OF TRENCHLESS TECHNOLOGIES VERSUS TRADITIONAL OPEN TRENCHING FOR THE REPLACEMENT OF AGEING POTABLE WATER PIPELINES

BY

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NOVEMBER 2013

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ABSTRACT

The urgent need to rehabilitate or replace ageing deteriorated buried potable water pipeline networks is one of the many critical service utility provision challenges faced within the municipalities in South Africa. The majority of these unreliable deteriorated pipeline networks consist of un-dipped (not coated with bitumen) AC piping which have long passed their planned economic and technical lifespan. Traditionally, the open trenching method has been utilised for the replacement of aged and deteriorated piping. However, this traditional open trenching method has shown to be expensive and difficult to implement, particularly in congested high traffic use urban areas.

The need to rehabilitate or replace the ageing deteriorated buried potable water pipelines in South Africa, taking into account the above mentioned expensive factors has a solution. This solution is termed ótrenchless technologyô and sometimes also termed óno digô. Recent advancements in trenchless technologies now include innovative methods such as pipe bursting, close-fit lining and sliplining. Close-fit compact pipe manufactured by Wavin Overseas B.V. was newly introduced in South Africa in 2010 for the rehabilitation of deteriorated pipelines. These trenchless methods require further research into their technical application merits, drawbacks and costs in relation to the traditional open trenching method in order to determine which method is more expensive and also least suitable.

Traditionally, the ótotal costô associated with pipe rehabilitation or replacement projects consisted only of the direct costs. The indirect and socio-economic inconvenience costs were often ignored and resulted in costly expenses to the municipalities. However, this research will show that these indirect and socio-economic inconvenience costs must form part of the total cost of a project as it assists with the successful completion of the project without expensive unforeseen costs to the municipalities. In addition, this research will provide insight as to which indirect and socio-economic inconveniences are dominantly experienced by the public. To achieve this, a quantitative socio-economic survey questionnaire was developed. This questionnaire was aimed at residents and business owners who were affected during a project of this nature.

This research study will serve as a support tool to municipalities of South Africa when selecting a pipe rehabilitation or replacement method. This support tool will provide key technical merits and drawbacks of the traditional open trenching method, pipe bursting method, close-fit compact pipe method and sliplining method. In addition, this research study will compare the ótotal costô of the traditional open trenching method against the trenchless pipe bursting method.

The decision making process lies in the hands of the municipal technical managers. Therefore, their knowledge and experience of up to date information on trenchless methods (as well as the traditional open trenching method) is vitally important. This research provides insight as to the knowledge and experience of technical municipal staff on trenchless methods, its application and use in South Africa. A quantitative survey questionnaire was developed by the researcher. This questionnaire was aimed at technical staff in the water departments of district and local municipalities of South Africa.

The results of the above questionnaire surveys formed part of the eThekwini Water and Sanitation (EWS) Feasibility study funded by the Dutch Government.

When comparing the costs of the trenchless pipe bursting method against the traditional open trenching method, the results revealed that trenchless methods are undoubtedly cheaper and far less disruptive to the public.

The results of the socio-economic survey revealed that trenchless methods were preferred by the public since it was less disturbing and the hindrances experienced were also far less than the traditional open trenching method.

The results of the technical municipal survey questionnaire revealed that at least 50% of municipal technical staff of South Africa are not adequately informed about trenchless methods, its application and technical merits and drawbacks respectively. This survey questionnaire revealed that South Africa may be advancing over the years on the use of trenchless methods, however, more educating in the form of training, seminars and other methods of marketing must be undertaken starting at a municipal level.

DECLARATION

This research study compiled by Mr Shanley Hay (student number: 20301080) is being submitted to the Durban University of Technology (DUT), Civil Engineering Faculty for the degree of Magister Technologiae: Engineering: Civil.

I, **Shanley Hay** hereby declare that this research study is the result of my own research and has not been submitted for any degree purpose to any other institution.

Submitted by:

[redacted]

Shanley Hay

Student Number: 20301080

DEDICATION

This research study is dedicated to my family who have supported me during the compilation of this research study.

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I am heartily thankful to my Lord and Saviour Jesus Christ for blessing me in abundance and being my constant strength allowing me the opportunity to complete this research study.

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GLOSSARY OF ACRONYMS AND SI UNITS

AC : Asbestos Cement

ACW : Asbestos Containing Waste

BEE : Black Economic Empowerment

CBD : Central Business District

CCTV : Closed Circuit Television

CAD : Canadian Dollar

CIPP : Cured in Place Pipe

CS : Cost Saving

DAEARD : Department of Agriculture, Environmental Affairs and Rural Development

DN : Diameter Nominal

DUT : Durban University of Technology

DWA : Department of Water Affairs

EPWP : Expanded Public Works Programme

EWS : eThekwini Water and Sanitation

EXCO : Executive Committee

GIS : Geographical Information Systemŝs

GPR : Ground Penetrating Radar

HDD : Horizontal Directional Drilling

HDPE	:	High Density Polyethylene
ID	:	Inside Diameter
ISTT	:	International Society for Trenchless Technology
kHz	:	Kilohertz
MFL	:	Million Fibres per Litre
mm	:	Millimetres
mPVC	:	Modified Polyvinylchloride
MTSQ	:	Municipal Technical Survey Questionnaire
MTU	:	Mapping the Underworld
NOM	:	Nominal
OD	:	Outside diameter
PE	:	Polyethylene
P&Gs	:	Preliminary and General
PLM	:	Polarised Light Microscopy
POS	:	Public Open Space
PVC	:	Polyvinylchloride
QNTY.	:	Quantity
SABS	:	Southern African Bureau of Services
SASTT	:	South African Society for Trenchless Technology
SESQ	:	Socio-economic Survey Questionnaire

SI	:	International System of Units
TT	:	Trenchless Technology
uPVC	:	Unplasticised Polyvinylchloride
US EPA	:	United States Environmental Protection Agency
VAT	:	Value Added Tax (14% in South Africa)
WISA	:	Water Institute of Southern Africa
ZAR	:	South African Rands

1 INTRODUCTION

1.1 Background to the study

The urgent need to rehabilitate or replace ageing deteriorated potable water pipeline networks is one of the many critical service utility provision challenges faced within the municipalities in South Africa. These unreliable deteriorated pipeline networks consisting of asbestos cement (AC), unplasticised polyvinylchloride (uPVC), modified polyvinylchloride (mPVC), high density polyethylene (HDPE), cast iron or steel piping operate at their full capacity. The majority of these unreliable deteriorated pipeline networks consist of un-dipped AC piping which have long passed their planned economic and technical lifespan e.g. Cities of Durban and Pietermaritzburg in KwaZulu Natal.

If the water is ósoftô i.e. lacking in calcium and magnesium, then the water reacts chemically with the lining of the AC pipe inner wall. As a result, softening and deformation of the AC pipe occurs. The asbestos fibres within the pipe wall then become loosened by the internal water quality. As a result of this, leaks and bursts occur along the AC pipeline route.

Leaks, continuous bursts and possible health risks form the major component of the critical challenges faced by municipalities due to ageing pipes. The results of these leaks lead to non-revenue water losses at the expense of the responsible municipality.

Traditionally, the open trenching method has been utilised for the replacement of aged and deteriorated piping. However, this traditional open trenching method has shown to be expensive and difficult to implement, particularly in congested high traffic use urban areas. The traditional open trenching method can also be expensive to implement in cases where there is an absence of existing underground mapping records for the aged and deteriorated pipelines. Other factors (in order of most expensive to least expensive) include, but not limited to:

a) Costs (i.e. direct, indirect and socio-economic inconveniences);

b) Damage to other existing service utilities e.g. electricity, telecommunications and sewer networks;

c) Intrusive damage to existing road surfaces, pavements and sidewalks; and

d) Disruptions to the existing water supply as a result of non-identification of a tie-in position to the existing unmapped deteriorated water pipeline.

The urgent need to rehabilitate or replace ageing deteriorated potable water pipelines in South Africa, taking the above mentioned expensive factors into account has a solution. This solution is termed ótrenchless technologyô and sometimes also termed óno digô. Trenchless technology serves as an alternative approach to the traditional open trenching method for the rehabilitation or replacement of ageing potable water pipelines. This trenchless method adopts a non-intrusive limited open trenching approach which is environmentally friendly. Numerous forms of trenchless technologies are currently already available and have been in use in South Africa for many years. These forms are mainly horizontal directional drilling and pipe jacking.

Recent advancements in trenchless technologies now include innovative methods such as pipe bursting, close-fit lining and sliplining. These innovative methods will be discussed in this research study. Pipe bursting is a óreplacementô method. Sliplining and close-fit lining are ‘rehabilitationô methods.

Matthews *et al.* (2012: 1) stated that the majority of municipalities, government organisations and engineering consultants do not have sufficient knowledge on the performance of new innovative trenchless methods. Therefore, a need to examine these innovative new trenchless methods based on its application merits and drawbacks are important.

Close-fit compact pipe manufactured by Wavin Overseas B.V. was newly introduced in South Africa in 2010 for the rehabilitation of deteriorated pipelines.

The use of pipe bursting in South Africa requires further research since the existing old deteriorated host pipe fragments are burst into the natural ground. The main reason for the research of the effects of the burst host pipe fragments into the natural ground is that majority of the existing pipes in South Africa are AC. Therefore, this could result in health risks i.e. effect on groundwater due to leaching of the asbestos fibres. Asbestos contains crocidolite and chrysotile which are carcinogenic fibres also known as óblueô and ówhiteô asbestos.

Sliplining has been widely used throughout South Africa yet requires further investigation especially concerning the hydraulic capacity of the replacement pipeline. The reason for this investigation is due to the fact that the sliplining method only sleeves a new smaller diameter pipe into the existing host pipe and not a larger diameter pipe. Thus, the hydraulic capacity is reduced rather than increased.

EWS recently replaced 2000 kilometres of their existing deteriorated potable water AC pipelines. The traditional open trenching method and three (3) trenchless methods i.e. close-fit compact pipe, pipe bursting and sliplining were utilised (Kee 2011: 1). Technical information and data from this project was granted by the EWS for use and reference in this research study.

Trenchless Technologies cc (Mr Sam Efrat - Director), an approved EWS service provider, who specialises in pipe replacement and rehabilitation projects also provided technical information and data which forms part of this research study.

The detailed aims of this research are listed under Section 1.6.

1.2 Nomenclature

Annulus - defined as the space between the new pipe and the existing (host) old deteriorated pipe.

Asbestos containing waste material - includes mill tailings or any waste that contains commercial asbestos. The term includes filters from control devices, friable asbestos waste material, and bags or other similar packaging contaminated with commercial asbestos.

Consumer - is the ultimate user of the product or service. The consumer may not have paid for the product or service.

Customer - purchases and pays for a product or service.

Direct cost - defined as a price that can be completely attributed to the production of the specific service i.e. the pipeline network.

Friable asbestos material - is any material containing more that 1% asbestos as determined using Polarised Light Microscopy (PLM), that when dry, can be crumbled, pulverised, or reduced to powder by hand pressure.

Non-friable asbestos containing material - is any material containing more than 1% asbestos as determined by Polarised Light Microscopy (PLM) that when dry, cannot be crumbled, pulverised, or reduced to powder by hand pressure.

Offline replacement - described as the laying of a new pipe in a new trench adjacent or parallel to the existing ageing deteriorated pipeline.

Online replacement - described as the removal of the existing ageing host pipe from its existing trench and installing a new pipe. The new pipe can be a different diameter size (larger or smaller) and of different manufactured material. The traditional open trenching method or trenchless methods can be selected to carry out the replacement process.

Pipe rehabilitation - defined as the restoration or repair of the existing pipeline necessary for the upgrading of the performance respectively.

Pipe replacement - defined as the laying of a new pipe either ñonlineò or ñofflineò from the existing ageing pipeline.

Trench - defined as a narrow excavation of the existing ground that is deeper than it is wide, and no wider than 4.5 metres.

1.3 Problems to be investigated

The following problems form the basis of this research study investigation:

1.3.1 Traditional open trenching

Application merits and drawbacks which include:

a) Dealing with conflicting service utilities e.g. sewer, telecommunications, electricity and stormwater;
b) Damage to existing service utilities and the associated costs thereof;
c) The connection of each individual household off-take onto the newly rehabilitated or replaced pipeline;
d) The effects on the Extended Public Works Programme (EPWP) i.e. need to create or promote local labour;
e) The direct cost comparison of the traditional open trenching method versus the trenchless pipe bursting method; and
f) Identification of the dominant indirect costs and social inconveniences associated with the traditional open trenching method.

1.3.2 Trenchless technologies

Application merits and drawbacks which include:

a) Initial high setup costs of equipment required (Chapman *et al.* 2007: 493);
b) Dealing with conflicting service utilities e.g. sewer, telecommunications, electricity and stormwater;
c) Damage of existing service utilities and the associated costs thereof;
d) Damages (if any) to the new HDPE liner pipe installed inside of the existing deteriorated host pipe:
    i. Rupture of the new HDPE liner pipe during installation;
    ii. Failure of the new HDPE liner pipe to pass through the bends along the existing host pipeline;
    iii. New HDPE liner pipe buckling around grout pressure when the new liner pipe is empty of water and is being grouted into place.
e) Costs associated with the provision of a temporary surface rider main pipeline in order to maintain essential water supply to consumers during the pipeline rehabilitation or replacement project process;

f) The effect on the hydraulic capacity of the pipeline before and after installation of the HDPE liner pipe;
g) The effects on the EPWP i.e. need to create or promote local labour versus the use of highly technical equipment to complete a project;
h) The direct cost comparison of the trenchless pipe bursting method versus the traditional open trenching method; and
i) Identification of the dominant indirect costs and social inconveniences associated with the trenchless technology methods discussed in this research study.

1.3.3 General

a) The effect/s on the pipe rehabilitation/replacement project process when records of the existing deteriorated host pipe is non-existent;
b) The effect/s which the asbestos fibres have on humans upon ingestion through drinking water through the existing deteriorated AC host pipe (i.e. is it a health hazard to ingest the asbestos fibres?); and
c) The effect/s which the loosened pipe asbestos fibres have on the groundwater quality when leached from the pipe walls.

1.4 Hypothesis to be investigated

At this early stage, it is assumed that the trenchless methods are expensive during the project start-up phase and construction (laying of pipes) period (i.e. highly expensive technical equipment required). However, trenchless methods eliminate indirect costs and social inconveniences (e.g. traffic delays, damage to road and access driveway surfaces) during construction. These indirect costs and social inconveniences are eliminated since trenchless methods are faster and more efficient than the traditional open trenching method. As a result, the overall costs of trenchless methods will be lower. Since the majority of the existing old pipelines in South Africa consist of AC pipelines and have limited as-built records, municipalities will incur further costs for the detection of existing services in congested built up areas using radar equipment e.g. a Central Business District (CBD).

Trenchless methods will reduce (or possibly eliminate) the costs for safe temporary storage, transportation and disposal of the AC piping at a licensed hazardous waste disposal site (which is very costly). Since trenchless methods either (1) lay a new pipe inside of the old host pipe or (2) burst through the old host pipe into the ground.

1.5 Limits of the study

a) For the purposes of this research study, the following innovative trenchless methods will be examined based on their application merits and drawbacks. These trenchless methods are:

   i. **Close-fit compact pipe -** a new trenchless rehabilitation method developed by Wavin Overseas B.V. (2009);

   ii. **Pipe bursting -** a trenchless replacement method; and

   iii. **Sliplining -** a trenchless rehabilitation method.

b) The application merits and drawbacks of the trenchless methods listed above will be compared against each other and also compared to the traditional open trenching replacement method respectively;

c) Direct cost comparison - only the trenchless pipe bursting method will be compared against the traditional open trenching method in terms of its direct cost. Direct cost rates for the close-fit compact pipe and sliplining methods could not be obtained from local specialists at the time of undertaking this research study and was therefore excluded. The direct cost comparison of the close close-fit compact pipe and sliplining methods can form a new research study in the future;

d) The extent (kilometre length of) AC piping in South Africa will be discussed in general. A survey to determine the actual extent of AC piping in South Africa (per municipal jurisdiction) will not be covered in this research study. A survey to determine the kilometre length of AC piping in South Africa can form a new research study;

e) The effects of loosened asbestos fibres leached in the groundwater through the trenchless pipe bursting method will be discussed in general in this research study. The laboratory testing to verify that the loosened asbestos fibres have no effect on the groundwater will not be undertaken as part of this research study. This can form new a new research study; and

f) A general overview of the contribution of the traditional open trenching method and trenchless methods towards the promotion of the Extended Public Works Programme (EPWP) will be discussed in this research study. A detailed comparison including statistical data will not be covered in this research study. This can form a new research study.

1.6 Research aims

a) This research study will serve as a technical support tool during the decision making process of municipalities and consultants when selecting a rehabilitation or replacement method for old deteriorating pipelines;

b) This research study will serve as a supporting document towards the EWS Feasibility Study funded by Dutch Government and provide research output as follows:

  iv. Socio-economic Questionnaire ï customer/consumer perspective, determining which inconveniences are dominantly experienced by the public;

  v. Municipal Survey Questionnaire - determining the percentage of technical staff in municipalities of South Africa whom are adequately informed on trenchless technologies and their applications;

c) The study will help to determine which is the most cost effective and practical option using national and local research. The aims associated are as follows:

  i. Maximise the lifespan of adjacent existing service infrastructure such as road pavements by preventing damage to these services during the pipeline replacement or rehabilitation process; and

  ii. Minimise loss of service to the customer/consumer, especially in high use areas;

d) The dissertation will disseminate this information as widely as possible as to increase the body of knowledge.

1.7 Objectives of the research study

a) To compile a concise list of application merits and drawbacks by reviewing existing international and local literature including technical information for the following methods:
   i. Traditional open trenching;
   ii. Pipe bursting;
   iii. Close-fit compact pipe (Wavin Overseas B.V.); and
   iv. Sliplining.

b) To collate and analyse direct costs data (received from an approved local specialist) for the traditional open trenching method and pipe bursting method respectively;

c) To develop a socio-economic questionnaire:
   i. In order to undertake a customer/consumer perspective field survey;
   ii. The area selected will be one in which a potable water pipeline rehabilitation/replacement was recently completed;
   iii. This research survey questionnaire will provide results of the customer/consumerọs perspective on method selection and also provide an indication as to which inconveniences (e.g. traffic delay, dust and noise) are dominantly experienced;

d) To develop a municipal technical survey questionnaire:
   i. In order to undertake a municipal technical staff survey;
   ii. This survey will determine the extent of knowledge of trenchless technologies by municipal technical staff within various municipalities in South Africa;

e) Synthesising available international and local published literature to expand knowledge in the broad field of trenchless technologies; and

f) To analyse the factors in which trenchless methods are the cheaper option as opposed to the traditional open trenching method, e.g. costs for site clearance, excavations, bedding of pipes, pipeline laying, removal and re-instatement of roads and driveways.

2 LITERATURE REVIEW

2.1 Background

Buried potable water pipeline networks in South Africa are one of the most complex underground networks that exist. Since these pipelines are hidden beneath the earthôs surface, they are not given the attention deserved. They are only given attention if the pipes burst and water leakage is evident on the earthôs surface (Metje *et al.* 2012: 569). The service provider (e.g. a municipality) then has to temporarily shut off the water supply, excavate through the surfacing and natural ground, expose the pipe and then carry out the pipe rehabilitation or replacement exercise. For many decades, the rehabilitation or replacement of existing deteriorated pipes has been completed using traditional open trenching methods. By this stage, the customer/consumer then becomes frustrated and blames the municipality for poor service delivery. The reliability of this water network is thus of utmost importance. These existing potable water networks in South Africa as a whole are worth billions of Rands (ZAR) and are in a state of decay (Kramer 1998: 48).

Years of utilisation and neglect of potable water pipeline networks have resulted in the negative impacts of this service. These include pressure losses, non-revenue water losses and in turn costly budget constraints to the municipalities. Municipalities become inundated with customer/consumer complaints ranging from lack of provision to water cuts and pipe bursts. In emerging economies, the need for basic utility services is growing as well as the resultant upgrading of each service respectively (Kramer 1998: 48). Barber *et al.* (2005: 23) stated that the out of sight, out of mind attitude adopted for maintenance and repair of many of these service utilities have left entire potable water pipeline networks in a serious state of degradation and desperate need for repair. The majority of these existing potable water networks are forced to operate at their maximum output since they have not been upgraded to cater for increasing demands (Fedotoff, Frutchey and Thomson 1990: 24).

Municipal water sectors (including wastewater and stormwater) account for the largest monetary investments made by municipalities. The main reason is that often their infrastructure requires expensive repairs (Struzziery 2010: 18). Municipalities are continually requested to maintain and improve the potable water pipeline networks with minimal budget since the maintenance of underground deteriorated services does not attract public attention. The monitoring of the condition of these pipeline networks is problematic. Potable water pipeline networks are only monitored at discrete points and not the entire network itself since these networks are buried beneath the earthộs surface (Metje *et al.* 2012: 316).

Pipe replacement processes can be costly due to the difficulty in accessing underground pipes and valves, especially in heavy vehicular and pedestrian traffic use areas (Barber *et al.* 2005: 24). Contractors cautiously excavate the ground in order to protect numerous existing underground service utilities from damage or destruction (Zaneldin 2007: 96). This disruptive open trenching method is not acceptable especially when working with underground infrastructure in dense cities and urban areas (Mckim 1996: VEC93). This disruption results in the slowing down of the progress of construction and thus is, again, very costly to the client.

With the recent introduction of trenchless technologies, more authorities worldwide e.g. Netherlands, China, United States of America, United Arab Emirates, South Africa, consider trenchless methods for pipe rehabilitation or replacement. The reason for this is that trenchless methods minimises excavation and can also save approximately 15 to 20 percent of the overall costs (i.e. direct, indirect and social inconveniences) of a project (Zhao and Rajani 2002: 2-3).

The International Society for Trenchless Technology (ISTT) provides descriptive illustrations for each scenario i.e. traditional open trenching and trenchless methods. Figure 1 describes the traditional open trenching scenario (International Society for Trenchless Technologies 2011a):

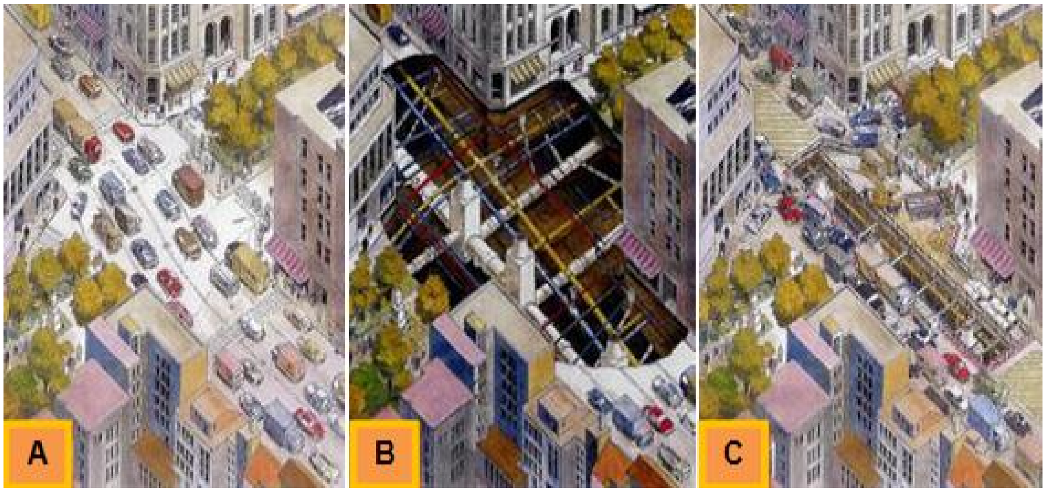

Figure 1 Traditional open trenching approach

Plate A: Illustrates a typical city junction with traffic which is congested with vehicular and pedestrian traffic, yet flowing normally.

Plate B: Illustrates the unseen maze of existing underground service utilities beneath the roadways and walkways.

Plate C: Illustrates the chaos and disruption which occurs when the underground services need to be replaced using the traditional open trenching method. Streets have to be dug up, lanes closed, traffic backlog and unnecessary dust and noise generated.

If the access points (i.e. under road access covers) to the underground services are utilised then there remains no need to dig up streets and sidewalks, and incur traffic delays, complaints and disruptions. Trenchless methods will minimise if not eliminate them (International Society for Trenchless Technologies 2011a).

Figure 2 reflects smooth flowing traffic with minimal disruption when trenchless methods are utilised (International Society for Trenchless Technologies 2011a).

Figure 2 Trenchless approach

Trenchless methods adopt the following procedures (Yemelin 2011: 69):

a) Broaching a cable;
b) Pipeline drainage;
c) Transportation of clearing tools (brushed, scraper, pistons, etc);
d) Pipeline condition assessment (defects);
e) Pulling in a new pipeline (liner);
f) Connecting existing off-takes to houses etc;
g) Disinfecting; and
h) Commissioning the new pipeline.

The numerous trenchless methods available on the market today depend on client and contractor preference, expertise and equipment availability (Sterling 2010: 66). These methods differ under various factors (Halloran and Slattery 1999: 28). These factors include the type of material and shape that the existing ageing deteriorating host pipe consists of (Wrobel, Szymiczek and Wierzbicki 2004: 638).

Chin and Lee (2005: 276) stated that there are about eighty (80) forms of trenchless methods that have been developed. A detailed diagram indicating the many forms of trenchless methods available is shown in Figure 3 (International Society for Trenchless Technologies 2011b):

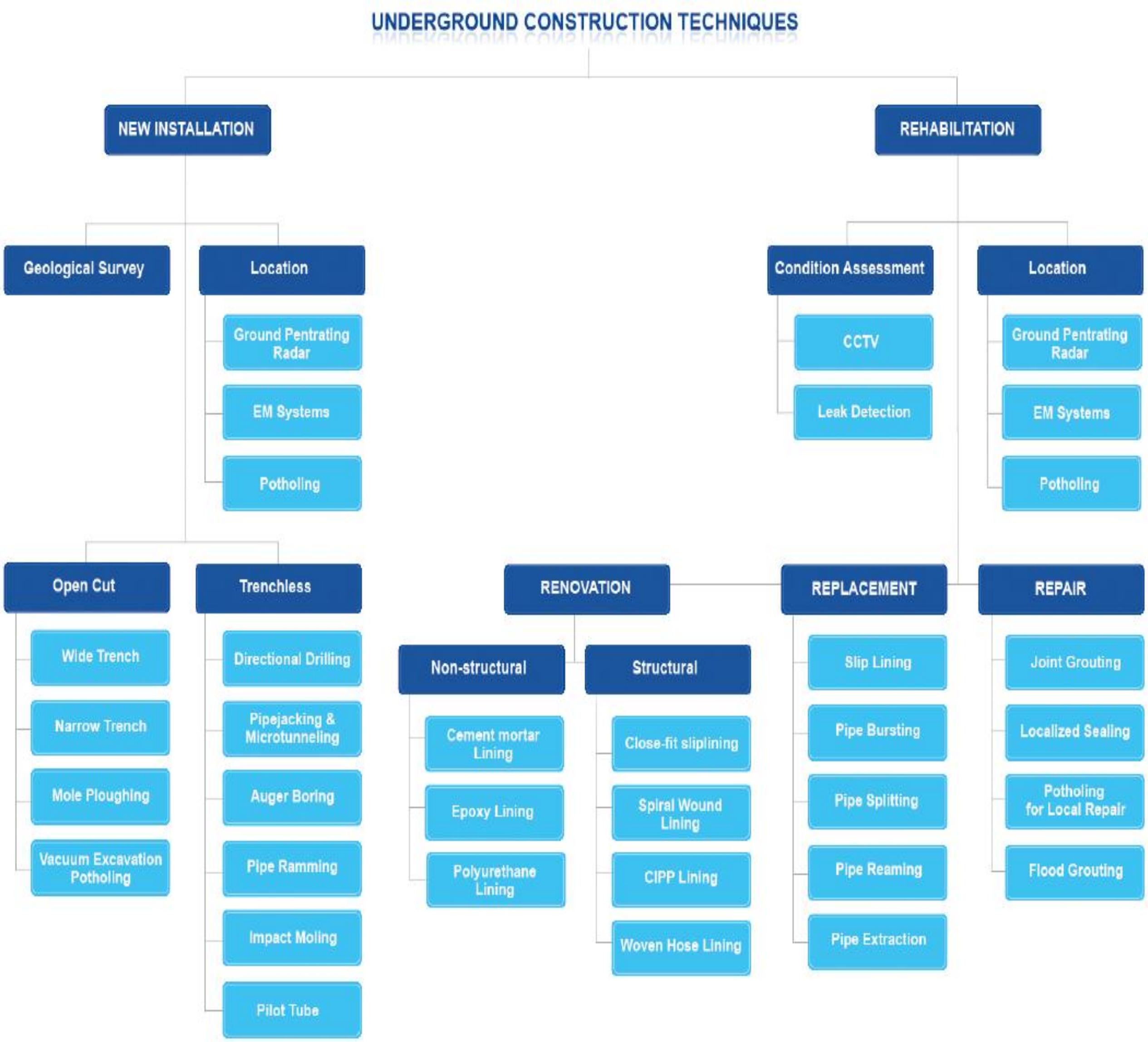

Figure 3 Underground construction techniques

Zaneldin (2007: 97) defined trenchless technologies as a family of methods, materials, and equipment capable of being used for the rehabilitation and replacement of existing deteriorated potable water pipeline networks with minimal disruption to surface traffic, business, and other activities. Each trenchless method has its own proper application merits and drawbacks which should form the baseline of the method selection process within municipalities (Mckim 1996: VEC91).

Matthews *et al.* (2012: 8) stated that any trenchless method that successfully rehabilitates or replaces a potable water pipeline network with limited surface excavation and ensures reliable connections under pressurised conditions is considered favourable. However, further research by Chapman *et al.* (2007: 492) stated that there evidently still remains a need to justify the use of trenchless methods even after many years of use. This need for justification is also present in a paper by Zhao and Rajani (2002: 1) which stated that over the past few years there were numerous inquiries on the costs of projects utilising trenchless technologies. In addition to these, a further article stated that trenchless methods that are in place in todayŝ market have some drawbacks such as the high costs and inconvenience of operation (Chin and Lee 2005: 267). One should analyse as to whether the trenchless method under consideration for selection is the most cost effective method to be utilised. The actual cost of a project depends largely on the specific conditions and the nature of the project in addition to sound engineering judgement (Zhao and Rajani 2002: 1). Further research stated that it is necessary to analyse many factors and technical parameters prior to the selection of the pipe rehabilitation or replacement method (Zwierzchowska 2006: 696).

2.2 Asset management

2.2.1 Introduction

Water utility service providers and municipalities throughout South Africa have been mandated by the national government to efficiently manage their infrastructure (assets). The rehabilitation and replacement of existing deteriorated potable water pipelines are the most expensive intervention. Therefore it is critically important to ensure that the correct pipeline networks be targeted for rehabilitation and replacement (Scruton, Bosboom and Fijma 2011: 1C-3-1).

2.2.2 Pipeline condition assessment

It is important for the condition of the existing potable water pipeline network to be understood. This plays a major role in the decision making process when selecting the most appropriate and cost effective method (i.e. rehabilitation or replacement). The Department of Water Affairs (DWA) estimated in 2011 that an annual investment of at least ZAR1.4billion is required to maintain existing buried service utilities in South Africa. To effectively manage these buried service utilities, effective technologies are required to assess their condition (Prinsloo, Wrigglesworth and Webb 2011: 20-21).

A pipeline condition assessment should include the following:

a) Inspection of its material;
b) Residual wall thickness samples;
c) Calculation of the hoop stress;
d) Density of the pipe;
e) Corrosion intensity;
f) Water tightness; and
g) Shape and length of individual sections.

Wall thickness samples of the existing pipe must be obtained. These samples will then be analysed to determine as to whether or not that specific pipe needs to be rehabilitated or replaced. In addition to this, an analysis of the soil and pipeline condition needs to be undertaken before an appropriate rehabilitation method is selected (Wrobel, Szymiczek and Wierzbicki 2004: 637).

In addition to working in a congested busy area such as the CBD, the absence of underground service utility records also makes the traditional open trenching method even more difficult to implement. The risks of damage to the existing underground services are much higher. Figure 4 gives an example of the complexity and intensity of services that exist underground (van de Zwan 2010: 12).

Figure 4 Complexities of underground service utilities

2.2.3 Historical mapping records for underground service utilities

The majority of the existing underground service utilities (i.e. water, electricity, sewer and so forth) were laid almost 80 to 100 years ago. Costello *et al.* (2007: 525) stated that throughout the world buried service utilities were even dated as far back as the Victorian times. During these early years there was no compulsory need to accurately record the details of underground utilities i.e. location and depth. The main reason for this was that the degrees of underground services were low (Costello *et al.* 2007: 525-526).

However, this is not the case in todayôs modern world where numerous service vendors lay their utilities underground. The need to rehabilitate or replace existing ageing deteriorated potable water pipeline networks are accompanied by the increase in instances of damage to these vendorsô service utilities. These damages then lead to service disruptions which raises complaints by customers (Jeong and Abraham 2004: 175).

Currently, the demand to expand essential services such as potable water supply is equally challenged by budget constraints within municipalities and the absence of service utility records. The task of now trying to determine the location of these buried service utilities due to the absence of complete and accurate historical mapping records is very problematic. In addition, the condition assessment of the buried infrastructure remains unknown (Rogers *et al.* 2012: 202).

The inspections of these pipes are difficult and expensive to undertake. In cases where historical mapping may be available for underground service utilities, it is also not 100% accurate and is often out of date. Each service utility network was constructed individually by its owner and no uniform platform was created on which every service utility mapping was recorded.

Costello *et al.* (2007: 526) also stated that often this historical underground mapping information is only in two (2) dimensional format (i.e. X and Y co-ordinates) which only reflects a line on a map with occasional depth indications. These ñXYò co-ordinates were usually measured from reference points such as an existing farm/property fence which today, may not even be present anymore. The most important information for a pipeline is the third dimension which is the depth (Z) of the pipeline underground. This ñZò value forms the basis for generation of underground mapping records in a computer aided programme such as Geographical Information Systems (GIS) (Costello *et al.* 2007: 526).

Mapping the Underworld (2011) identified a need for a multi-sensor tool to be applied when locating underground service utilities. This included mapping data, knowledge of the existing services and asset tagging so that new or repaired service utilities can be identified.

Many forms of service utility tracing technologies have been developed and investigated, highlighting its limitations. This research lists some of the tracing technologies developed and their limitations as follows (Metje *et al.* 2007: 569-576):

a) GPR technologies

Ground Penetrating Radar (GPR) utilises a very short burst of radio-frequency energy radiated into the ground and reflected back to antennas at the surface to detect electromagnetic discontinuities in the ground where there is a change in permittivity and conductivity e.g. CATT and JENNINGS (a brand of radar penetrating equipment). GPR is limited by the attenuation of the signal in moist soils with high clay content.

b) Quasi-static fields

Quasi-static service utility detectors consist of high frequency acoustics (greater than 1 kHz). This was developed to serve as an alternative method to complement GPR which is limited to ground conditions detailed above.

c) Acoustic technologies

A multi-sensor detecting location tool with low frequency acoustics (lower than 1 kHz), and expected to supplement GPR technologies.

The above-mentioned tracing technologies work best for steel and cast iron piping underground but in the majority of cases, the actual material that the existing potable water pipeline consists of is unknown. The existing water marks such isolating valves, manhole chambers and fire hydrants will help to provide an indication of the approximate location (ñXôYò) of the buried pipeline underground.

The open trenching method will achieve the following results:

a) Determine what material the pipe is manufactured from;
b) The diameter of the pipeline by the detailed printed of the pipe or by cutting a section of pipe to take measurements. (Note: the isolating valves can be used to determine the approximate pipe diameter by counting the number of turns to open/close the valve, but will not provide accurate details); and
c) Allows a sample of the pipe material to be assessed (pipeline condition assessment) necessary for concluding as to whether the pipeline requires rehabilitation or replacement.

2.2.4 Summary

To ensure that the underground service utility mapping records are accurate and up to date, it is essential that the service provider (municipality) survey any new or rehabilitated service on a regular basis. A central database preferably in GIS format, must also be maintained and continuously updated. This statement can be supported by Bosch (2011: 2) who stated that it is necessary to frequently survey all pipes and fittings that were constructed to identify ñas builtò positions prior to backfilling of the trenches of newly laid pipes. If no mapping for the ageing deteriorated potable water pipeline network is available then closed circuit television (CCTV) inspection will have to be undertaken.

Appropriate methods of adequate management of the potable water pipeline networks (and other service utilities) needs to be in place. Management and maintenance of these service utilities should ideally have been carried out ever since the installation of modern networks about 200 years ago (Rogers *et al.* 2012: 205).

Asset management is a sustainable way to manage and operate these potable water pipeline networks to provide improved customer/consumer service. In addition, to address the growing need for maintaining and upgrading the infrastructure within communities by utilising trenchless methods as part of an asset management plan, municipalities can minimise the effects associated with maintaining infrastructure, especially rehabilitation and replacement (Struzziery 2010: 19).

2.3 Trenchless pipeline cleaning techniques

Pipeline rehabilitation techniques often require the interior cleaning of the existing deteriorated host pipe prior to the insertion of a new pipe. The following cleaning techniques can be utilised (van de Zwan 2011: 10):

a) Self-cleaning;
b) Flushing;
c) Air scouring;
d) Ball scouring;

e) Swabbing;
f) High pressure jet cleaning; and
g) Mechanical scraping.

High pressure jet cleaning and mechanical scraping are commonly used in South Africa. These cleaning techniques eliminate soft slime layers, soft sediments and hard encrustations.

2.4 Rehabilitation and replacement of ageing water pipelines in South Africa

Potable water pipelines installed 50 years or more ago, have been subjected to environmental stresses and normal service stresses. As a result, these pipelines degrade to a point that they can no longer perform adequately.

According to international standards, an acceptable rehabilitation or replacement rate for the upgrading of ageing potable water pipelines is 1% per annum (van Rooyen 2011: 43). This will cost municipalities billions of Rands in order to bring the existing deteriorated pipelines up to design capacities.

The choice of the adequate rehabilitation or replacement method will depend on which performance parameters the pipe will fail to meet and why the failures occur. The following main design criteria are vital (Wavin Overseas B.V. 2006: 4):

a) Condition of the host pipeline;
b) Technique aspects;
c) Hydraulic aspects; and
d) Structural aspects.

Municipalities must critically evaluate the feasibilities of traditional open trenching against trenchless methods. In addition, selection of the preferred method for a specific project requires careful analysis of tangible and intangible factors. These factors include (Gokale and Hastak 2000: 1):

a) Need-based criteria;

b) Economic criteria;

c) Technological criteria;

d) Project specific criteria; and

e) Safety/risk criteria.

Cost also plays an important role in the decision making process within municipalities. Figure 5 gives the four step approach that should be followed once a preferred method has been selected (Wavin Overseas B.V. 2006: 5):

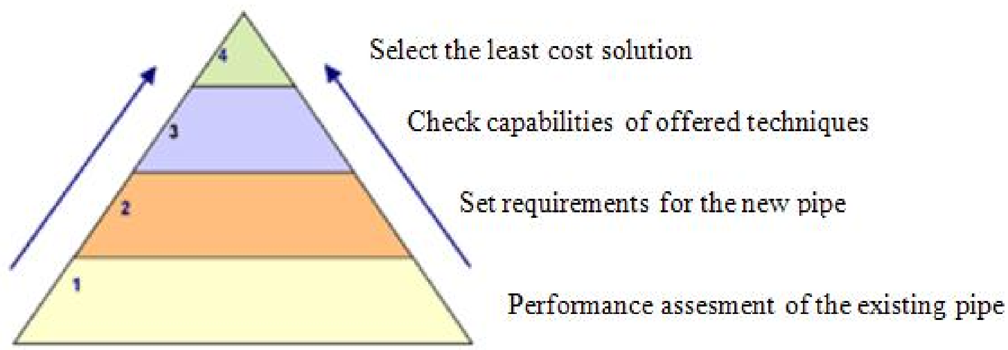

Figure 5 Four step approach to rehabilitation

2.5 Deteriorated potable water AC pipelines in South Africa

2.5.1 History of Asbestos

The Asbestos Resource Center (2012) stated that the term ‘asbestos’ was named by the Ancient Greeks and has been in use for more than 2000 years. Asbestos is the common name for any variety of silicate materials that are fibrous in structure and are more resistant to acid and fire than other materials.

AC pipes are manufactured from a mixture of asbestos fibres and Portland cement with or without silica. Wang *et al.* (2011: 810) stated that AC piping was used extensively in the mid 1900’s in potable water systems in the United States and Western Canada. AC pipe degradation was believed to be a chemical process of free lime leaching due to the conveyance of water either having an acidic pH or low alkalinity. Hence the loss of free lime in AC pipes leads to pipe softening and a reduction in the effective thickness of the pipe wall. This resulted in the reduced mechanical strength of the pipeline. When stresses imposed on the pipe by external forces exceed the reduced strength the pipe then fails (Wang *et al.* 2011: 810).

As stated by the Asbestos Resource Center (2012), there are three main types of asbestos which are (1) chrysotile, (2) amosite and (3) crocidolite. Chrysotile is the chief commercial asbestos sold today. Amosite is used in insulating materials and crocidolite is used for making AC products such as piping for potable water systems.

2.5.2 Classification of asbestos

In their research, Harris and Kahwa (2003: 1) stated that whilst asbestos has been used for over two millennia, there has been evidence of respiratory diseases associated with occupation and environmental exposure to asbestos fibres. Their article further reveals that South Africa has had a much publicised major asbestos pollution and asbestos related disease problem openly being tackled, including by the use of litigation.

The Asbestos Resource Center (2012) stated that asbestos is a potent carcinogen which is a cancer-causing substance, and is a serious health hazard. It is the known cause of pleural plaques, asbestosis, mesothelioma, and causes cancers of the lung, oesophagus, intestinal polyps and colon. Diseases caused by asbestos have a long latency period, usually taking ten to forty years before showing any symptoms.

Browne *et al.* (2005: 224) stated that asbestos contamination in drinking water was discovered as early as year 1985 in the Town of Woodstock, Ulster Country in New York. The source of the asbestos was the AC piping that was installed in the town in the mid to late 1950ꞌs. When examined, the pipes showed significant deterioration of its inner walls which could be as a result of the high oxidisation of the water in the Town of Woodstock. Their paper stated that it was also assumed that the townꞌs water supply could have started containing some level of asbestos fibres from around 1960 which is approximately 10 to 15 years after the AC pipes were installed.

When five (5) water samples were taken from various locations along the Woodstock water supply, four (4) results revealed that the asbestos levels were greater than 10 million fibres per litre (MFL). The US Environmental Protection Agency (2012) stated that any person who ingests drinking water containing asbestos fibres well in excess of maximum contaminant level of 7MFL for many years may develop cancer related diseases such as intestinal polyps.

Browne *et al.* (2005: 224) further stated that the latency period for occupationally induced cancer from asbestos is reported to be twenty to thirty years. This makes the relationship between asbestos ingestion and disease occurrence very difficult to establish. More and more people are dying from cancer every year despite all advances in medical drugs and treatment. This is mainly due to the inhalation of asbestos fibres. Ingested asbestos fibres may be a contributing factor in this regard given the long time frame for the development of the cancer to a body organ. However, the latter has to date not been verified. In his study, Bosch (2011: 1) stated that regulations are in place for the handling of asbestos and AC piping in South Africa which will become more stringent in the future to be in line with internationally accepted norms.

The KwaZulu-Natal. Department of Water Affairs (1989) policy for the handling and disposal of asbestos containing waste (ACW) in South Africa stated that many studies have made a link between occupational exposures to various types of asbestos and lung cancer and associated diseases, and termed this a ócarcinogenic activityö. The policy later stated that this carcinogenic activity is directly linked to the air pathway inhalation of ground asbestos dust and that the ingestion of asbestos fibres in drinking water does not carry any associated cancer risks. The reasons are that the asbestos showed a slight solubility in water and the fibres became blunted on a molecular scale which reduced the associated cancer risk. The World Health Organization (1996: 2-3) also stated that there is no consistent or conclusive evidence that ingested asbestos is hazardous to the health. This guideline further stated that there is no need to establish guidelines for asbestos carried in drinking water.

Table 1 presents the asbestos containing waste classes and examples of waste falling into each ACW class respectively (KwaZulu-Natal. Department of Water Affairs 1989: 2):

Table 1 List of classes of ACW and examples of waste falling into each class

ACW Hazard Call	Examples of ACW
Class A: Any friable ACW	• Raw asbestos (e.g. asbestos damaged in transit or no longer required). • Bags previously used to transport raw asbestos (that have not been melted into a solid mass). • Asbestos insulation, limpet spray of pipe lagging removed from power stations, buildings, boilers or pipe works. • Pure asbestos rope or textiles
Class B: Any non-friable ACW that has become crumbled, pulverised or reduced to powder during manufacturing, installation, renovation or demolition operations, such that it is likely to release fibres into the air.	• Dry swarf or cutting dust from the asbestos cement or friction material production process. • Used filter bags from dust extraction units at the workplace. • Asbestos cement that has unavoidably been crumbled, pulverised, or reduced to powder during demolition operations. • Disposal equipment and clothing contaminated with asbestos.
Class C: Any Class B ACW that has been adequately wetted or otherwise encapsulated such that it will not release fibres into the air	• Wet swarf or cutting dust from the AC or friction material production process. • Sludge, slurry or wet waste from the production process. • Bags previously used to transport asbestos that have been melted into a solid mass in an autoclave.
Class D: Any non-friable ACW that is essentially in the same condition as when manufactured and is unlikely to release respirable fibres after being declared a waste product	• Asbestos cement sheets or pipes. • Off-cuts of AC sheets or pipes. • Disused friction products such as gaskets, brake pads or clutch plates

The potential hazard or risk associated with the release of fibres is highest in Class A and lowest in Class D, where the risk posed by the waste is extremely small. Therefore, if the traditional open trenching online replacement method is utilised then the hazard call of Class A, B, C and D will be experienced when removing the old deteriorated decommissioned potable water AC piping from the ground. AC piping exposed after a long period of time is brittle and will disintegrate into dust fragments. The regulations for the safe handling, transporting and disposal at a licensed hazardous waste site will have to be followed. In this scenario, the risk of inhalation of the asbestos fibres will pose a threat.

If the open trench offline replacement method is selected then the decommissioned deteriorated AC piping is left buried underground. Over time, the pipe may degrade even further and the loosed asbestos fibres may leach into the groundwater. The same will apply if the pipe bursting method is utilised, however the rate of leaching will be faster since the AC pipe is burst into smaller fragments thus increasing the rate of asbestos fibre leaching. Chemical tests on the effects to which the asbestos fibres have on the groundwater is not covered under this research study.

The guidelines of the World Health Organization (1996: 3) and the KwaZulu-Natal. Department of Water Affairs (1989: 1) will take precedence, i.e. inhalation of asbestos fibres in dust form poses a threat as opposed to ingestion in drinking water thus making the removal of the deteriorated AC piping from the ground an unnecessary option.

2.5.3 Extent and degradation of AC pipes in South Africa

According to Bosch (2011: 16) there are tens of thousands of kilometres of ageing AC water pipes that are in service throughout the municipalities of South Africa which require replacement.

Mr Neil Macleod, Head of Water and Sanitation ï eThekwini Municipality stated that un-dipped AC pipes were first used for potable water networks in the city of Durban in year 1948. The degradation of the existing un-dipped AC pipes was caused by the soft water because it is low in calcium and magnesium. Conditions such as warm temperatures also accelerated this degradation.

Soft water found along coastal areas such as Durban, Northern Richards Bay, Port Elizabeth and the Eastern Cape produces a different reaction to hard water found in non-coastal cities such as Bloemfontein and Johannesburg. Calcium hydroxide is leached from the AC pipe wall. As a result, the alkaline conditions cannot be maintained in the cement once the initial calcium hydroxide has been leached. This cycle continues to a point where the original cement material is broken down to an extent that it no longer binds the aggregates together, thus causing the AC pipes to burst and collapse (Jackson 2009: 1).

In 1980, it was discovered that the soft water attacked the inner walls of the un-dipped AC piping and practically chewed away the asbestos piping. In 1985, EWS started using bitumen dipped AC piping (Mr Neil Macleod, Head of Water and Sanitation ï eThekwini Municipality). Bitumen served as a protective layer preventing the AC pipe from disintegrating into fragments.

2.5.4 Summary

All deteriorated leaking AC piping in South Africa will need to be replaced at some stage. Municipalities will have to set budgets to carry out the pipe replacement process from the feasibility study phase to the commissioning of a brand new pipeline network. Municipalities will have to compare the costs of online replacement versus offline replacement. In most cases, the AC pipes are left underground as the costs of safe removal, transportation and disposal are excessively high.

2.6 Pipe replacement methods

A description overview, installation procedure, merits and drawbacks of the following methods are discussed in this section:

a) Traditional open trenching ; and
b) Trenchless close-fit compact pipe (Wavin Overseas B.V.).

2.6.1 Traditional open trenching method

a) Overview

The traditional open trenching method has been utilised for pipeline replacement since the early 1900s. This method is suitable for all pipe materials and is most familiar to almost all contractors undertaking some sort of excavation project (Sterling 2010: 63). The traditional open trenching method is divided into six (6) major elements:

a) Surface demolition and repairs;
b) Protection of existing services;
c) Trench excavation;
d) Support of excavated side walls;
e) Dewatering of trench (if necessary); and
f) New pipe installation.

Figure 6 shows these elements (Harbuck 2000: 4):

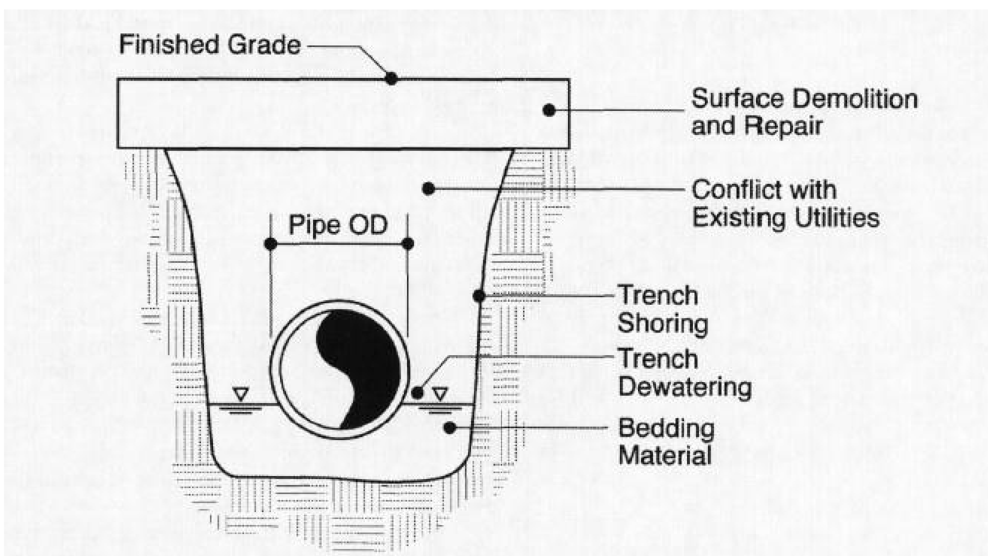

Figure 6 Pipe trenching elements

Traditional open trenching is a disruptive method (Mah 2005: 1). Open trenching causes needless excavation of the ground, mainly because the existing surface has to be trenched in order to get to the pipeline that requires replacement.

Traditional open trenching can adapt to any site condition uncovered during construction. This reveals that site identification is less critical as opposed to trenchless methods. However, the direct costs associated with open trenching increase rapidly with depth and particularly when excavating below the groundwater level (Sterling 2010: 64). At some point even trenchless methods require an excavation. This is at the point of connection of the customerõs/consumerõs service pipe and stop valve to enable the household service pipe to be transferred to the new main.

The use of traditional open trenching in roads with pavement structures and layerworks can have a severe detrimental influence on pavement performance when compared to trenchless methods. Traditional open trenching methods have a high risk in terms of safety. Construction workers are killed as a result of collapsed open trenches (Sullivan 2002: 49). Excavated soil stockpile on the edge of a trench adds pressure to the trench sidewalls thus increasing the risk of collapse (Tighe *et al.* 2002: 752).

Chin and Lee (2005: 267) stated that the initial set-up costs of trenchless methods may be more expensive than traditional open trenching, since trenchless methods require highly technical operations in order to function. The direct cost comparison will be discussed in Chapter 4 of this research study.

b) Installation method

Traditional open trenching is defined as the operation of excavating to the required pipe installation level and then backfilling. The following procedure is typically utilised for online pipe replacement:

a) The section of above ground infrastructure (road surfacing and layer works or sidewalk pavements) is removed;

b) The pipeline trench is excavated and the material is stockpiled for reuse as backfill;
c) Mapping records for existing underground service utilities including the ageing deteriorated pipeline must be available for online pipe replacement;
d) The ageing deteriorated pipeline is removed;
e) Approved bedding material is laid on the base of the trench and compacted according to design specifications;
f) A new pipe is laid and jointed together to form a distribution system and pressure tested for any leakages;
g) The trench is then backfilled with the spoiled material;
h) All off-take points to buildings are connected; and
i) The above ground infrastructure is then restored according to design specifications.

The following procedure is typically utilised for offline pipe replacement:

a) Mapping records for existing underground service utilities including the ageing deteriorated pipeline must be available for offline pipe replacement;
b) A section of above ground infrastructure (road surfacing and layer works or sidewalk pavements) is trenched adjacent or parallel in close proximity to the existing ageing deteriorated pipeline;
c) The new pipeline is jointed, laid and trench backfilled; and
d) Approved bedding material is laid on the base of the trench and compacted according to design specifications. The above ground infrastructure is then restored according to design specifications.

c) Merits and drawbacks

The merits and drawbacks of the traditional open trenching method are listed under Table 2:

Table 2 Merits and drawbacks of traditional open trenching

Merits	Drawbacks
Less expensive and cost effective (direct costs) method to bury pipes and cables where surface damage is not an issue and where easements are not cluttered utilities (Zayed, Salman and Basha 2011: 200).	Creates severe problems when numerous underground services utilities exist. Excavation (for water pipeline replacement) from the surface has to negotiate with a complex network of other services which are put at risk or even terminated temporarily (Rees 1989: 202).
Digging by hand is more practical than machinery use for excavation due to congested existing underground service utilities present.	Often considers direct costs of construction only and not the indirect and social costs borne by the end user (customer/consumer) which are expensive (Mah 2005: 2).
Process is easy (especially for larger diameter pipes) and does not require highly specialised skills.	Open trenching presents dangers to innocent bystanders especially children playing close to these trenches (Sullivan 2002: 49).
Cleaning of the existing pipeline is not necessary (Chapman, Ng and Karri 2007: 504).	Shoring and shuttering is required if the trench depth is greater than 1.8m. (Health and Safety requirement). The majority of accidents and deaths are incurred by construction workers.
Readily adaptable to conditions uncovered during construction (Sterling 2010: 63).	Risks of damage to other buried service utilities are present.
Suitable for areas with low vehicular traffic densities.	Mapping records for the existing ageing potable water pipeline must be available in order to carry out online pipe replacement.
Does not provide protection to existing trees as sections of the pipeline route cannot be diverted (Jim 2003: 89).	If no mapping records are available then GPR detection or physical ground excavation is required to locate the existing pipe.
	Impact on the environment such as dust, noise and general disruptions (Costello *et al.* 2007: 525).
	Creates road closures, unnecessary detours, traffic disruptions and delays (Ma and Najafi 2008: 476).

Table 2 Merits and drawbacks of traditional open trenching (continued…)

Merits	Drawbacks
	Business disruptions and loss of access to homes (Ma and Najafi 2008: 476). As a result, customers/consumers are turned away from trade (Rees 1989).
	Duration of work is relatively long.
	Uses a substantial amount of working space, especially for stockpile of excavated material.
	Creates a substantial amount of noise pollution, emission of dust, and health hazards.
	Several conventional plant, machinery and heavy trucks are required.
	Inclement weather conditions have a great impact due to extensive inherent dewatering requirements (Ariaratnam 2010: 806).
	Not suitable for CBD and high vehicular and pedestrian traffic congested areas. Traffic diversion into minor roads result in delays and waste effective operating time and increase fuel consumption. Driver frustration raises tempers, accident rates and hospital costs (Rees 1989: 202).
	Disruptions to the existing landscaping (Bakeer *et al.* 2005: 452).
	Open trenching causes injuries, felling and destruction to street trees resulting in a loss of urban amenity and degradation (Jim 2003: 88).
	Cannot minimise the time of occupance of a roadway hence cannot minimise disruption, damage and time to restore the road surface after construction (Sterling 2010: 63).

Table 2 Merits and drawbacks of traditional open trenching (continued…)

Merits	Drawbacks
	When open trenching is used under a flexible pavement structure, the excavation can create soil deformation due to difficulties associated with trench restoration and soil and asphalt compaction (Tighe *et al.* 2002: 752).
	Reduces the potential life of the road structure whether by stress relief displacements, subsequent softening of the subgrade and/or capping of the subbase (Rogers *et al.* 2012: 203).
	Costs to reinstate the integrity of pavement layerworks and surfaces to their original state are high and these reinstatements are not always done properly (does not look or feel as it was). (Dukart 2000: 30)
	Open trenching is more expensive when digging around existing service utilities (Dukart 2000: 30).
	From an environmental point of view, construction activities cause extensive damage existing to flora especially in dense urban areas. Roadside trees in particular are repeatedly harmed due to trenching damage. Root damage takes several years to become evident and by then the cause-effect project would have already been completed, if not forgotten.

The drawbacks associated with the traditional open trenching method outweigh its merits from a disturbance and cost aspect respectively. In his paper, Sterling (2010: 63) stated that trenchless methods cause little disturbance at the ground surface.

2.6.2 Pipe bursting replacement method (TT)

a) Overview

Pipe bursting is a trenchless pipe replacement method that was developed in the United Kingdom in the late 1970ôs. Its aims were to replace existing ageing pipelines in its existing alignment (online) without physical removal of the pipe (Ariaratnam and Hahn 2007: 644).

Pipe bursting is a cross between new construction (pipe replacement) and pipe rehabilitation. The reason for this is due to the fact that pipe bursting is the only trenchless method that can replace an existing ageing deteriorated pipeline with a new pipe in-situ. Also, the new pipe can be of the same diameter or even larger (up to 50%) to cater for future demands and increasing the hydraulic capacity (Ariaratnam and Hahn 2007: 644).

For many years a specification for the pipe bursting method was less defined and the installation method was left up to the judgment and experience of the contractor. However, in 2013 the South African Society for Trenchless Technologies developed a technical standard for the pipe bursting method for South Africa (Southern African Society for Trenchless Technology 2013). Efrat (2011: 1) stated that pipe bursting is widely utilised in South Africa by all major municipalities for potable water pipeline replacement to minimise water losses as a result of leaking pipes. Efrat (2011: 2) further stated that on average 300km of pipelines a year are installed using pipe bursting, making it a popular and well known method. The proper identification of the host pipe composition and replacement pipe material greatly influences the method of bursting employed (Ariaratnam *et al.* 1999: 758).

b) Installation method

Pipe bursting replaces brittle pipes such as clay, concrete and cast iron. The application makes use of a hydraulic or pneumatic bursting head to fragment the existing aging pipe (Halloran and Slattery 1999: 27). This process involves multiple fractures of the existing pipeline creating relatively small shards of pipe fragments. The burst fragments of the host (existing) pipe are drawn behind the bursting head (Rogers *et al.* 2002: 100). Simultaneously a new product pipe e.g. HDPE pipe is attached to the back of the bursting head which is installed in the same alignment as the original pipe (International Society for Trenchless Technologies 2012a).

The pipe bursting project is divided into sections or lengths. This enables the equipment being used to burst the pipe based on the geometry and layout of its total length. The new pipe (whether continuous or sectional) will determine the type of equipment that will be required (Ariaratnam *et al.* 1999: 760).

An important design consideration that needs to be taken into account is the potential point loading that the burst fragments may exert on the newly installed pipeline. It is common practice to upsize the diameter of the new pipeline being installed to cater for an increase in hydraulic capacity requirements. However significant geotechnical knowledge is required for the safe planning and operation of pipe bursting (Rogers *et al.* 2002: 100).

Access pits are required at each end of the pipeline to be replaced. On one end of the line, the machine pit is excavated into which the pipe bursting machine that pulls or directs the bursting head is located. Opposite the machine pit is the insertion pit through which the new pipe and bursting head are inserted into the host pipe. Figure 7 provides a graphical understanding of the pipe bursting method for a continuous pipe installation (van de Zwan 2010: 9):

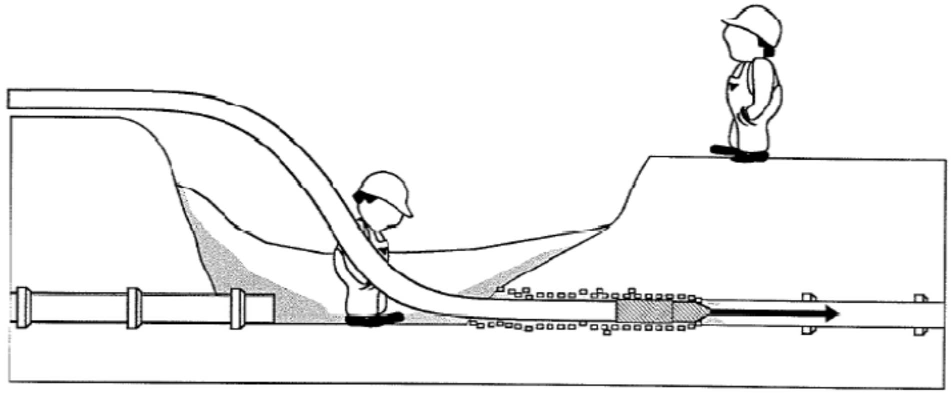

Figure 7 Trenchless pipe bursting for pipe replacement

The pipe bursting head bursts through the existing ageing deteriorated pipe as shown in Figure 8 (Efrat 2011: 13):

Figure 8 Trenchless pipe bursting head

c) Merits and drawbacks

The merits and drawbacks of the pipe bursting method are presented in Table 3:

Table 3 Merits and drawbacks of the pipe bursting method

Merits	Drawbacks
A very popular and widely used trenchless technology (Halloran and Slattery 1999: 26).	Potential to influence the impact of operations on the surrounding environment especially in urban areas with buried infrastructure and sensitive surface structures (Rogers *et al.* 2002: 100).
Minimal excavation is required (Ariaratnam *et al.* 1999: 757). Trench excavations are virtually eliminated.	Causes ground displacements and consequent damage to adjacent services and structures (Rogers *et al.* 2002: 100). Especially if the existing pipe is laid on concrete haunching (Ariaratnam, Lueke and Michael 2012: 5).
No loss of internal diameter (ID) - pipe diameter can be increased by up to 50% in size as opposed to rehabilitation with a liner where the new liner pipe has a smaller diameter that the ageing deteriorated host pipe.	Requires window cutting for adjacent services especially in urban areas to avoid damage to these services respectively (Chapman, Ng and Karri 2007: 505).
Reduces construction time, traffic delays and lowering of the direct construction costs (Bakeer *et al.* 2005: 23).	Pipe upsizing greater than 50% of the original size is not recommended as it will have an effect on the geological conditions, length and volumetric displacement (Ariaratnam, Lueke and Michael 2012: 805).
Increases overall productivity of a pipe rehabilitation project (Ariaratnam *et al.* 1999: 764). Interruption in the operation of the existing system is reduced. Can burst through any type of pipes including steel (Efrat 2011: 9).	Pipe bursting works best in straight line sections without any bends. Bends present a challenge due to the stiffness of the drill rods and/or new pipe material (Ariaratnam, Lueke and Michael 2012: 5).
The continuous pipe eliminates the weaknesses associated with joints and the position, grade and elevation of the existing line remains unaltered.	
Reduces the carbon footprint by avoiding road closures, reducing traffic detours and avoiding the rehabilitation of roads and pavements (Schmidt 2005: 1).	

The merits of the pipe bursting method outweigh its drawbacks. This method has been in use for a long period of time and contractors in South Africa are fully equipped and experienced with its application. The pipe bursting method inserts a new HDPE pipe which is also manufactured and readily available in South Africa by many pipe manufacturers and distributors. Also, the pipe bursting equipment is sold and serviced locally. Special bursting heads can be fabricated based on the existing conditions e.g. a fabricated tungsten coated blade can burst through a 150NB steel pipeline and a 400NB concrete pipe with internal 4mm reinforcing wire (Efrat 2011: 3).

From an environmental and health and safety aspect, pipe bursting does disperse the burst AC fragments (if the existing pipe is made of AC) into the ground. In his article Bosch (2011: 16) stated that although pipe bursting is still utilised for the replacement of AC pipelines in South Africa, this method is outlawed in many overseas countries (and only in some municipalities of South Africa) as the AC fragments left in the ground leach into the groundwater and thus is regarded as hazardous waste. Environmentally, it may be an issue but as previously stated in Chapter 2.5.2, this environmental risk has not been tested.

Overall, pipe bursting is a faster method which reduces social inconveniences and allows for the existing aged pipeline to be upsized (10% minimum and 50% maximum) thus increasing the hydraulic capacity (Ariaratnam, Lueke and Michael 2012: 2).

In addition to the above, the South African Society for Trenchless Technologyǿs (SASTT) have developed a specification for the use of pipe bursting in South Africa (Southern African Society for Trenchless Technology 2013).

The direct cost of pipe bursting versus the traditional open trenching method is discussed under Chapter 4 of this research study.

2.7 Pipe rehabilitation methods

The installation of a new pipe ñlinerò (structural close-fit or non-structural sliplining) within the existing deteriorated host pipe is completed using trenchless rehabilitation methods. The host pipe is usually retained in the ground to provide structural strength to the new liner installed. A description overview, installation procedure, merits and drawbacks of the close-fit compact pipe (Wavin Overseas B.V. 2006) and sliplining methods are discussed under this section:

2.7.1 Structural close-fit lining (Compact Pipe)

a) Overview

The close-fit compact pipe is one of the new comprehensive ranges of trenchless pipeline rehabilitation products manufactured only by Wavin Overseas B.V, a company situated in Dedemsvaart in the Netherlands. Techniques belonging to the close-fit family were developed as a derivative from lining with continuous pipes, also known as ósliplining ô. The close-fit compact pipe is pulled into the existing deteriorated host pipeline. The existing pipe is not demolished or removed. However, the close-fit compact pipe conforms to the shape of the existing deteriorated pipe whereas a sliplined pipe has an annular space between the new liner pipe and the existing deteriorated host pipe.

The close-fit compact pipe is utilised for the rehabilitation of deteriorated water, sewer and gas pipelines made of traditional materials such as asbestos cement, cast iron and steel. The close-fit compact pipe serves as a structurally sound independent pipe within the existing deteriorated host pipe (Wavin Overseas B.V. 2009: 1). This new close-fit compact pipe prevents contamination of the surrounding soil, groundwater filtration out of the pipeline (compact pipe) and groundwater infiltration into the pipeline (Bakeer *et al.* 2005: 461).

Compact pipe is classified as a class A pressure pipe liner as it boasts the following characteristics (Wavin Overseas B.V. 2006: 1):

a) Ability to survive internally or externally induced failure of the host pipe i.e. bursting, bending or shear;
b) Allowable operating pressure;
c) Inherent ring stiffness ï minimum requirement is for the liner to be self-supporting when pipe is depressurised;
d) Long-term hole and gap spanning at the allowable operating pressure; and
e) Serves as an internal barrier layer to corrosion, abrasion and contamination of the host pipe.

Compact pipe is made of PE80 (for sewer) or PE 100 (for water) with pipe diameters ranging from 100mm to 500mm respectively. Coiled on drums (see Figure 9) the pipe lengths are up to 600m dependant on the diameter and class of pipe required (Wavin Overseas B.V. 2009: 1).

Figure 9 Compact pipe coiled on drum

b) Installation methods

Supplied in continuous lengths and wound on a sturdy metal drum, the compact pipe is a circular PE pipe folded along its length during the factory extrusion process to form a óCô shape. As a result of the pipe being folded, the cross section of the pipe is slightly reduced. The compact pipe can then be easily inserted into the deteriorated host pipe, as shown in Figure 10 (Wavin Overseas B.V. 2009: 1):

Figure 10 Deformed compact pipe inside host pipe

Figure 11 shows how the compact pipe is held in place as it slides into an existing AC pipe (Wavin Overseas B.V. 2006: 1).

Figure 11 Steam reversion to original shape

Following the insertion, the compact pipe is reversed with steam and regains its original circular shape as a result of the ómemory effectô of poly ethylene. Thereafter, compressed air is used during the cooling process which then brings the compact pipe in close contact to the deteriorated host pipeós inner wall. The process of insertion of the compact pipe within the ageing and deteriorated host pipe is shown in Figure 12.

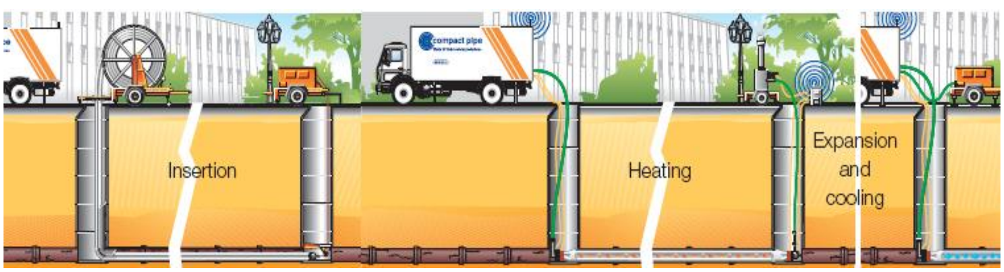

Figure 12 Compact pipe process

The result of this process is a structurally independent pipe within the deteriorated host pipe with the quality and durability of a newly installed pipe. The outside diameter (OD) of the compact pipe is slightly smaller than the inside host pipe diameter. This allows the compact pipe to adhere to the inside surface of the existing host pipe. The result offers a tight fit to the host pipe and hence the term óclose-fitô (Syachrani *et al.* 2010: 683).

c) Merits and drawbacks

The merits and drawbacks of the close-fit compact pipe method are presented in Table 4:

Table 4 Merits and drawbacks of close-fit compact pipe method

Merits	Drawbacks
Quality and durability of a new installation.	Requires initial cleaning and CCTV of the host pipe prior to insertion of the compact pipe in order to get rid of encrustations and sediments.
Cost effective alternative to open trenching.	Expensive and highly technical trained personnel and equipment is required. These installers have to be licensed.
Reduced installation time due to long lengths and reduced working areas.	Cannot accommodate bends greater than 22.5 degrees. The pipe ruptures as a result.
Excavations are limited to small start and end pits ï little space is required.	The new pipe liner is slightly smaller in diameter than the existing deteriorated as a result of the pipe liner wall thickness. However, the hydraulic capacity is not reduced since the leaks from the existing pipe are eliminated (Barber *et al.* 2005: 24).
Local residents, traffic and the environment is hardly disturbed during installation ï construction work is restricted to a small start and end pits ï Excellent for use in busy CBDs.	Compact pipe is restricted to 500mm diameter maximum.
Universal use, suitable for both pressure and non-pressure pipelines.	
Optimum flow properties due to smooth surface of the rehabilitated pipe.	
Advantageous where the host pipe is inaccessible.	

Table 4 Merits and drawbacks of close-fit compact pipe method (continued…)

Merits	Drawbacks
PE pipe is non-toxic, odourless and tasteless and represent no risk to public health. In addition no tainting the taste or quality of the drinking water passed through the compact pipe.	
PE pipe does not corrode, rot, rust or lose wall thickness through chemical reaction.	
PE pipe has higher abrasion resistance than other materials.	
Long term pressure resistance (design life of 50 years minimum) has ratings of 6.4 to 10 bar respectively (Smith 2011: 1).	
Installed in continuous lengths without any joints ï for larger pipe size application (> 150mm diameter).	
Can accommodate bends less than 22.5 degrees without limitation.	
Bends greater than 22.5 degrees to 45 degrees requires the use of a 5xdiameter nominal (DN) compact pipe.	
Where bends are greater than 45 degrees then an appropriate section of the old (host) pipe accommodating a bending radius of 8xDN will have to be removed before lining with the compact pipe.	
Suitable for use for the rehabilitation of potable water pipelines as several tests carried out in accordance with international regulations. Therefore suitable for use in contact with water for human consumption.	
Minimise impacts/intrusion of construction on the environment when undergoing pipeline rehabilitation	
Bends in pipeline track can easily be mastered in one go.	
Ideal technology for built up areas e.g. CBDs.	

Technically, the merits of the close-fit compact pipe method are more numerous than its drawbacks. However, the costs of importing highly sophisticated equipment, piping and associated fittings from the Netherlands into South Africa must be taken into account. Since this method is relatively new in South Africa not many local contractors are familiar its application, merits, drawbacks and the associated costs thereof. Additional costs for international advice and consultation will be required up and until such time that this method is widely used in South Africa and a specification is compiled according to local standards and requirements (as that compiled by SASTT for the pipe bursting and sliplining methods).

Overall, the costs detailed above require further research. Due to the absence of data at the time of conducting this research study, the cost comparison of the close-fit compact pipe against its associated trenchless variants or the traditional open trenching method was excluded.

2.7.2 Non-structural sliplining TT

a) Overview

Sliplining has been used since the late sixties and since then has become popular worldwide for its use on pressure pipeline applications (Wavin Overseas B.V. 2006: 682). Sliplining is a trenchless rehabilitation method in which a continuous liner pipe is pulled into the existing deteriorated host pipeline. This form of trenchless technology is one of the oldest and simplest methods (Syachrani *et al.* 2010). The existing pipe is not demolished nor removed. This method is similar to the close-fit compact pipe method, however the new continuous liner pipe is of a much smaller diameter than the compact pipe method. The new pipe has an outside diameter (OD) that is 10% (approximately) smaller in diameter than the inside diameter (ID) of the existing deteriorated host pipe. This smaller diameter allows ease of installation of the new liner into the existing, partially deteriorated pipeline.

The space between the new pipe and existing host pipe is referred to as the annulus. This annular spacing may or may not be grouted. Ungrouted sliplining is more cost effective from the installation point of view and may provide additional long term benefits. However, grouting of the annulus will prevent migration of soils and water, and also transfer loads to the new liner pipe (Zhao, Daigle and Rajani 2004: 97). Common practice in designing sliplined rehabilitation pipelines is to neglect the structural contributions of the existing host pipe and grout (Zhao and Daigle 2011: 969). The existing deteriorated host pipe serves as a retaining conduit for the new continuous HDPE liner pipe but offers no structural support due to the annular spacing between them. Figure 13 shows a typical length of continuous HDPE liner pipe being inserted into an existing host pipe. (van de Zwan 2010: 4).

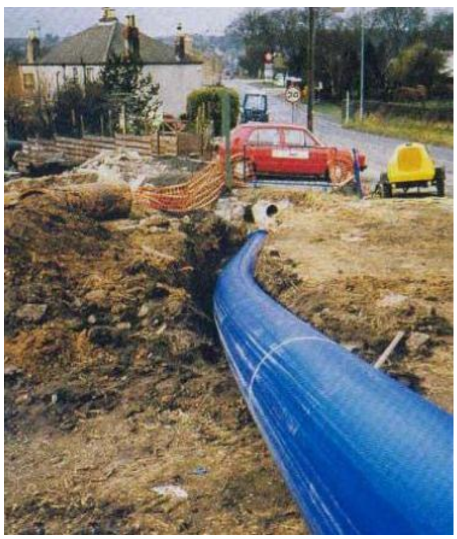

Figure 13 Sliplining – continuous lengths

HDPE, PE or polyvinylchloride (PVC) pipes are commonly used for continuous sliplining, non-man entry pipes (International Society for Trenchless Technologies 2012b: 1). Sliplining rehabilitates deficiencies such as cracks along pipes, broken or collapsed pipes or degraded or deformed existing pipelines.

Zhao, Nassar and Hall (2005: 203) stated that the pipe liner will sustain externally applied pressure if the liner is installed beneath the ground water level. Zhao, Nassar and Hall (2005: 204) further stated that this applied pressure may lead to inward radial deflections that may increase creep deformation of the liner wall. Therefore the correct pipe liner thickness needs to be selected. The thickness of the liner needs to be chosen to ensure that the radial deflections do not become large within the design life which in turn will lead to liner collapse.

b) Installation methods

Continuous sliplining involves the pulling of a liner pipe (e.g. HDPE) into an existing deteriorated host pipe requiring rehabilitation. The liner pipe sections are laid above ground and are butt-welded together to form continuous pipeline lengths. This is shown in Figure 14 (van de Zwan 2010: 23).

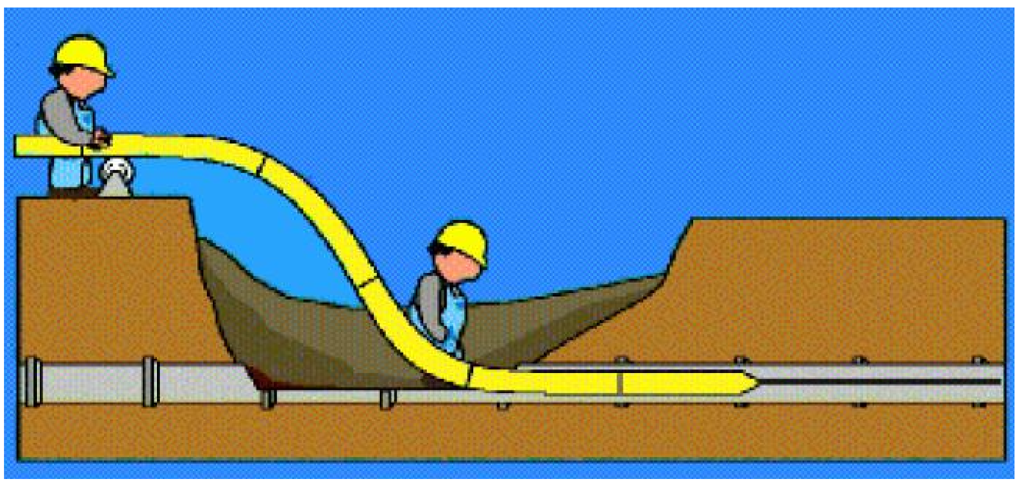

Figure 14 Sliplining installation

The continuous HDPE liner is then inserted into the existing host pipe using a launch pit. This launch pit can be an existing manhole or access point to the existing host pipe. This applies only if the size of the new HDPE liner pipe can manoeuvre through the host pipe access points.

The Southern African Society for Trenchless Technology (2010) developed a draft technical standard for sliplining trenchless construction works in South Africa. The guideline highlights the installation method for the insertion of a continuous liner into existing gravity pipelines with minimal disturbance of the surface, traffic or existing services. Sliplining insertion and annular grouting can be performed while the host pipe is under continuous external loading (Zhao and Daigle 2011: 971).

c) Merits and drawbacks

The merits and drawbacks of the sliplining method are detailed in Table 5:

Table 5 Merits and drawbacks of the sliplining method

Merits	Drawbacks
Uses tools and equipment that is widely available in South Africa to contractors practising trenchless rehabilitation methods.	Diameter reduction. The flow capacity is reduced due to the reduced diameter of the host pipe. It is sometimes possible to increase the working pressure and thus compensate for the loss in flow capacity but this is not always wise to do.
Restores the structural strength of the host pipe (since it conforms to the shape of the host pipe) and decreases infiltration and inflow in the sliplined area (Paggioli 2005: 1).	Large access space required for butt-welded HDPE pipelines prior to winching into the host pipe.
Grouted annulus causes new HDPE liner pipe to act as a composite, increasing the pipes stiffness and resistance to external hydrostatic loading - decreases or eliminates infiltration and inflow in the sliplined area.	Sliplining only rehabilitates in straight lines of the host pipe and does not line through bends. Not suitable for smaller diameter pipes where a significant decrease in diameter and reduction in hydraulic capacity thereof is a concern (Syachrani *et al.* 2010: 682)
Often the most cost effective method of rehabilitation (Halloran and Slattery 1999: 27).	Requires initial cleaning of the host pipe prior to the new pipe insertion.
	Surface rider main is required to maintain supply.
	Flotation forces may cause the liner to float (e.g. when filling with water or grouting in stages) especially in larger diameter pipes (International Society for Trenchless Technologies 2012b: 2).

The drawbacks of the sliplining method outweigh its merits. Sliplining reduces the hydraulic capacity of the pipeline network due to the reduction of diameter size i.e. a total of 10% reduction upon installation. Therefore an existing 160mm pipeline network will lose 16mm in diameter once sliplined. In addition to this, the annular spacing has to be grouted otherwise the HDPE pipe liner floats and distorts. If excessively grouted, the pipe can collapse at certain points along its route making sliplining a non cost effective option. This method does not allow for the existing pipeline to be upsized. Municipalities will have to firstly consider if the existing pipeline network requires an increase in the hydraulic capacity (which in most cases is required). If not, then sliplining can be considered.

Overall, the pipe bursting method and close-fit compact pipe methods (respectively) outweighs the sliplining method in terms of its application and merits.

2.8 Influence of Trenchless technology on the ethos of the EPWP

The Expanded Public Works Programme is a South African government initiative launched in April 2004. The aims of the EPWP are as follows (Expanded Public Works Programme 2004):

a) Providing poverty and income relief through temporary work for the unemployed to carry out socially useful activities;
b) Promoting economic growth and sustainable development; and
c) Alleviate unemployment by creating at least 1 million work opportunities.

Public bodies from all spheres of government (in terms of their normal mandates and budgets) and the non-state sector (supported by government incentives) are expected to deliberately maximise the creation of work opportunities for unemployed and poor people in South Africa. In addition to this, training and expertise development will be implemented in sector specific programmes to enhance service delivery and beneficiary well being (Expanded Public Works Programme 2004).

In simple terms, the EPWP is aimed at creating employment and skills to the less fortunate by allowing them the opportunity to work on projects in their area of abode.

The ethos of the EPWP is achieved when local unskilled labour is employed to form part of a construction project e.g. a potable water pipeline project. This labour force serves as manpower required to excavate trench routes, assist with the laying of pipelines and other site works which require unskilled assistance. As described, the core functions of the local unskilled labour will consist of excavation of trenches along the pipeline route required for the laying of new pipes. This description is known as the traditional open trenching method described earlier in this chapter. Therefore the percentage contribution of the traditional open trenching method to the ethos of the EPWP is significantly beneficial.

Trenchless methods require minimal excavation of the ground surface necessary to carry out the existing pipe rehabilitation or replacement. The quantity (QNTY.) of excavation required is far less as opposed to the traditional open trenching method. However, a casual unskilled labour force is still employed to assist with aspects of the project scope of works e.g. setting up of equipment and preparation of piping for insertion. However, the contribution to the ethos of the EPWP is far less than the traditional open trenching method since the trenchless method consists mainly of highly sophisticated equipment which assists with the pipe insertion and requiring skilled operation.

Currently, no research is available on the comparison of percentage contribution to the EPWP by each method (trenching and trenchless).

2.9 Costs associated with pipeline rehabilitation and replacement

2.9.1 Introduction

Cost plays an important role in the decision making process when undertaking a potable water pipeline network rehabilitation or replacement project. An economic evaluation involves the assessment of both the initial construction cost and associated benefits of each method under consideration. The goal of which is the selection of a single alternative with the greatest benefit at the lowest overall cost (Harbuck 2000: 12.11). These costs can be divided into the following categories (van de Zwan 2010: 13):

a) Direct costs;
b) Indirect costs; and
c) Socio-economic inconvenience costs.

2.9.2 Direct costs

These are costs paid by the client (municipalities) which include:

a) Planning costs;
b) Bidding costs (which are recovered in the contractor's costs);
c) Contractor construction costs; and
d) Consultant/project management costs.

Municipalities must consider these direct costs when selecting an appropriate pipe rehabilitation/replacement method. Municipal decision makers may revert to the professional expertise of an engineering consultant for assistance with the method selection, quantification, budgeting and scheduling (Zhao and Rajani 2002: 1). However, the final decision is made by the in-house executive committee (EXCO) of the respective municipality. Various procurement protocols are completed prior to the EXCO decision. These include the bidderþs price (direct cost), technical experience and Black Economic Empowerment (BEE) status. In most cases, the bidderþs price takes precedence but municipalities may reserve the right not to select the lowest bidder.

The perceived savings of projects utilising the traditional open trenching may be further overcome by costs to which the municipality will pay for damages resulting from accidents and injuries (Sullivan 2002: 49).

Currently, information on the direct costs of trenchless methods in South Africa is minimal and requires further inquiry. From an international perspective, Zhao and

Rajani (2002: 12) stated that numerous inquiries were made from municipal engineering departments on the costs of pipe rehabilitation and replacement using trenchless methods. Table 6 provides the average costs of trenchless techniques (Zhao and Rajani 2002: 7):

Table 6 Average cost of trenchless techniques

Method	**Overall Cost ***	**Diameter Range ***, mm**				**# of data records from TT Magazine**
	($/m m.dia./ m length)**	**Small (≤300)**	**Medium (330-940)**	**Large (960-1,830)**	**Very Large (≥1,830)**	
		($/m)	**($/m)**	**($/m)**	**($/m)**	
Microtunneling	9.52	2,614	4,770	15,399	46,898	51
Tunnelling	3.74	-	1,962	7,093	7,969	24
Cured in place concrete (CIPP)	1.38	299	531	2,654	-	39
HDD	2.97	265	1,791	6,239	-	10
Sliplining	**1.38**	**231**	**988**	**2,441**	**2,567**	**16**
Pipe Bursting	**2.20**	**726**	**1,165**	**-**	**-**	**11**
Pipe Jacking	4.29	-	-	7,540	9,515	6
Relining	0.95	295	-	-	-	6
Open Cut	**3.85**	**609**	**2,314**	**2,225**	**-**	**14**

*: For the reported projects that contained more than one diameter, the average diameter was used for determining the overall average cost.

**: All costs are expressed as the 2001 value and in $ Canadian Dollars (CAD). $US 1 = $1.48 CAD

***: The data records that could not be separated for the diameter ranges were not used in these diameter ranges, but used in the overall average.

Zhao and Rajani (2002: 7) compiled the average cost comparisons using information from five (5) data records. The cost comparisons presented show that sliplining is 64% cheaper than the traditional open trenching method whilst pipe bursting is 43% cheaper respectively. However, this cost comparison had many limitations/variables. Variables such as depth and width of excavation, equipment and consumable costs, reinstatement costs of existing side-walks and asphalt surfaces were not specified. Efrat (2011: 1) compiled a paper which examined the history of the use of pipe bursting in South Africa. His paper made reference to various projects indicating its versatility, usage and cost comparisons. Table 7 presents the cost comparisons from the paper (Efrat 2011: 9).

Table 7 Cost comparison of pipe bursting and traditional open trenching

Methodology	**Pipe Diameter**			**Class**	**Material**	**P.O.S* (ZAR/m)**	**Reserve (ZAR/m)**	**Road* (ZAR/ m)**
	Nom (mm)	**OD (mm)**	**ID (mm)**					
Open Cut	110	110	100	12	uPVC	252	277	510
Pipe Bursting	110	110	92.9	12.5	HDPE	283	297	322
Cost Saving						**-12.5%**	**-7.2%**	**37.0%**
Open Cut	160	160	145	12	uPVC	347	383	633
Pipe Bursting	160	160	135.1	12.5	HDPE	433	447	472
Cost Saving						**-25.1%**	**-16.7%**	**25.5%**
*: 100m length at 1m depth, including excavation, and reinstatements. Exclude P&Gs, lateral connections, valves, hydrants, bend specials. Rates being inclusive of VAT.								
P.O.S	Public Open Space, parks open areas or undeveloped land							
Reserve	Road Reserve, unpaved sidewalks and paved driveways							
Road	Road Surface, tarred							

This cost comparison prepared by Efrat (2011: 9) was in a summary format. Detailed variables were also not provided. Therefore, a gap in the direct cost comparison of the traditional open trenching method versus trenchless methods was identified. This research will provide an in-depth direct cost comparison of the traditional open trenching method and the trenchless pipe bursting method.

2.9.3 Indirect costs

Indirect costs are neither always definable nor expressible in financial terms since they are difficult to quantify. These costs are incurred by the municipalities. Some of these costs include:

a) Compensation costs for claims submitted by the customer/consumer of the water supply; and
b) Compensation claims for contingent damage to property e.g. asphalt driveways.

Determining a reasonable cost for damage to property, loss of business costs or traffic delay costs is a difficult process (Harbuck 2000: 12.14). The cost elements in a pipeline rehabilitation or replacement project are only minor in specific cases and therefore are not always relevant to the decision making process (Arends *et al.* 2003: 33).

2.9.4 Social inconvenience costs

These costs are incurred by the public (Tang *et al.* 2004: 938).

Social costs are said to be in order of twice the sum of the actual direct and indirect costs paid by the municipality and include (van de Zwan 2010: 30):

a) Traffic delay;
b) Business disruptions - loss of trade;
c) Accidental costs;
d) Vehicle operating costs;
e) Damage to vehicles as a result of a decrease in road surface value;
f) Loss of parking spaces;

g) Environmental impact - damage to trees and other vegetation;
h) Quality of life; and
i) Pollution ï dust and noise.

Gilchrist (2005: 89) describes social costs as the costs incurred due to the execution of a construction project. These social costs cannot be classified as either direct or indirect costs as they are incurred by the parties not engaged in the contractual agreement.

Often the social costs of a pipeline rehabilitation or replacement project are overlooked by municipalities (Rees 1989: 201). Municipalities base the overall cost of a project only on its direct cost component. Dukart (2000: 30) stated that municipalities often underestimate the social costs of construction. A study by Sterling (2010: 63) stated that the total cost of a project must include social costs. These costs are also vital in the selection of the most appropriate method for either rehabilitation or replacement respectively. The reasons for this are that social costs often exceed the direct construction costs itself (Sterling 2010: 63-64).

There are various types of associated adverse impacts that may exist such as traffic, economic activities, air and water pollution. Results of these impacts include traffic congestion and delays, disruption of economic activities, excessive generation of pollution, damage to the ecosystem and infrastructure systems.

Traditionally, municipalities did not have to justify their choice of selection or method adopted for construction activities. In todayôs modern world this traditional policy does not apply. Municipalities need to understand the significance of socio-economic costs, establish a method to measure them and also try to minimise them at the same time (Gilchrist 2005: 89).

Reasons compelling municipalities to consider social costs are due to the following factors (Tighe *et al.* 2002: 752):

a) Tremendous growth in traffic densities and road congestion;

b) Increase in the amount of work that must be carried out in developed suburban and urban areas to maintain and upgrade service levels;
c) Increased awareness associated with road maintenance and rehabilitation costs due to open excavations; and
d) Increased public awareness of trenchless methods.

Mckim (1996: 9.1) stated that social inconvenient costs, direct and indirect costs have forced municipalities to consider the use of trenchless methods when undertaking pipeline rehabilitation or replacement projects in built up areas. Trenchless methods eliminate social costs such as disruption of business trade, and make a better option than traditional open trenching from a social cost point of view and long term cost effectiveness (Sullivan 2002: 49)

EWS identified a research gap in the preparation of their feasibility study (Kee 2011: 26). This gap was the quantification of the social costs associated with the traditional open trenching method and trenchless methods respectively. Although it would be impossible to accurately quantify social costs of a project, a customer/consumer survey questionnaire would assist in providing this information. This survey would assist EWS in determining which social costs are dominant and should be considered in future projects. This survey forms part of this research study and is compiled and administered in support of the EWS feasibility study. The results are presented under Chapter 4 of this research study.

2.10 Reduction of the carbon footprint

Municipalities will also have to consider the effects that each pipe rehabilitation or replacement method has on the carbon footprint. The reduction of carbon emissions and methodologies to do so will have to be amongst the decision making criteria.

Traditional open trenching contributes a significant percentage of carbon emissions to the environment as opposed to trenchless methods. If a trench is dug 2.5metres deep to install a 200mm diameter pipe, a total of 2.5cubic metres of material is excavated to lay a pipe with a volume of 0.031cubic metres per linear metre of trench. Trenchless methods require minimal excavation which results in a reduction (approximately 90%) in the emissions of various gases including carbon (O'Sullivan 2010: 18).

2.11 Qualitative and quantitative research

2.11.1 Introduction

People conduct research either to test a theory, or to generate a new theory. Both require a plan for the systematic interpretation of data and are associated with quantitative and qualitative research which serves as a common method for classifying research (English *et al.* 2006: 301-305).

Quantitative research is described as the numerical representation and manipulation of observations for the purpose of describing and explaining the phenomena that these observations reflect. Qualitative research is defined as the non-numerical examination and interpretation of observation for the purpose of discovering underlying meanings and patterns of relationships. At a basic level, quantitative data is in the form of numbers and qualitative data is in forms other than numbers, such as words, pictures or recorded sounds.

There are a number of advantages and disadvantages of both the quantitative and qualitative approach. Qualitative research included flexibility allowing researchers to be innovative, although this may result in anecdotal or unstructured data (Edwards, Nebel and Heinrich 2005: 36).

2.11.2 Formulation of questionnaires

A questionnaire is defined as any structured research instrument which is used to collect social research data in a face-to-face interview, self-completion survey, telephone survey or Web survey. A questionnaire consists of a series of questions set out in a schedule e.g. form or Web page (Kelly, Harper and Landau 2008: 123). Questionnaires comprise of closed questions, open questions or in some cases a combination of both. Closed questions provide a fixed response and do not solicit the feelings or perceptions of the person completing the questionnaire. The use of Likert scales (e.g. using a scale from 1 to 5) and simple yes/no is also used to answer closed questions. Both Likert scales and yes/no questions provide ordinal data. Open questions do not provide a response set and subjects are able to provide any type of response they feel is appropriate. Hence open ended questions solicit the feelings or perceptions of the person completing the questionnaire (Kelly, Harper and Landau 2008: 126).

In designing questionnaires it is important to focus on the outcomes prior to developing a series of question. The outcome is what is expected and hence the questions should systematically build on each other in achieving the outcome.

The following eight (8) rules guide the framing of the questionnaires (discussed in Chapter 3) which form part of this research study (Fundamental Principles of Questionnaire Design 2010: 132-134):

1) Think about the objectives of the survey;
2) Think about how the interview will be carried out;
3) Think about the knowledge and interest of the respondent;
4) Think about the introduction;
5) Think about the order of the questions;
6) Think about the type of questions;
7) Think about the possible answers at the same time as thinking about the question itself; and
8) Think about how the data will be processed.

With reference to these eight (8) guiding rules, it was also necessary to take into account that a thorough informed literature review of previous studies of the same nature should be completed. These rules and previous studies coincide in order to develop the questionnaires. The questions in the questionnaire were designed such that they are capable of answering the research aims.

3 RESEARCH METHODOLOGY

3.1 Introduction

This chapter discusses the research methodology adopted.

3.2 Indirect and socio-economic inconvenience costs: survey

3.2.1 Compilation of a socio-economic survey questionnaire (SESQ)

A quantitative socio-economic survey questionnaire was developed by the researcher. This questionnaire was aimed at residents and business owners. For consistency, the word ócustomer/consumerô (Chapter 3) and óparticipantsô (Chapter 4) will be substituted for residents and business owners in this research study respectively.

The purpose of this questionnaire was to obtain the customer/consumersô perspective on the óEWS 1.2km AC Pipeline Replacementô project completed in Pinetown between July 2007 and November 2010. As mentioned previously, this project utilised both the traditional open trenching method as well as various trenchless methods (namely pipe bursting, close-fit compact pipe and sliplining).

The outcomes of this questionnaire are as follows:

a) Provide insight as to which disturbances e.g. traffic delays, noise, dust, damage to roads and so forth are more dominant;
b) To compare the rate of frequency of disturbances (as above) for the traditional open trenching method and trenchless methods respectively; and
c) Determine which method (traditional open trenching method and/or trenchless methods) the customer/consumer preferred.

This survey was administered in support of the EWS Feasibility Study and the results detailed in this research study. Ethical clearance was obtained by EWS.

A sample copy of the SESQ is attached under Appendix A of this research study.

3.2.2 Compilation of a municipal technical survey questionnaire (MTSQ)

A quantitative survey questionnaire was developed by the researcher. This questionnaire was aimed at technical staff in the water departments of district and local municipalities of South Africa. The purpose of this questionnaire was to obtain insight on the levels of knowledge on the traditional open trenching method and trenchless methods by technical staff.

This survey was administered in support of the EWS Feasibility Study and the results detailed in this research study. Ethical clearance was obtained by EWS.

A sample copy of the MTSQ is attached under Appendix B of this research study.

3.2.3 Socio-economic survey questionnaire study area

The research study area for the administration of the SESQ was Pinetown, KwaZulu Natal, South Africa. Pinetown is inland from Durban. The SESQ survey was undertaken in various streets of Pinetown including Anderson Street, Roselle Street, Davidson Road, Bath Road, Nigella Road and Halifax Street.

3.2.4 Municipal technical survey questionnaire study areas

The MTSQ study area was not limited to a specific region or municipal jurisdiction. Appendix C provides a detailed list of the eight (8) metropolitan municipalities and forty four (44) district municipalities that were invited to participate. The survey results obtained from district municipalities included for their local municipalities respectively. The reason for this widespread distribution throughout South Africa was to ensure that a thorough analysis be completed.

3.2.5 Administering of the questionnaires

A series of questions, both open ended and closed ended, were formulated for the SESQ and MTSQ based on the aims of this research.

The following methods were considered:

a) **Administration in a public place -** such as a residential area, shopping centre, hospital, school or pub. In this case a research study area in which both traditional open trenching replacement and trenchless rehabilitation methods were undertaken. The purpose of the study was explained to each and every respondent (residents and business owners in the research study area). This method was very time consuming;
b) **Mailed questionnaire -** the technical questionnaire was mailed (electronically E-mailed in this case) to all prospective respondents (municipal technical staff) throughout South Africa. Details of all municipal technical staff of all municipalities throughout South Africa were sourced. However, this method of mailing questionnaires results in a very low response rate.

Where a low response was received for the MTSQ through e-mail, telephonic interviews were undertaken.

The main objective of the socio-economic and technical questionnaires were to provide an indication of current and likely future trends in the application of trenchless technological methods for the rehabilitation of potable water pipeline networks, including awareness of the term trenchless technology (TT), the benefits and preference respectively (Ariaratnam 2010: 807).

A covering letter was formulated in order to provide the customer/consumer and municipal technical staff with the following background information (Kumar 2005: 129):

a) Introduction of the researcher and the institution representing;
b) Description of the objectives of the study in two (2) to three (3) sentences;
c) Explanation of the relevance of the study;
d) Conveyance of general instructions e.g. completion of questions;
e) Indication that participation in the study is voluntary ï ethics were also highlighted;
f) Assurance to respondents of the anonymity of information provided by them;
g) Provision of contact numbers if any questions or queries arose; and

h) Thanking the respondents for their participation in the study.

A sample copy of the covering letter compiled is attached under Appendix D.

3.2.6 Role of the researcher

The roles of the researcher were as follows:

a) Undertake interviews (face to face and telephonic) with technical staff of municipalities to ascertain familiarities with the traditional open trenching method and trenchless methods, including its application;
b) Undertake fieldwork (door to door visits) survey in Pinetown essential for the completion of the socio-economic survey questionnaire. The researcher was assisted by two Durban University of Technology (DUT) students;
c) Collate and analyse data to provide answers to the research problems; and
d) Provide highly useful results in support of the EWS Feasibility Study.

3.2.7 Analysis of the questionnaire feedback data

Once data was collected, the following analysis procedure was followed (English *et al.* 2006: 308-309):

a) Data scales ï where ordinal data in the form of rating scales were categorised, named and numbered; each category was assigned a unique number;
b) Data preparation ï data was collated, and scrutinised in order for analysis preparation;
c) Descriptive statistics ï organising data such that the frequency and spread of responses was revealed and recorded i.e. positive and negative responses;
d) Summarising data/statistics ï this involved the presenting of data in tables and graphs and the writing up of results and discussions pertaining to the findings in the results.

The results of these findings are detailed in Chapter 4 of this research study.

3.3 Direct cost comparison

3.3.1 Data analysis

In order to analyse data, a list of costing variables was formulated. These costing variables include:

a) Hire/purchase of equipment associated with trenchless methods;
b) Purchase of consumables (petrol, diesel, etc) in order to work equipment associated with trenchless methods;
c) Materials: piping, associated fittings and bedding;
d) Degree of labour required: contribution to the EPWP;
e) Pre-installation: excavation of access pits for the trenchless option including excavating into existing paved sidewalks and roadways (asphalt surfaced);
f) Installation of pipeline; and
g) Reinstatement of paved sidewalks and roadways.

3.3.2 Role of the researcher

a) Collect existing data (provided by EWS and Trenchless Technologies cc);
b) Collate, correlate and analyse data to achieve results for the costing variables; and
c) Produce comparison tables and graphs for each costing variable.

3.3.3 Assumptions

a) The direct costs of each method will be limited to the following design dimensions of pipeline installation as used under the EWS Pipe Replacement Project:
   i. Per metre length;
   ii. Two (2) metre width; and
   iii. One and a half (1.5) metre depth.

4 RESULTS AND DISCUSSION

4.1 Socio-economic survey questionnaire

4.1.1 Results of the SESQ

A total of four hundred (400) customers/consumers were approached during the field survey in Pinetown, South Africa. Only three hundred and eighty (380) participants (of the 400 approached) were aware of the project. Thus, these 380 participants formed part of this socio-economic survey.

4.1.2 Discussion of the results of the SESQ

Following the completion of the field survey questionnaires, the results were then captured into Microsoft Excel for analysis. The detailed results of the survey are included under Appendix E of this research study.

Discussed in this section are the most critical outcomes of this socio-economic survey.

4.1.2.1 Familiarity as to why pipelines need to be rehabilitated or replaced

Table 8 presents the results of the familiarity with pipeline rehabilitation and replacement.

Categories ranged from 1 (not familiar) to 5 (familiar). 54% of the responses were received as a category 5 status. Only 10% of the participants were not aware why potable water pipelines are replaced.

Table 8 Familiarity as to why pipelines need to be replaced or rehabilitated

%	Number	Category
10	38	1 (not familiar)
8	29	2
11	43	3
17	64	4
54	206	5 (familiar)
100	**380**	**Total**

4.1.2.2 Familiarity with trenchless technology

A total of 207 (54%) participants were familiar with the term ótrenchless technologiesô for the rehabilitation and replacement of existing deteriorated potable water pipelines.

Participants that were at home during the daytime showed most knowledge and understanding of trenchless methods since they were able to view the method in use.

Figure 15 shows the ómethod familiarityô percentage difference between traditional open trenching and trenchless technologies for potable water pipelines.

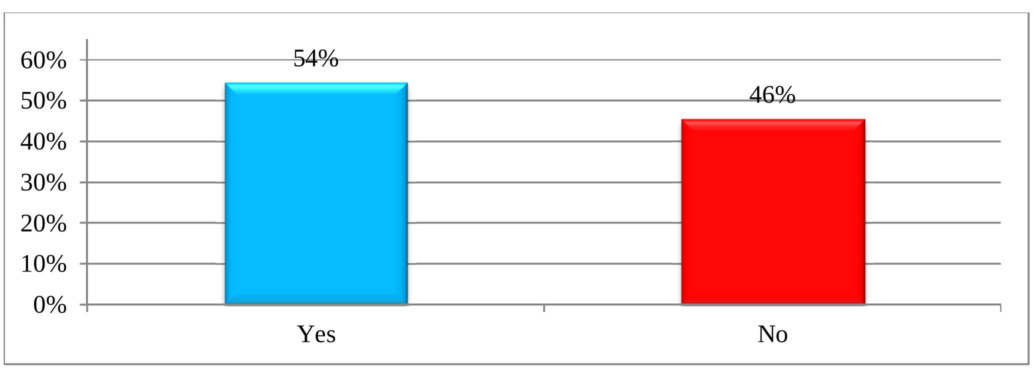

Figure 15 Familiarity with trenchless technology

4.1.2.3 Experience of major hindrances

A list of major hindrances which included noise, traffic disruptions and access to properties were discussed with the participants. Table 9 presents the results.

Table 9 Experience of major hindrances

%	Number	Category
11	43	Dust
14	52	Noise
31	119	Traffic disruption
23	88	Access to your property
21	78	Interruption of service (water, electricity, sewer)
100	**380**	**Total**

31% of the participants stated that the disruption of traffic was the major hindrance experienced during the óEWS 1.2km AC Pipeline Replacementô especially along Halifax Street, York Street and Manchester Street situated in the industrial business areas of Pinetown. The traditional open trenching method was utilised to replace the existing deteriorated potable water AC pipelines along the streets mentioned above. Participants who own businesses along these streets complained about the interruption of services (especially water and electricity) during the pipe replacement project duration.

In areas where a trenchless method (close-fit compact pipe and pipe bursting) was utilised, the study revealed that no hindrances were experienced by the participants e.g. along Nigella Road.

Figure 16 shows that traffic disruptions (31%) followed by access to properties (23%) and interruption of service (21%) are the most disturbing hindrances experienced by the public. When trenchless methods were used (e.g. Nigella Road), no hindrances were experienced by the public. This reveals that the socio-economic inconveniences of trenchless methods are far less as opposed to the traditional open trenching method.

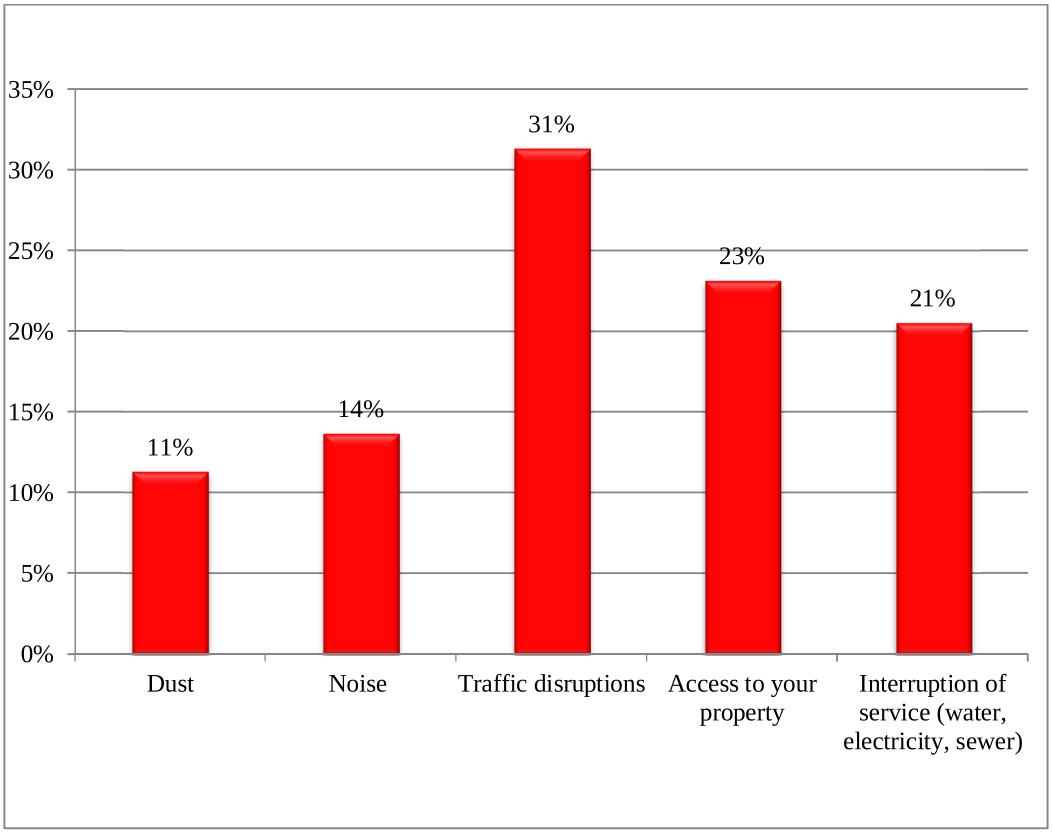

Figure 16 Experience of hindrances

4.1.2.4 Severity of hindrances

Each participant was required to rate the severity of hindrances on a scale of 1 to 5 (least severe to very severe). 94 participants stated that traffic disruptions were very severe. Table 10 reveals that traffic disruptions account to 129 votes ranking it as the highest disruption experienced.

The second highest hindrance experienced was access to properties (88 votes) followed by interruption of services.

Table 10 Severity of hindrances

1 (Not severe)	**2**	**3**	**4**	**5 (Very severe)**	**Total**	**%**	**Category**
10	14	8	6	5	43	11	Dust
7	11	13	15	6	52	14	Noise
1	2	7	25	94	129	34	Traffic disruptions
5	8	9	12	54	88	23	Access to your property
3	2	1	5	57	68	18	Interruption of service (water, electricity, sewer, phones)
26	**39**	**41**	**67**	**216**	**380**	**100**	**Total**

It can be graphically seen in Figure 17 that traffic disruptions was the most dominant hindrance experienced.

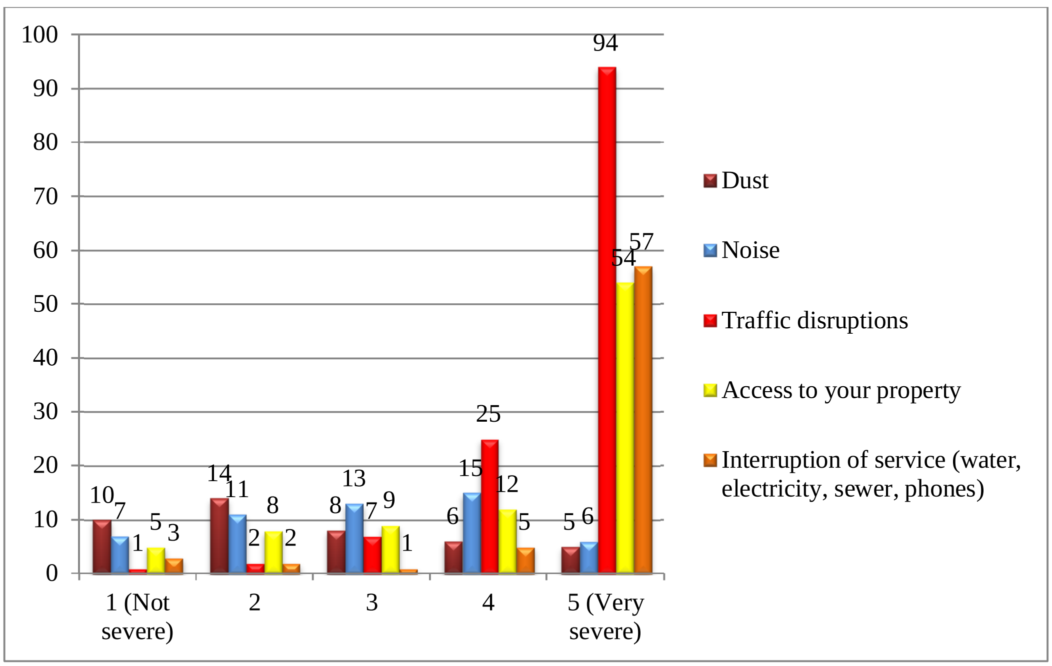

Figure 17 Severity of hindrances

4.1.2.5 Quality after completion of project

84% of the participants were happy with the overall water quality after the completion of the óEWS 1.2km AC Pipeline Replacementô.

23% of the participants stated that the patching/repairs to the existing road surface had been poorly completed and that the damage to vehicles was severe as a result. These statements were received from participants along Nigella Road, Roselle Road and Halifax Street where the traditional open trenching method was utilised. Figure 18 shows the results graphically.

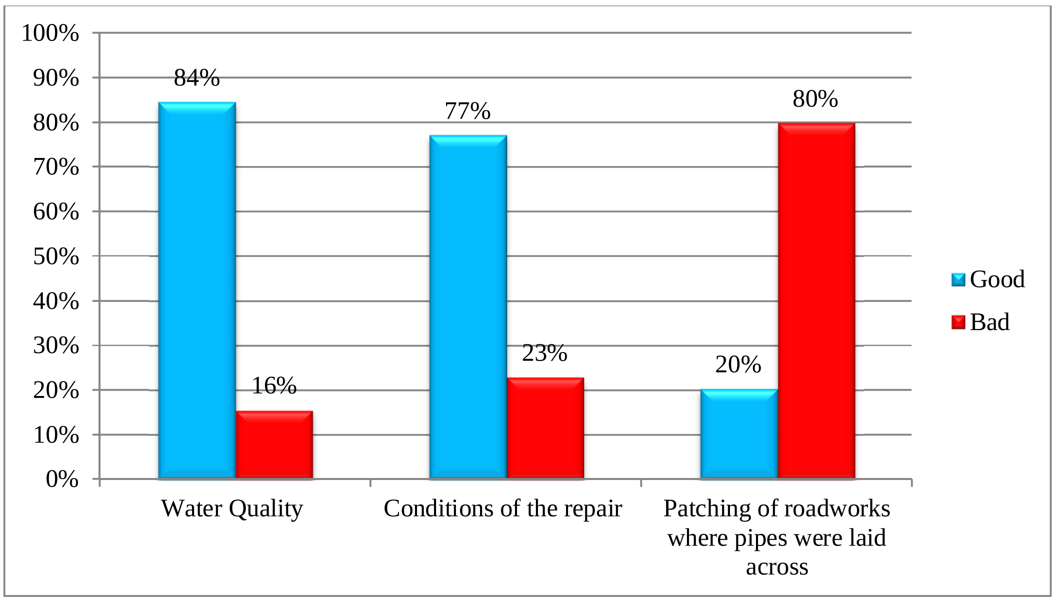

Figure 18 Qualities after completion of project

4.1.2.6 Method preference

267 participants (70%) preferred trenchless methods as opposed to the traditional open trenching method as shown in Figure 19.

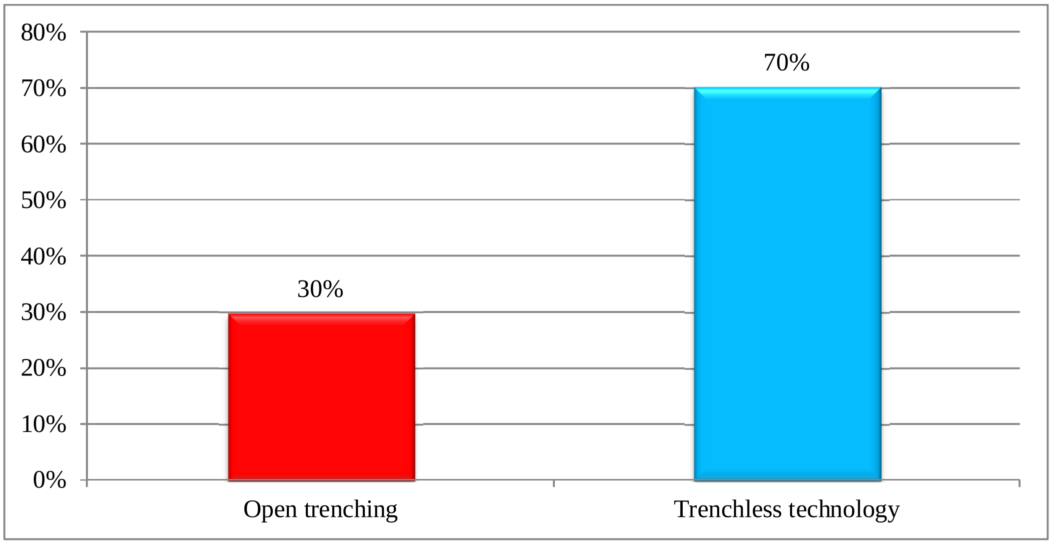

Figure 19 Method preference

4.1.2.7 Consideration of direct, indirect and social-inconvenience costs

The results revealed that 62% of the participants expect municipalities to include the indirect and social inconvenience costs along with the direct costs when implementing future projects of this nature. Figure 20 shows the results graphically.

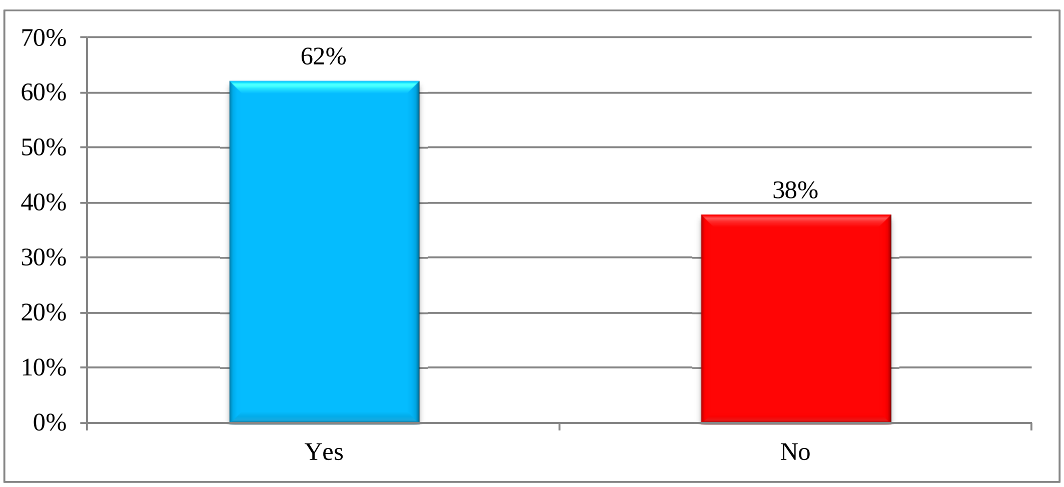

Figure 20 Consideration of direct, indirect and social inconvenience costs

4.1.3 Discussion

54% of the participants were familiar as to why the AC pipelines were being rehabilitated and in some streets replaced respectively. The same 54% of the participants were also familiar with trenchless technologies which were utilised. At least 35% (of the 54%) could even provide a brief description of the trenchless method procedure.

The responses from participants in areas which utilised the traditional open trenching method (e.g. Halifax Street) were mostly negative towards the traditional open trenching method. The participants experienced the traditional open trenching method to be disruptive and time consuming. The damage to access driveways and poor road surface patching repairs were visible during the undertaking of this survey questionnaire. Participants complained about the even greater than normal congested traffic due to traffic calming and road lane closures during the project duration.

70% of the participants preferred trenchless methods since it was least disruptive. The remaining 30% were aware of the benefits of trenchless technologies mentioned during the survey study. However, they selected traditional open trenching as they were familiar with this method. 62% of the participants want the municipalities to consider indirect and socio-economic inconvenience cost factors during future projects of the same nature. These responses received from the participants coincide with a separate study by Sullivan (2002: 49) who stated that trenchless construction prevents costly lawsuits, injuries and virtually eliminates expensive social costs. A further study by Selvakumar, Clark and Sivaganesan (2002: 305) also revealed this significant benefit. These responses also concur with DeMarco and Muenchmeyer (1993: 36) who stated that trenchless methods have been applied successfully without disruption to the surface.

4.1.4 Conclusions drawn from the socio-economic questionnaire survey

The trenchless methods (i.e. pipe bursting and close-fit compact pipe) which formed part of the óEWS 1.2km AC Pipeline Replacementô demonstrated to be successful.

The participants preferred the trenchless methods since its hindrances to society were far less as opposed to the traditional open trenching method. Social costs must be taken into account during the method selection process within municipalities. This will provide the municipality with an indication of the ótotal costô of a project i.e. direct, indirect and socio-economic inconvenience costs respectively.

Understanding the views of the customer/consumer is essential in improving the quality of service delivery by the municipalities of South Africa. The participants expect the municipality to consider social costs when implementing any future project of the same nature. Social costs are considerably lower when trenchless methods are utilised.

The results of this study conclude that trenchless methods result in less socio-economic inconveniences to the customer/consumer. Trenchless methods are the preferred method by the public.

4.2 Municipal technical questionnaire survey

4.2.1 Results of the municipal technical questionnaire survey

A total number of fifty (50) questionnaires were circulated to key managerial technical staff (participants) in the water sectors of district municipalities, local municipalities and metropolitan organisations for completion. Thirty-two (32) participants completed the questionnaire. Fifteen (15) responses were completed by telephonic interview, six (6) completed electronically and eleven (11) completed by face to face scheduled interviews. These participants were from various widespread municipalities based in Durban, Pietermaritzburg, Johannesburg, Cape Town, Ixopo, Greytown, Port Shepstone and Drakensberg.

4.2.2 Discussion of the results of the municipal technical questionnaire survey

The results of the MTSQ were captured into Microsoft Excel for analysis. The detailed results of the survey are included under Appendix F. Listed and discussed in section 4.2.2.1 are some of the most critical aspects of the municipal technical questionnaire results.

4.2.2.1 Familiarity with open trenching

A total of twenty-six (26) participants were very familiar with the traditional open trenching method for pipeline replacement. This figure translates into 81% (as shown graphically in Figure 21), indicating its dominance as the most commonly used method in South Africa for many years.

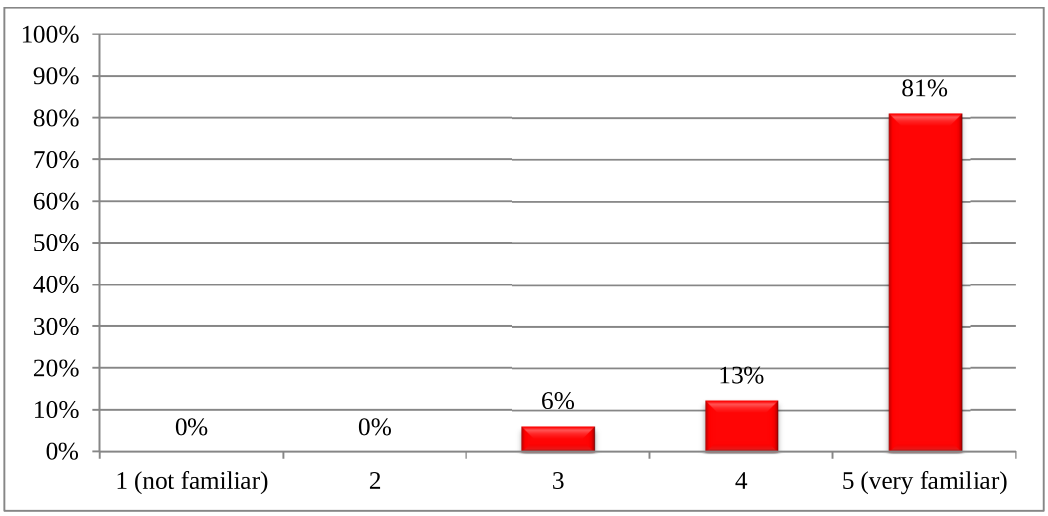

Figure 21 Familiarity with open trenching

4.2.2.2 Familiarity with trenchless technology

In order to obtain an understanding of the levels of knowledge of trenchless technologies, the participants were requested to answer this question in a two-fold manner i.e. (1) before and (2) after explaining the term TT to them.

Only 19% of the participants were very familiar with trenchless technology and have been actively involved with TT projects. A total of 25% of the participants were unfamiliar with the trenchless technologies for pipeline rehabilitation or replacement.

Figure 22 reveals that 44% (category 1 and 2) of the participants are unfamiliar with TT and have not been involved with any projects of this nature.

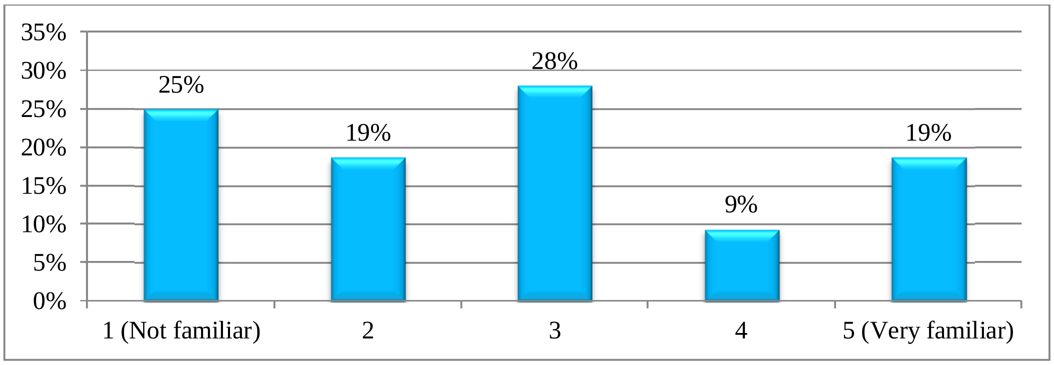

Figure 22 Familiarity with trenchless technology (before explanation of TT)

After explaining the term TT, there was no change to the results of category 4 and 5 respectively (shown graphically in Figure 23). Category 2 increased from 19% to 22%. Category 3 increased from 28% to 31%. This reveals that only a few of the municipalities in South Africa are informed and up to date with trenchless technologies for pipeline rehabilitation/replacement.

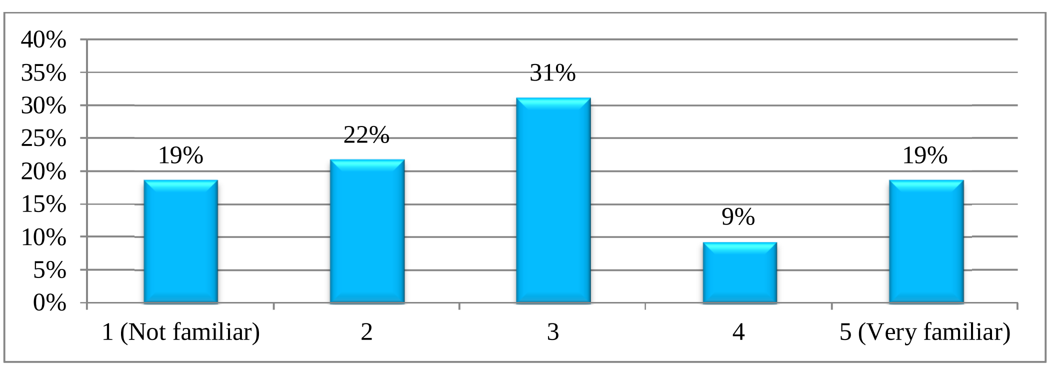

Figure 23 Familiarity with trenchless technology (after explanation of TT)

4.2.2.3 Method preference

Before explaining the benefits of trenchless technologies, a total of 59% of the participants preferred the traditional open trenching method over TT. Figure 24 graphically shows this method preference split between the traditional open trenching method and trenchless technologies.

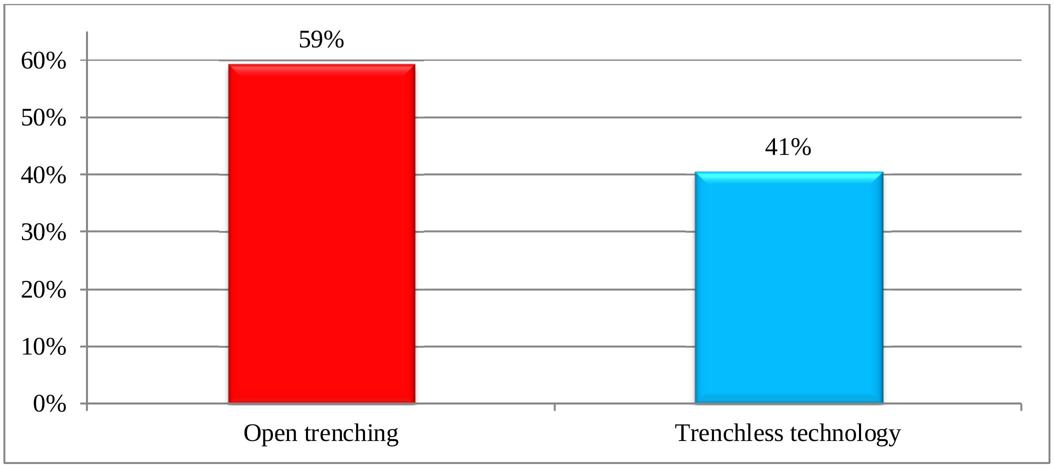

Figure 24 Method preference (before explanation of benefits of TT)

After explaining the benefits of trenchless technology to the participants, a tie (i.e. 50% each) was received for each method respectively. 9% of the participants had changed their vote to trenchless technologies as opposed to traditional open trenching method. Figure 25 shows this 50% equal vote.

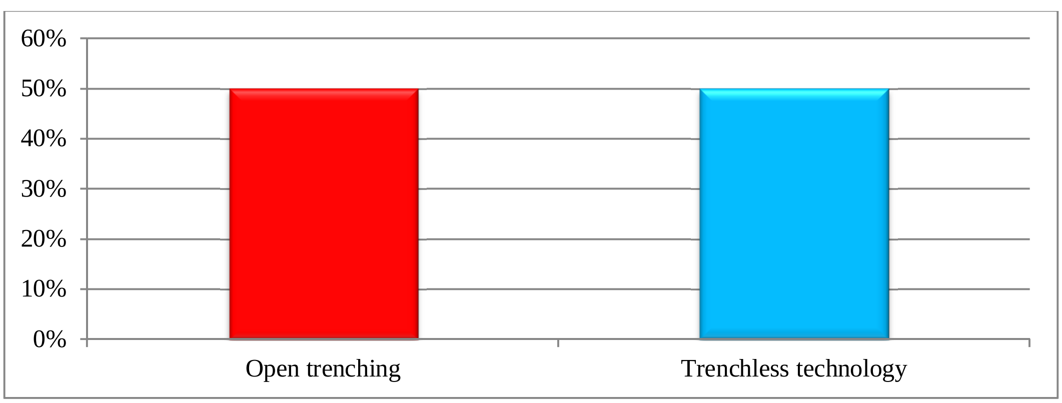

Figure 25 Method preference (after explanation of benefits of TT)

4.2.2.4 Availability of trenchless technology resources

36% of the participants stated that trenchless technology resources were available within their municipality. A further 36% of the participants responded as ómaybeô. A total of 27% stated that trenchless technology resources were not available. At least half of the participants who stated ónoô i.e. 13-14% were also unsure but responded as ónoô. This 13-14% added to the 36% who stated ómaybeô confirms the 50% method preference and knowledge of TT as per section 4.2.2.3. Table 11 presents the results.

Table 11 Availability of trenchless technology resources

%	Number	Category
36	12	Yes
27	9	No
36	11	Maybe
100	**33**	**Total**

4.2.2.5 Knowledge and experience with trenchless technology

A total of 8 participants (25%) rated their knowledge and experience with trenchless technologies as excellent (graphically shown in Figure 26). This is mainly due to the fact that they were actively involved with projects utilising this method. 16% of the participants rated their knowledge and experience as óvery goodô. Overall, only 50% (i.e. rated from excellent to satisfactory) of the participants have sufficient knowledge of trenchless technologies in the municipalities of South Africa.

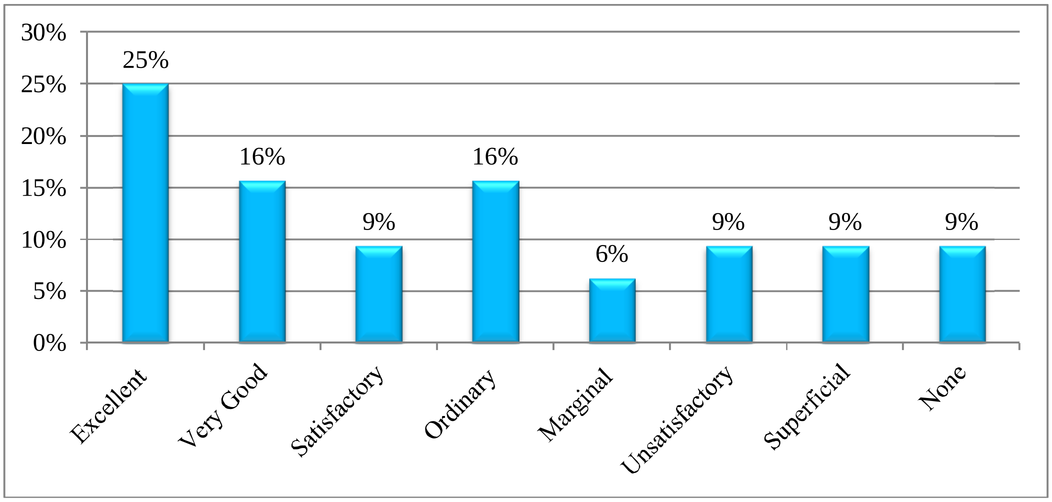

Figure 26 Method preference (after explanation of benefits of TT)

4.2.2.6 Infrastructure budget for new service utilities construction

A total of 76% of the participants stated that their infrastructure budget for the construction of new service utilities i.e. potable water pipelines, sewer pipelines, etc range from R500 000 to R5million. Table 12 presents the findings.

Table 12 Infrastructure budget for new construction

%	Number	Category
0	0	Under R500 000
16	5	R500 000 to R1mil.
22	7	R1mil. to R2.5mil.
22	7	R2.5mil. to R5mil.
28	9	R5mil. or R10mil.
9	3	R10mil. to R25mil.
3	1	Above R25mil.
100	**32**	**Total**

4.2.2.7 Infrastructure budget for rehabilitation of service utilities

Table 13 shows that municipalities in South Africa budget on average a total of R5million to R10million for the rehabilitation and replacing of existing service utilities every year.

Table 13 Infrastructure budget for new construction

%	Number	Category
0	0	Under R500 000
13	4	R500 000 to R1mil.
16	5	R1mil. to R2.5mil.
25	8	R2.5mil. to R5mil.
28	9	R5mil. to R10mil.
16	5	R10mil. to R25mil.
3	1	Above R25mil.
100	**32**	**Total**

4.2.2.8 Utilisation of trenchless technologies

A total of 41% of the participants stated that their municipalities have utilised trenchless technologies for water and sanitation pipeline rehabilitation and replacement projects. Figure 27 illustrates the results.

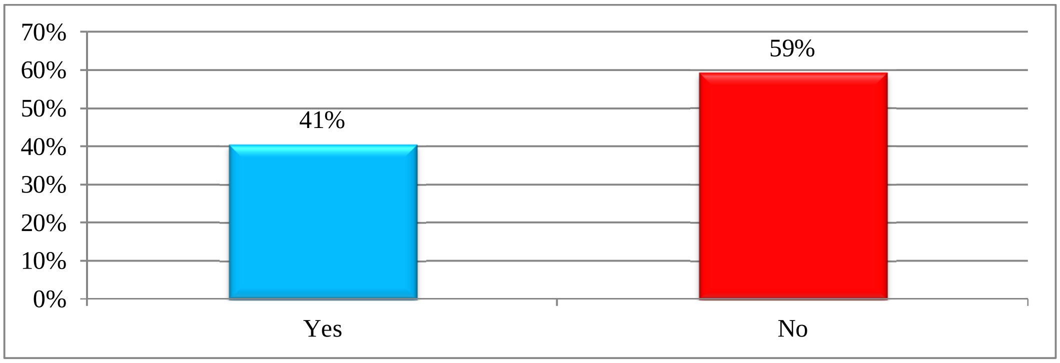

Figure 27 Utilisation of trenchless technologies (before enquiry)

These 41% of the participants were then required to state the types of TT utilised. Table 14 presents the responses received.

Table 14 Utilisation of trenchless technologies

%	Number	Category
19	6	Pipe bursting
9	3	Close-fit lining for mains
25	8	Horizontal directional drilling
0	0	Pipe scanning & evaluation
6	2	Sliplining of pipe
0	0	Other: Nil
6	2	Auger boring
3	1	Close-fit lining for service connections
0	0	Microtunneling
0	0	Robotic spot repair
31	10	Pipe jacking
100	**32**	**Total**

Horizontal directional drilling (25%) and pipe jacking (31%) were the most commonly utilised TT methods. This can be expected since these two forms of TT have been in use for many years in South Africa. Pipe bursting (19%) was rated as one of the popular methods as stated by six participants. The close-fit compact pipe method was rated at 9%. This rating clearly confirms the previous statement (Chapter 2) that the close-fit compact pipe method is new to South Africa and requires further research so that municipalities and contractors can consider this method.

4.2.2.9 Utilisation of open trenching 5 years ago

Participants were required to provide information on the percentage of utilisation of the traditional open trenching five (5) years ago. A greater than 50% utilisation rating was received which is presented in Figure 28.

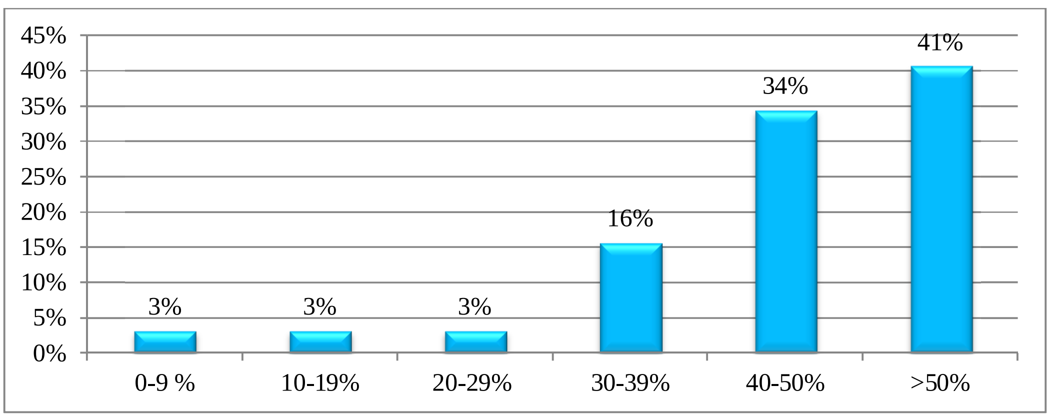

Figure 28 Utilisation of open trenching 5 years ago

4.2.2.10 Utilisation of open trenching 5 years from now

31% of the participants (i.e. 7% less than those indicated in 4.2.2.9) stated that a percentage greater than 50% will be utilised. This rating confirms that even though the traditional open trenching method has numerous drawbacks, it will still serve as a ótraditionalô method. Table 15 presents the results.

Table 15 Utilisation of open trenching 5 years from now

%	Number	Category
3	3	0-9%
3	3	10-19%
3	1	20-29%
17	5	30-39%
41	12	40-50%
31	9	>50%
100	**32**	**Total**

4.2.2.11 Utilisation of TT 5 years ago

A total of 25% of the participants stated that a rating of 40-50% utilisation of TT were executed within their municipalities (Figure 29 shows the results graphically). 6% stated that a rating of greater than 50% utilisation was executed.

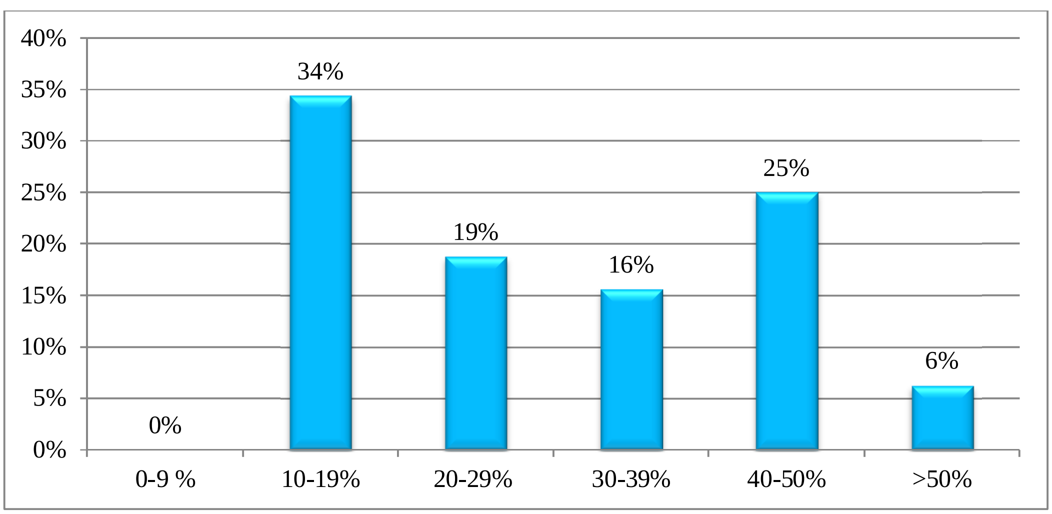

Figure 29 Utilisation of open trenching 5 years ago

4.2.2.12 Utilisation of TT 5 years from now

Participants stated that they foresee an increase in the use of trenchless methods in the future especially for potable water and sewer pipeline rehabilitation and replacement.

A total of seven participants stated that a 40-50% utilisation is possible. 19% of the participants stated that a percentage utilisation of greater than 50% is foreseen in the next five (5) years. The results are shown in Figure 30.

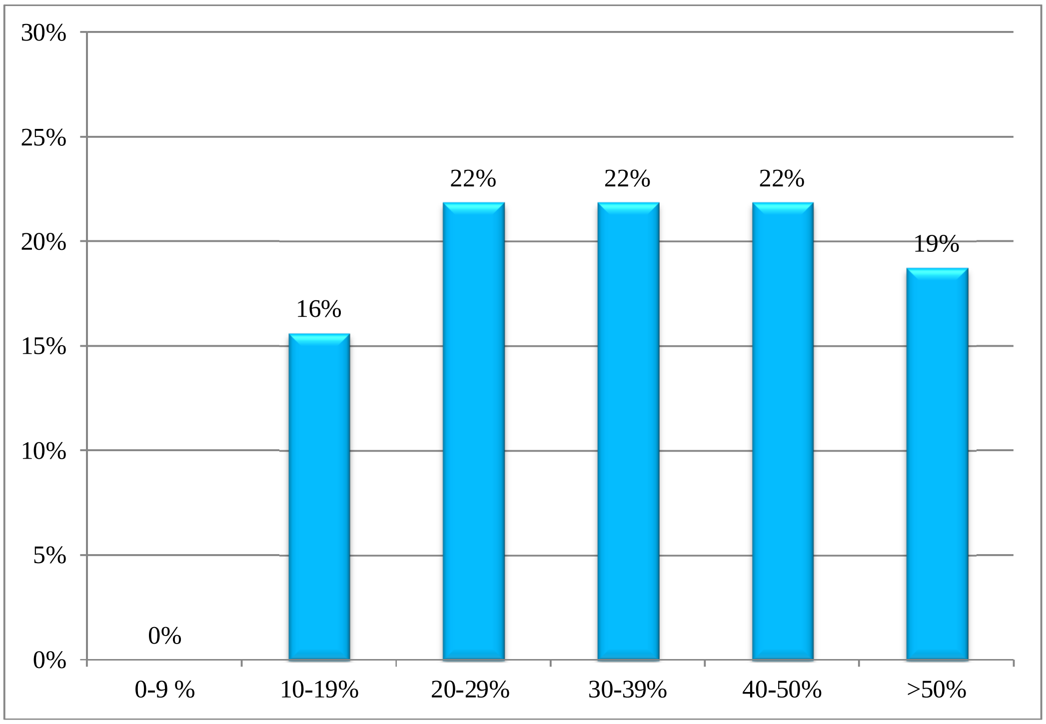

Figure 30 Utilisation of TT 5 years from now

4.2.2.13 Rating of importance of costs

Participants were requested to rate the importance of costs on a scale of 1 to 5 (i.e. least important to most important). Direct costs received the highest rating followed by quantifiable social costs. Participants stated that the social costs play an important role in terms of the success of the project in the stipulated project duration. Table 16 presents the findings.

Table 16 Rating of importance of costs

1 (Least Important)	2	3	4	5 (Very Important)	Total	Category
0	3	5	11	13	32	Direct cost
2	5	5	9	11	32	Indirect costs
0	4	7	9	12	32	Quantifiable socio economic costs
3	4	6	8	11	32	Non-quantifiable socio economic costs
100				**32**		**Total**

Figure 31 shows the results graphically. Direct costs and quantifiable socio-economic inconveniences are dominant followed by indirect and non-quantifiable costs respectively.

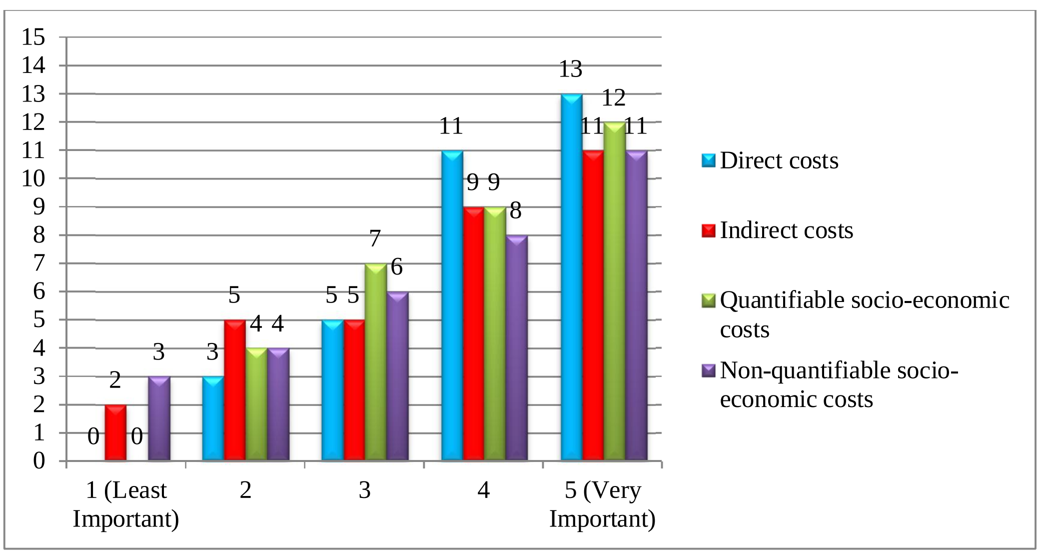

Figure 31 Rating of importance of costs

4.2.2.14 Future trends of trenchless technology

One of the important questions presented to participants in the questionnaire survey was their rating of trenchless technologies in terms of future developments (i.e. whether trenchless methods will outweigh the traditional open trenching method). In order to ensure that the results of this question were correctly obtained, participants were required to provide answers óbeforeô and óafterô reading the explanation of the term ótrenchless technologyô.

Table 17 presents the results. A total of 41% of the participants stated that TT will be the larger future role player than the traditional open trenching method.

Table 17 Future trends of trenchless technology (before explanation of TT)

%	Number	Category
41	13	Yes
59	19	No
100	**32**	**Total**

Some of the responses received were that all pipe rehabilitation or replacement projects will have to utilise a percentage of traditional open trenching method even if a trenchless method is selected (presented in Table 18). A second response was that trenchless methods only work well in selected areas, such as highly public or vehicle use areas.

Table 18 Future trends of trenchless technology (after explanation of TT)

%	Number	Category
53	17	Yes
47	15	No
100	**32**	**Total**

After the explanation of the benefits of trenchless technologies, 53% of the participants (a 12% increase in votes) were in favour of TT based on future growth.

4.2.3 Discussion

The results of this survey questionnaire reveal that at least half of municipal technical staff of South Africa are not adequately informed about trenchless methods, its application and technical merits and drawbacks respectively. During this research survey, some participants were unsure of how to answer questions as they were not exposed to trenchless technologies and its applications.

Only 19% of the participants who were involved and up to date with trenchless technologies could answer the questionnaire in full, i.e. to indicate budgets allocated, types of trenchless technologies utilised, its merits, drawbacks and future growth trends.

A similar study by Ariaratnam (2010: 807) revealed that technical staff of municipalities and even contractors have some awareness of trenchless technologies.

The low percentage of rehabilitation and replacement applications for ageing potable water pipeline networks in the last five (5) years confirm that even when trenchless methods could have been utilised, the traditional open trenching method was instead selected. This is mainly due to the lack of awareness of trenchless methods and its applications respectively.

4.2.4 Conclusions of the Municipal Technical questionnaire survey

At least 50% of municipal technical staff in South Africa have sufficient knowledge of trenchless technologies, its applications, merits, drawbacks and are involved with projects utilising this method.

This survey questionnaire reveals that South Africa may be advancing over the years on the use of trenchless methods, yet, more education in the form of training, seminars and other methods of marketing must be undertaken, starting at a municipal level. This statement reaffirms Fernandez (2004: 24), who stated that the greatest hurdle to the growth of trenchless technology is the educating of industry on the availability, serviceability and reliability of trenchless methods.

4.3 Direct cost comparison (open trenching vs. pipe bursting)

4.3.1 Introduction

The data (rates) used in this section were provided by Mr Sam Efrat, the director of Trenchless Technologies cc (an approved service provider of the EWS). Trenchless Technologies ccős core speciality is pipeline replacement for both potable water distribution networks and sewer reticulation systems. One of the trenchless variants used by Trenchless Technology Cc is the pipe bursting method.

The data used refers to a project area in which 90% of its existing potable water network consisted of AC piping and 10% cast iron piping. The existing AC pipeline networks ranged from DN50 (Class 10), DN75 (Class 10) and DN 90 (Class 12) size pipes.

The project area consisted of the following:

a) Paved asphalt roadways;
b) Combination of asphalt, paved brick and grassed verge sidewalks;
c) High vehicular traffic;
d) High pedestrian traffic;
e) High extent of existing service utilities; and
f) To a certain degree, as-built records for the existing service utilities.

The following assumptions were taken into account during the direct cost comparison:

a) All rates were escalated to current values (as at 15 January 2013);

b) All costs (amounts) stipulated exclude:

   i. VAT;
   ii. P&Gs;
   iii. Lateral connections (from bulk line to house connections);
   iv. Fire hydrant connections;
   v. Bends along the pipeline route; and
   vi. Special fittings (for house connections).

c) Per metre lengths of pipe to be installed at a depth of 1.5m.

d) Excavation and reinstatement costs were included;

e) The cost for consumables (i.e. diesel, petrol, oil) and equipment (for the pipe bursting method) were included in the rates for pipeline laying. The costs for consumables could not be measured on its own as this cost varies from project to project;

f) The ócost of pipingô included:

   i. HDPE piping that is supplied in 100m rolls;
   ii. uPVC pipes that are supplied in 6m lengths; and
   iii. The cost of piping is priced per metre (m);
   iv. Purchase from a local large supplier, transporting costs to site and contractor profit mark-up;

g) The ócost for pipeline layingô included:

   i. Cost of piping;
   ii. Handling;
   iii. Jointing and fitting (i.e. uPVC piping spigot and socketed together, and HDPE piping fitted together by buttwelding) ;
   iv. Bedding;
   v. Installing;
   vi. Pressure testing; and
   vii. Disinfecting;

h) The ótotal cost of pipeline layingô comparison included:

i. Cost for pipeline laying (as per item [g]);
ii. Pipe sizes (diameters) installed are larger than the existing AC pipes.
iii. Site clearance;
iv. Excavation;
v. Backfilling;
vi. Reinstatement; and
vii. Commissioning.

4.3.1.1 Site clearance

Table 19 compares the costs for site clearance which include clear and grub of the site and removal of 150mm of topsoil.

Table 19 Site clearance

Method			Open trenching		Pipe bursting		C.S
Item	**Unit**	**Rate**	**QTY.**	**AMT.**	**QTY.**	**AMT.**	**%**
Clear and grub	m^2	R8.00	1	R8.00	0.24	R1.92	+76
Remove topsoil to nominal depth of 150mm and stockpiled for reuse	m^2	R16.00	1	R16.00	0.20	R3.20	+80
			Total	**R24.00**		**R5.12**	**+79**

Table 19 shows that a 79% cost saving can be expected for site clearance when the pipe bursting method is utilised. For every square metre of clear and grub required using the traditional open trenching method, an equivalent average of 0.24m^2 of clear and grub is required when using the pipe bursting method. The results are presented graphically in Figure 32.

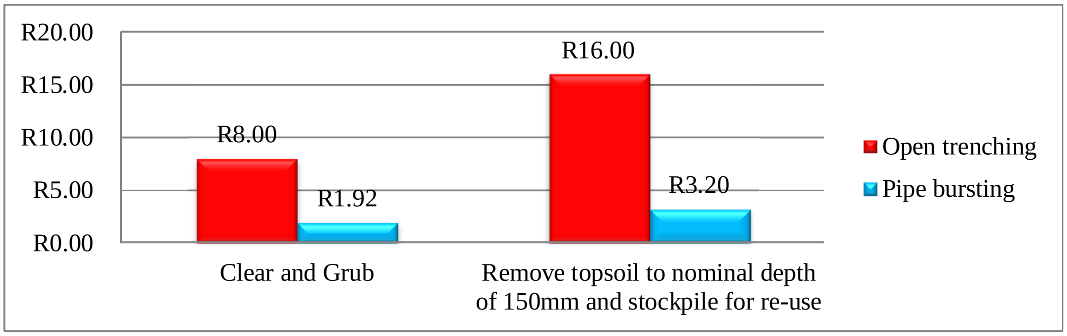

Figure 32 Site clearance

4.3.1.2 Removal of footways and driveways

Table 20 presents the rates for the removal of various existing surfaces. These range from asphalt surfaces to landscaped grassed verges.

Table 20 Removal of footways and driveways

Method			Open trenching		Pipe bursting		C.S
Item	**Unit**	**Rate**	**QTY.**	**AMT.**	**QTY.**	**AMT.**	**%**
Asphalt (50mm thickness)	m^2	R35.00	1	R35.00	0.20	R7.00	+80
Asphalt (50-100mm thickness)	m^2	R50.00	1	R50.00	0.22	R11.00	+78
Interlocking concrete segmental paving blocks (all colours)	m^2	R26.00	1	R26.00	0.20	R5.20	+80
Concrete slabs	m^2	R35.00	1	R35.00	0.25	R8.75	+75
Brick paving	m^2	R26.00	1	R26.00	0.20	R5.20	+80
Landscaped grassing and vegetation	m^2	R8.00	1	R8.00	0.20	R1.60	+80
Dump rock	m^2	R160.00	1	R160.00	0.24	R38.40	+76
			Total	**R340.00**		**R77.15**	**+77**

On average, the rates for the pipe bursting method is 77% cheaper than when the traditional open trenching method is utilised. This is due to the fact that the pipe bursting method requires far less excavations. Therefore, the amount of existing surfaces that would need to be removed is minimised. Figure 33 shows the results graphically.

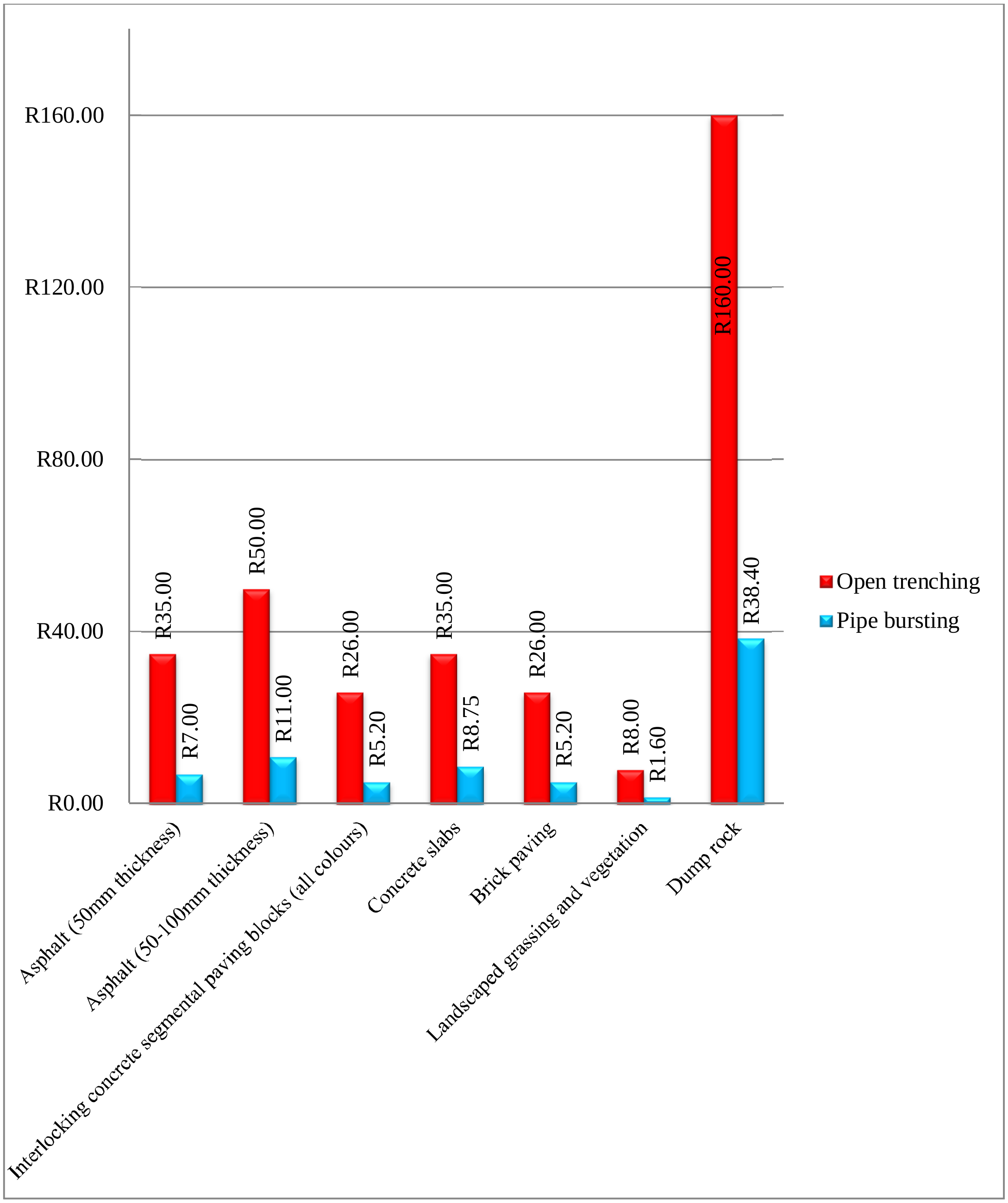

Figure 33 Removal of footways and driveways

4.3.1.3 Backfilling and reinstatement of footways and driveways

Table 21 presents the rates for the reinstatement of the various existing surfaces previously discussed.

Table 21 Backfilling and reinstatement of footways and driveways

Method			Open trenching		Pipe bursting		C.S
Item	**Unit**	**Rate**	**QTY.**	**AMT.**	**QTY.**	**AMT.**	**%**
Asphalt (50mm thickness)	m^2	R35.00	1	R35.00	0.25	R8.75	75
Asphalt (50-100mm thickness)	m^2	R50.00	1	R50.00	0.25	R12.50	75
Interlocking concrete segmental paving blocks (all colours)	m^2	R26.00	1	R26.00	0.20	R5.20	80
Concrete slabs	m^2	R35.00	1	R35.00	0.27	R9.45	73
Brick paving	m^2	R26.00	1	R26.00	0.20	R5.20	80
Landscaped grassing and vegetation	m^2	R8.00	1	R8.00	0.20	R1.60	80
Dump rock	m^2	R160.00	1	R160.00	0.25	R40.00	75
			Total	**R340.00**		**R82.70**	**76**

The cost to reinstate an asphalt surface (50 ï 100mm thickness) using the traditional open trenching method costs R50.00 (per square metre). Pipe bursting is 75% cheaper (i.e. R12.50). The overall cost for reinstatement is on average 76% cheaper when using the pipe bursting method.

4.3.1.4 Earthworks (excavations): pipe trenches

These rates include excavation in all material for trenches and disposal of surplus material using labour intensive construction methods for the depths presented in Table 22.

Table 22 Earthworks (excavation): pipe trenches

Method			Open trenching		Pipe bursting		C.S
Item	**Unit**	**Rate**	**QTY.**	**AMT.**	**QTY.**	**AMT.**	**%**
Over 0.00m and up to 1.0m	m^3	R220	1	R220	0.20	R180	+84
Over 1.0m and up to 1.5m	m^3	R240	1	R240	0.20	R40	+83
Over 1.5m	m^3	R260	1	R260	0.20	R44	+83
			Total	**R720**		**R120**	**+83**

When using the traditional open trenching method, a total of 1m^3 will be trenched at a rate of R220.00 (at a depth of 1.0m). An equivalent of 0.2m^3 will be trenched at a rate of R180.00 (at a depth of 1.0m) when the pipe bursting method is used. Figure 34 shows the results graphically.

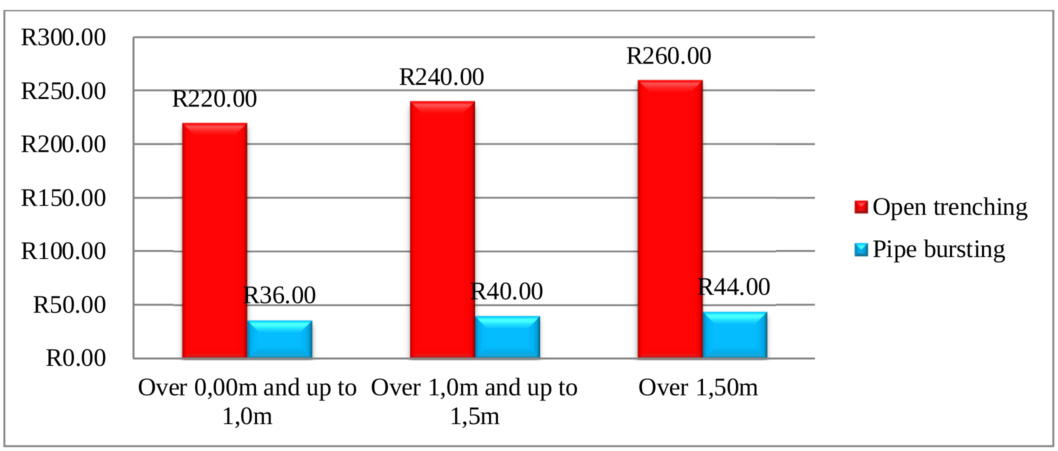

Figure 34 Earthworks (excavations): pipe trenches

4.3.1.5 Compaction in road reserves

Table 23 details the cost for compaction in road reserves based on 93% mod AASHTO density.

Table 23 Compaction in road reserves

Method			Open trenching		Pipe bursting		C.S
Item	**Unit**	**Rate**	**QTY.**	**AMT.**	**QTY.**	**AMT.**	**%**
Additional compaction to 93% mod AASHTO density in road reserve	m^3	R71.00	1	R71.00	0.21	R14.91	+79
			Total	**R71.00**		**R14.91**	**+79**

A total of 79% (based on $1m^3$) was saved when using the pipe bursting method. This saving results from the reduced amount of existing surfaces being removed. Figure 35 illustrated the results.

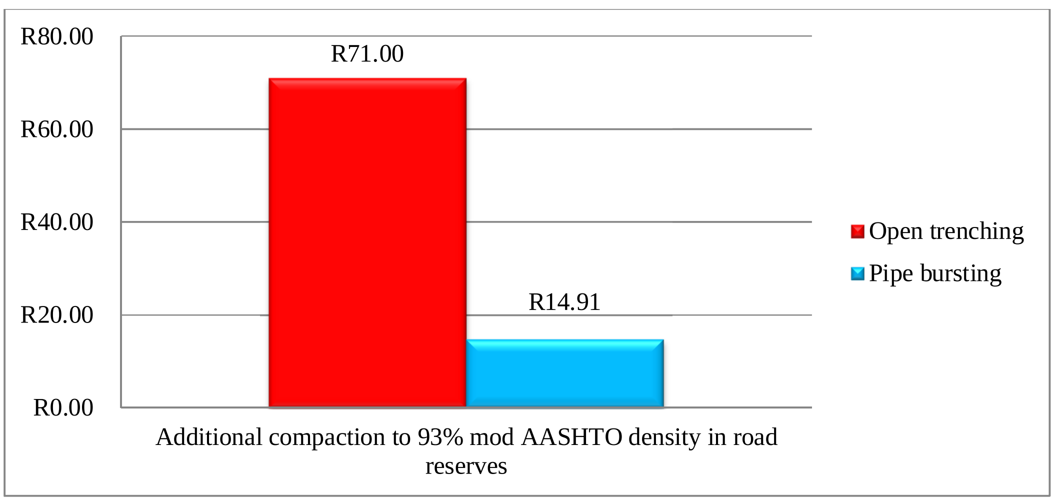

Figure 35 Compaction in road reserves

4.3.1.6 Bedding (pipes)

The rates stipulated in Table 24 include for the provision of Class B bedding from trench excavations.

Table 24 Bedding (pipes)

Method			Open trenching		Pipe bursting		C.S
Item	**Unit**	**Rate**	**QTY.**	**AMT.**	**QTY.**	**AMT.**	**%**
Selected granular material	m^3	R62.00	1	R62.00	0.20	R12.38	+80
Selected fill material	m^3	R62.00	1	R62.00	0.20	R12.38	+80
			Total	**R62.00**		**R24.78**	**+80**

An 80% cost saving can be expected when the pipe bursting method is selected. Minimal bedding is required (pipe bursting method) since the new pipe will be laid within the burst fragments of the old pipe. However, the open trench method will require bedding to be laid along the entire route prior to the piping being inserted. The results are graphically presented in Figure 36.

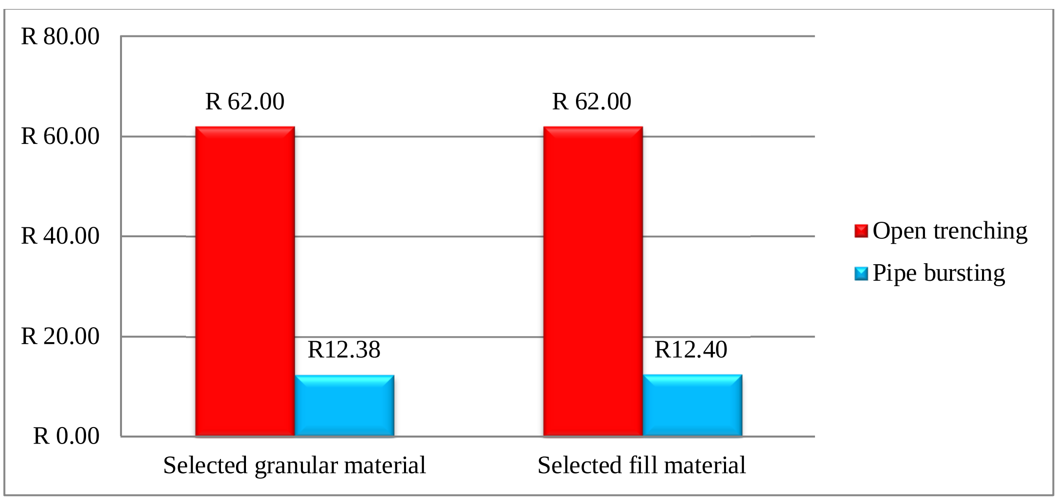

Figure 36 Bedding (pipes)

Figure 37 illustrates a typical section of Class B bedding (CSIR Building and Construction Technology 2003: 31).

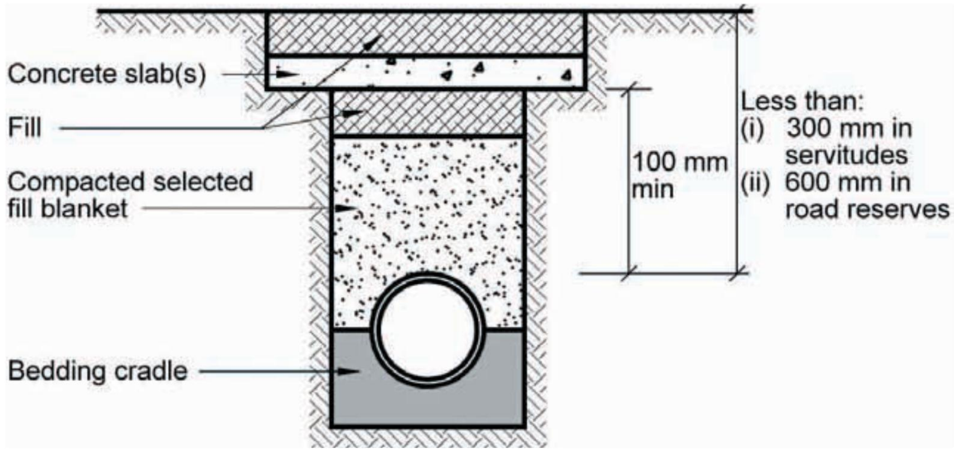

Figure 37 Typical section indicating Class B bedding (pipes)

4.3.1.7 Cost of piping

Table 25 presents the costs of uPVC and HDPE piping. For purposes of cost comparison it is assumed that uPVC piping will be under the open trenching method and HDPE piping under the pipe bursting method.

Table 25 Cost of piping

Pipe Material		uPVC		HDPE		C.S
Item	**Unit**	**QTY.**	**AMT.**	**QTY.**	**AMT.**	**%**
DN110 Class 16	m	1	R59.75	1	R57.23	+4
DN160 Class 16	m	1	R122.85	1	R119.44	+3
DN200 Class 16	m	1	R242.75	1	R236.51	+3
		Total	**R425.35**		**R413.18**	**+3**

The cost of HDPE piping results in a 3% saving based on the pipe sizes specified. This 3% saving is mainly due to the difference in pipe material. These results are graphically shown in Figure 38.

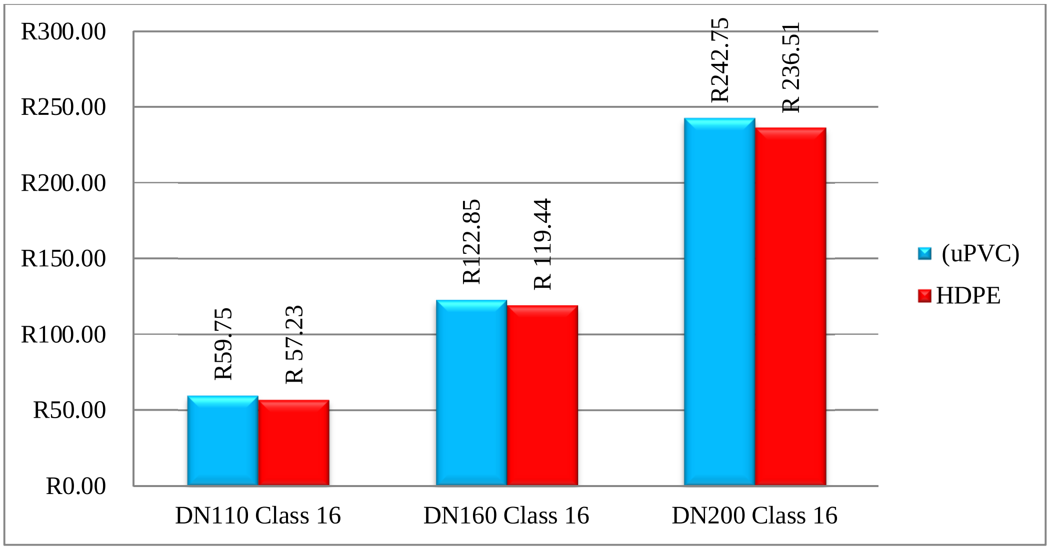

Figure 38 Cost of piping

4.3.1.8 Cost of pipeline laying

Table 26 presents the rates for pipeline laying per metre length.

Table 26 Cost of pipeline laying per metre length

Pipe Material		Open trenching		Pipe bursting		C.S
Item	**Unit**	**QTY.**	**AMT.**	**QTY.**	**AMT.**	**%**
DN110 Class 16	m	1	R206.00	1	R220.00	-26
DN160 Class 16	m	1	R332.00	1	R440.00	-35
DN200 Class 16	m	1	R458.00	1	R620.00	-43
		Total	**R935.00**		**R1 280.00**	**-37**

The cost for the laying of pipes utilising the open trenching method equates to R935 per metre based on the diameters specified. However, the cost for the laying of the same pipes equates to R1, 280.00 per metre when the pipe bursting method is utilised. This 37% increase includes for the cost of relevant equipment and consumables essential for the pipe bursting procedure. Figure 39 graphically shows the difference in costs between open trenching and pipe bursting.

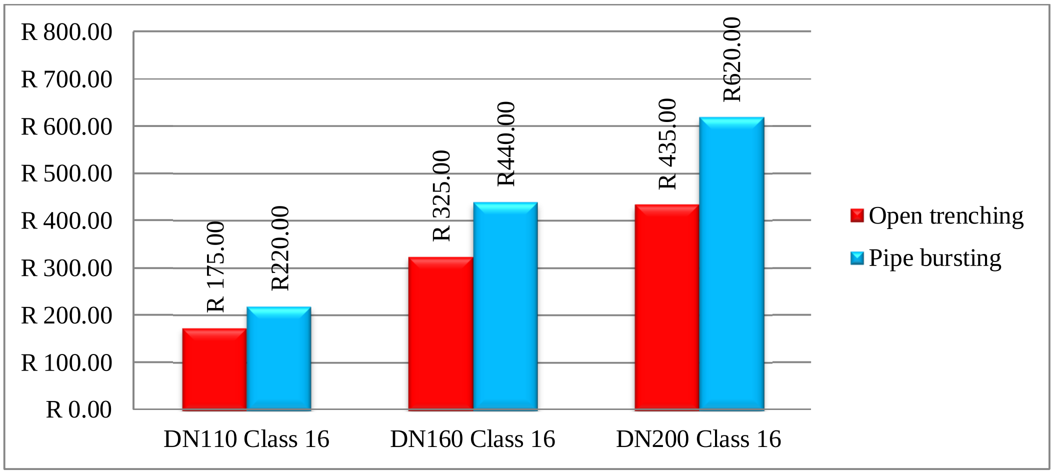

Figure 39 Cost of pipeline laying per metre length

4.3.1.9 Total cost of pipeline laying per metre length

Table 27 presents the cost rates for pipeline laying per metre length.

Table 27 Total cost of pipeline laying per metre length

Pipe Material		Open trenching		Pipe bursting		C.S
Item	**Unit**	**QTY.**	**AMT.**	**QTY.**	**AMT.**	**%**
DN110 Class 16	m	1	R578.75	1	R381.53	+34
DN160 Class 16	m	1	R791.85	1	R624.06	+21
DN200 Class 16	m	1	R1 021.75	1	R921.13	+10
		Total	**R2 392.35**		**R1 926.72**	**+19**

When comparing the total costs for pipeline laying per metre length, the pipe bursting method reveals a 34% saving (DN110 Class 16 pipe). The cost saving based on the use of all three pipe sizes equates to 19% which justifies the statement made in Chapter 2 (Literature Review) of this research study which stated that a cost saving of 15 to 20 percent can be expected. This saving can be increased to 30% under thick pavements, expensive landscaping or in heavily trafficked locations. Figure 40 graphically illustrates the results.

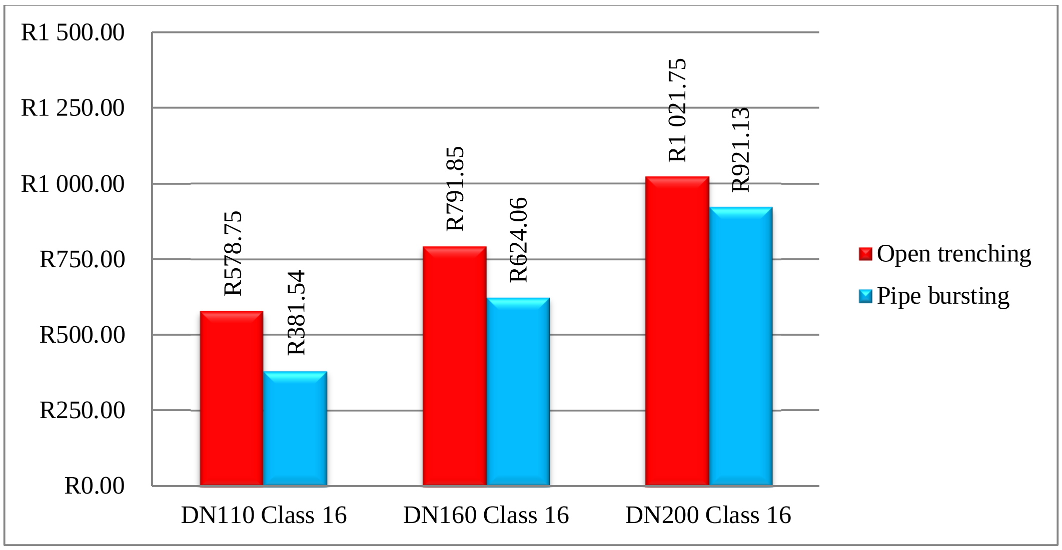

Figure 40 Total cost of pipeline laying per metre length

5 CONCLUSIONS

The aim of this research study was to compare trenchless methods against the traditional open trenching method for the rehabilitation or replacement of existing deteriorated buried potable water pipelines. The initial objective was to select a list of trenchless methods available which would then be compared against the traditional open trenching method in terms their technical merits and drawbacks, direct costs, indirect costs and levels of social inconveniences. In addition to this, the trenchless methods selected would also be compared against each other in order to determine which trenchless method would best suit the municipalities of South Africa for the replacement of the existing deteriorated buried AC potable water pipelines.

Three trenchless methods formed part of this research study, (1) Wavin close-fit compact pipe, (2) sliplining and (3) pipe bursting which were then compared against the traditional open trenching method in terms of their technical merits and drawbacks. By analysing existing published literature and also obtaining information from personnel who have utilised these methods on projects, concise tables of technical merits and drawbacks were collated for the close-fit compact pipe method, sliplining method, pipe bursting method and the traditional open trenching method.

The direct cost comparison of the trenchless pipe bursting method and the traditional open trenching method was completed in this research study as only data for these two methods could be obtained during this research study journey.

The comparisons of the indirect costs and levels of social inconveniences for the three trenchless methods detailed above against the traditional open trenching method were completed in the form of a field survey study. A questionnaire (SESQ) was compiled by the researcher and thereafter a field survey was conducted in an area in which a potable water pipeline rehabilitation and replacement project was completed which utilised the trenchless methods mentioned above and the traditional open trenching method. Residents and business owners (termed the participants in this research study) completed the questionnaire. The questionnaire aimed at determining which method the participants preferred, the dominant inconveniences or hindrances experienced and to state whether they prefer the municipalities to consider indirect and social inconveniences during potable water pipeline projects, which should form part of a project ‘total cost’.

The initial hypothesis stating that the overall costs (i.e. direct costs, indirect costs and social inconvenience costs respectively) of trenchless methods are cheaper than the traditional open trenching method turned out to be correct once investigated in this research study. The start-up phase for projects utilising trenchless methods are indeed more expensive due to the use of highly sophisticated technical equipment requiring experienced operators. The overall direct costs for pipe-laying using trenchless methods also showed to be further reduced as the length of pipeline increases. The indirect costs and social inconvenience costs are minimal (if not eliminated) when using trenchless methods due to this method being non-intrusive, faster and more efficient. Costs for damage to existing, buried service utilities are limited since minimal excavation is required. Further beneficial when historical as-built records are unavailable for the existing buried services since if the traditional open trenching method was utilised, the risk of damage to these services are high.

The pipe bursting method (TT) outweighed the close-fit compact pipe method and sliplining method from both the technical aspects to a cost comparison. Pipe bursting has been in use in South Africa by contractors for several years and contractors are equipped and experienced with its application. Since the existing buried potable water pipelines in South Africa are majority AC pipes needing replacement, pipe bursting is a viable option. The pipe bursting method is faster and allows for the existing aged pipeline to be upsized, thus increasing the hydraulic capacity required. This method also allows for the burst asbestos fragments to remain buried underground whilst laying a new pipe in-situ. As a result, the costs for the safe on-line removal, handling, transportation and disposal of the AC pipes at an approved licensed hazardous landfill site are eliminated. Environmentally, it has not been verified as to whether the burst asbestos fragments left underground cause a negative short term and long term impact on the groundwater during the process of leaching. However, the on-line removal of the deteriorated AC pipes will cause immediate harm to humans if the loosened asbestos fibres are inhaled. Therefore, the pipe bursting method remains the best trenchless alternative than the traditional open trenching method. In addition, leaving the burst asbestos fragments underground is the cheaper option when compared to the costs for the disposal at a licensed hazardous landfill site. The results of the SESQ showed that the public prefer trenchless methods as opposed to the traditional open trenching method. The main reasons for this preference are due to the fact that the traditional open trenching method is more disruptive and is therefore socially unacceptable. Traffic disruptions were rated as the most dominant hindrance experienced during a pipe replacement project when the traditional open trenching method is utilised. The participants of the SESQ expect the municipalities to consider indirect costs and social inconveniences when undertaking a pipe rehabilitation or replacement project. The traditional open trenching method has shown to be more expensive, disruptive and socially inconvenient, especially in busy areas such as CBDs. The results of the SESQ showed that the public are very familiar with this traditional method but due to its many drawbacks, do not prefer this method.

A further aim of this research study was to serve as a support tool to municipalities when selecting a potable water pipeline rehabilitation or replacement method by providing the municipality with a concise list of technical merits and drawbacks and cost comparison for at least one trenchless method (pipe bursting in this case) against the traditional open trenching method. This aim then lead to an auxiliary aim of this research study which was to obtain insight as to the levels of understanding of trenchless technologies by municipal technical staff who are the decision makers for the method selection respectively. This was completed in the form of a survey questionnaire. A questionnaire (MTSQ) aimed at the technical staff of municipalities in South Africa was compiled by the researcher in order to determine whether they understand the term trenchless technologies, its technical merits and drawbacks, its direct costs and its current levels of use or non-use in respective municipalities.

The results of the MTSQ showed that many staff members in technical departments of municipalities are not familiar with trenchless methods or its application. Technical staff of municipalities must be informed, trained and up to date on the latest developments of trenchless methods in order for this method to be fully functional and in use for pipe rehabilitation and replacement projects. Trenchless methods should be utilised in dense areas such as CBDs, business parks, industrial areas, and around hospitals and schools. Trenchless methods result in lower noise and dust, as well as fewer road excavations and traffic disruptions. Trenchless methods offer the decision makers of municipalities a number of tools to select from when managing their water systems. There is more than one option (solution) and a selection process must never replace sound engineering judgement which offers rational suggestions to assist the decision makers of the municipalities.

The outcomes of the MTSQ showed that most of the technical staff of municipalities prefer the traditional open trenching method since they have been utilising this method for pipe rehabilitation and replacement projects for numerous years. If these technical staff members of municipalities are adequately informed and trained on trenchless methods then another option (in addition to the traditional open trenching method) becomes available when making decisions. The traditional open trenching will always form part of the selection process as it is commonly used. However, the overall cost of a project must take precedence in the decision making process. The results of this study showed that the traditional open trenching method works best in non-busy areas such as farmlands and rural areas where there are limited existing buried service utilities and where the as-built information for these services are available.

The results of both the SESQ and the MTSQ compiled by the researcher formed part of the EWS Feasibility study funded by the Dutch Government.

In terms of the costing, all costs (i.e. direct, indirect and social) have to be taken into consideration when selecting a pipe rehabilitation or replacement method. The ótotal costô of a project is when the direct costs, indirect costs and social inconvenience costs are considered. It has been shown in this research study that trenchless methods outweigh the traditional open trenching method from an óall costô perspective.

6 RECOMMENDATIONS AND FURTHER RESEARCH

When selecting a method for the rehabilitation or replacement of existing deteriorated buried potable water pipeline networks in South Africa, municipalities must assess the merits and drawbacks of each method under consideration. A selection of one or combination of methods as that utilised under the ôEWS 1.2km AC Pipeline Replacementô project may be the better option according to the site conditions, location of the site, state of the existing buried potable water pipeline and the monetary budget available by the municipality to carry out the necessary feasibility studies, designs and project implementation.

The choice of method must be based on South African conditions i.e. total cost, site description and experience of local contractors and pipe suppliers.

In this research study, the pipe bursting method was found to be the preferred trenchless method as compared to the close-fit compact pipe method and sliplining method. Due to limited resources, the effect that the burst asbestos fragments have on the groundwater during leaching could not be investigated and confirmed to be an environmental issue. This gap in literature should form part of a separate research study in the future.

In terms of the direct cost comparison, data for the pipe bursting method and traditional open trenching method was obtained during this research study. Due to the limitation of time, the direct cost comparisons of the close-fit compact pipe method and sliplining method could not be obtained and should form part of a further research study.

Statistics for the contribution to EPWP could not be obtained during this research study and thus a general overview of contribution to EPWP was discussed. A detailed research study can be completed in the future if statistics of contribution to EPWP by each trenchless method versus the traditional open trenchless method are available.

The close-fit compact pipe method developed by Wavin Overseas B.V. needs to evaluated further in terms of its directs costs, since this method is newly introduced in South Africa. Therefore, currently, information regarding the direct costs of this method is still limited. A future research study should also conduct a survey to determine whether the market demand for the close-fit compact pipe method is high, or even viable in South Africa.

Other recommendations for future research include the exposure of the SESQ to other municipal areas of South Africa. The SESQ and MTSQ which formed part of this research study were based on a selected group of diversity of the public, i.e. Pinetown in KwaZulu Natal for the SESQ and selected municipalities for the MTSQ as not every municipality which were invited to participate submitted completed questionnaires. By exposing the SESQ and MTSQ to all municipal areas of South Africa, data from a broader spectrum will be obtained and in turn will provide holistic results for South Africa.

Due to the limitation of time, the above mentioned gaps in literature could not be completed. However, future investigations proposed by the researcher, at a doctoral level of study include the following:

1) Obtain buy-in and funding support from various municipalities and educational institutions (as between EWS and DUT) in South Africa in order to expose the SESQ and MTSQ to all municipal areas in South Africa, carry out the survey, tabulate and present the results. These results will assist the various municipalities of South Africa to understand which method was preferred by the public and gain insight as to whether municipal technical staff are adequately informed, trained and experienced with the use of trenchless technologies. By completing this research in all municipal areas of South Africa, a diverse spectrum of data will be obtained which in turn will be more viable and cost beneficial. Municipalities will then understand as to which method worked best and the areas in which they worked best respectively. As a result, the method selection for

future projects will be guided by the outcomes of this holistic investigation which includes all municipal areas of South Africa.

2) Obtain buy-in and funding from various municipalities, educational institutions and governmental organisations such as DWA in order to carry out the necessary investigations and laboratory testing to verify that the burst asbestos fragments have a negative effect on the groundwater table. This future research study has not been completed by other researchers. The answer to this gap in literature is crucial since majority of the existing deteriorated buried potable water pipeline networks in South Africa consist of AC pipes and municipalities need to weigh the costs of safe removal, handling, transporting and disposal at an approved hazardous landfill site versus the environmental effects on the groundwater table.

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8 APPENDICES

Appendix A: Socio-economic survey questionnaire (SESQ)

In association with:

SINGAKWENZA NDAWONYE
ENGINEERING SERVICES

P.O. Box 13006 Cascades 3202 Tel: 082 5911 400 Fax: 0880 333 475 005

ASBESTOS CEMENT (AC) PIPE REPLACEMENT PROJECT

"TRENCHLESS VERSUS OPEN TRENCHING"

SOCIO-ECONOMIC SURVEY QUESTIONNAIRE (SESQ)

1. There has been a water pipe replacement project in your area in the last 18 months to provide better water delivery service for the years to come.

   WERE YOU AWARE OF THIS CONSTRUCTION ACTIVITY?

	Yes		**No**

   This questionnaire will help the Ethekwini Municipality to understand the impact of the work done and going forward to help make decisions in how future work needs to be done.

2. **ARE YOU FAMILIAR WITH WHY WATER PIPES NEED TO BE REPLACED OVER TIME?**

   (**Scale: 1 – not familiar, 5 – very familiar**)

	1		**2**		**3**		**4**		**5**

   Water pipes degrade over the years and some pipes are over 90 years of age. These old pipes start to break causing leaks (water is lost – costly). The pipes become unreliable and do not operate at its capacity. Hence, the need to replace these pipes is the answer.

3. **ARE YOU FAMILIAR WITH THE TERM 'OPEN TRENCHING'?**

   Open trenching refers to the laying of a new water pipe by excavating with a TLB or by hand.

	Yes		**No**

4. **ARE YOU FAMILIAR WITH THE TERM 'TRENCHLESS TECHNOLOGY'?**

	Yes		No

It is an alternative approach to open trenching for replacing old pipes. This trenchless technological method adopts a non-intrusive limited open trenching approach which is environmentally friendly.

5. **BASED ON THE PIPE REPLACEMENT PROJECT IN YOUR AREA, DID YOU EXPERIENCE ANY OF THE FOLLOWING HINDRANCES:**

	Dust
	Noise
	Traffic disruptions
	Access to your property
	Interruption of service (water, electricity, sewer, phones)

6. **ON A SCALE OF 1 TO 5 (SCALE: 1 – NOT SEVERE, 5 – VERY SEVERE) WHICH OF THE FOLLOWING HINDRANCES ARE MOST IMPORTANT?**

	Dust
	Noise
	Traffic disruptions
	Access to your property
	Interruption of service (water, electricity, sewer, phones)

7. **HOW LONG WAS THE INTERRUPTION OF SERVICE, IF ANY?**

	<2 hours		2-12 hours		13-24 hours		>24 hours

8. HOW WOULD YOU RATE THE QUALITY OF THE FOLLOWING AFTER THE PROJECT WAS COMPLETED?

Water quality		Good		Bad
Conditions of the repair		Good		Bad
Patching of roadworks across which pipes where laid		Good		Bad

9. IN YOUR VIEW, DID THE HINDRANCES TAKE TOO LONG?

	Yes		No

10. ARE YOU HAPPY OR NOT HAPPY WITH THE ROADS WHICH WERE PATCHED UP AND NEED TO BE PROPERLY REPAIRED AFTER THE LAYING OF THE NEW PIPE?

	Happy		Not

11. AS A RESULT OF THE PATCHING UP OF THE ROADS, IS IT CAUSING DAMAGE TO YOUR VEHICLE?

	Yes		No

12. SHOULD THE FULL SECTION OF ROAD OR PART OF THE ROAD BE RESTORED?

	Full		Part

13. WHICH OF THE ABOVE (FULL ROAD OR PART) IS MORE IMPORTANT?

	Full		Part

14. **HOW LONG DID IT TAKE FOR THE ROAD TO BE FULLY RESTORED?**

	1 Week		**2 Weeks**		**1 Month**		**More than a month**

15. Trenchless technology is in principle the faster method of replacing the water pipes and causes less damage and inconvenience as it uses more machines and is a precision job. Open trenching is more labour intensive and results generally in more damage to the surface, creates more inconvenience and takes longer.

WHICH METHOD WOULD YOU PREFER?

	Open trenching		**Trenchless technology**

16. **WHAT IS MORE IMPORTANT?**

	Cost	**or**		**Creating work**

	Speed of service delivery	**or**		**Creating work**

	Speed of service delivery	**or**		**Cost**

17. **WOULD YOU MIND PAYING A PREMIUM FOR THE USE OF TRENCHLESS TECHNOLOGY RATHER THAN OPEN TRENCHING?**

	Yes		**No**

18. **HOW MUCH OF A PREMIUM WOULD YOU PAY?**

	10%		**30%**		**50%**		**100%**

19. In principle, direct costs of rehabilitation are ±30%. 70% is more or less "indirect costs" like road repairs after and inconvenience etc, which comes from a different budget (e.g roads agency) or is directly endured by the customer (length of inconvenience).

SHOULD THE MUNICIPALITY CONSIDER DIRECT COSTS ONLY?

	Yes		**No**

CONSIDER INDIRECT COSTS AS WELL?

	Yes		**No**

RETURN ADDRESS FOR QUESTIONNAIRE SUBMISSION

Thank you for taking the time to complete this questionnaire.

Should you have any queries or would like to submit your completed questionnaire contact me 0737154987.

Yours Sincerely,

[redacted] [redacted]

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References:

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Appendix B: Municipal technical survey questionnaire (MTSQ)

In association with:

SINGAKWENZA NDAWONYE
ENGINEERING SERVICES

ASBESTOS CEMENT (AC) PIPE REPLACEMENT PROJECT

"TRENCHLESS VERSUS OPEN TRENCHING"

MUNICIPAL TECHNICAL SURVEY QUESTIONNAIRE (MTSQ)

CONFIDENTIAL

Please complete and return to:-

Attention	:	Mr. Shanley Hay
Facsimile	:	033 845 8941
E-mail	:	hays@dut.ac.za

1. YOUR ORGANIZATION:

	Municipality		**Engineer**
	Contractor		**Contractor**
	Other (Please Specify):		

2. CITY:

Please state the city/town in which your organisation is situated?

3. MUNICIPALITY SIZE

a) What is the population of the municipality/city/region that you are responsible for?

	Under 50 000		**250 000 to 499 000**
	50 000 to 99 000		**500 000 to 999 000**
	100 000 to 149 000		**Over 1 000 000**
	150 000 to 249 000		

4. **FAMILIARITY WITH "OPEN TRENCHING" FOR PIPELINE REHABILITATION**

(Scale: 1 – not familiar, 5 – very familiar)

a) How familiar are you with the term 'open trenching' for the rehabilitation of ageing deteriorating potable water pipelines?

	1		**2**		**3**		**4**		**5**

Open trenching refers to the laying of a new water pipe by excavating with a TLB or by hand

5. **FAMILIARITY WITH "TRENCHLESS TECHNOLOGY" FOR PIPELINE REHABILITATION**

(Scale: 1 – not familiar, 5 – very familiar)

a) How familiar are you with the term 'trenchless' for the rehabilitation of ageing deteriorating potable water pipelines?

	1		**2**		**3**		**4**		**5**

It is an alternative approach to open trenching for replacing old pipes. This trenchless technological method adopts a non-intrusive limited open trenching approach which is environmentally friendly.

6. **PREFERENCE**

a) Would you prefer open trenching or trenchless technology for pipeline replacement/rehabilitation?

	Open trenching		**Trenchless technology**

7. **AVAILABILITY OF TRENCHLESS TECHNOLOGY RESOURCES**

a) To your knowledge, is the use of trenchless technological services readily available within your municipal jurisdiction?

	Yes		**No**		**Maybe**

8. **KNOWLEDGE AND EXPERIENCE WITH TRENCHLESS TECHNOLOGY**

a) How would you rate your knowledge and experience with trenchless technologies?

	Excellent		**Marginal**
	Very good		**Unsatisfactory**
	Satisfactory		**Superficial**
	Ordinary		**None**

9. IF APPLICABLE, WHAT IS YOUR ORGANISATION'S ANNUAL UTILITY INFRASTRUCTURE BUDGET FOR:

New Construction (in South African Rands):

	under R500 000		R5mil. to under R10mil.
	R500 000 to under R1mil.		R10mil. to under R25mil.
	R1mil. to under R2.5mil.		Above R25mil.
	R2.5mil. to under R5mil.		

Rehabilitation (in South African Rands):

	under R500 000		R5mil. to under R10mil.
	R500 000 to under R1mil.		R10mil. to under R25mil.
	R1mil. to under R2.5mil.		Above R25mil.
	R2.5mil. to under R5mil.		

10. HAS YOUR COMPANY/ORGANIZATION EVER UTILISED TRENCHLESS TECHNOLOGIES FOR WATER AND SANITATION PIPELINE REPLACEMENT AND REHABILITATION?

	Yes		No

If yes, please indicate all relevant technologies:

	Pipe bursting		Auger bBoring
	Close-fit lining for mains		Close-fit lining for service connections
	Horizontal directional drilling		Microtunneling
	Pipe scanning & evaluation		Robotic spot repair
	Sliplining of pipe		Pipe jacking
	Other (Please specify):		

11. WHAT PERCENTAGES (APPROXIMATELY) OF ALL NEW PIPELINE AND UTILITY CONDUIT CONSTRUCTION EXECUTED BY YOUR COMPANY/ORGANIZATION EMPLOY TRADITIONAL OPEN TRENCHING METHODS FOR PIPELINE REHABILITATION

Five years ago:

	0-9 %		10-19%		20-29%		30-39%		40-50%		>50%

Today:

	0-9 %		10-19%		20-29%		30-39%		40-50%		>50%

Five years from now:

	0-9 %		10-19%		20-29%		30-39%		40-50%		>50%

12. WHAT PERCENTAGE OF ALL REPAIRS AND REHABILITATION TO PIPELINE AND UTILITY CONDUIT CONSTRUCTION EXECUTED BY YOUR COMPANY/ORGANIZATION EMPLOY TRENCHLESS TECHNOLOGIES?

Five years ago:

	0-9 %		10-19%		20-29%		30-39%		40-50%		>50%

Today:

	0-9 %		10-19%		20-29%		30-39%		40-50%		>50%

Five years from now:

	0-9 %		10-19%		20-29%		30-39%		40-50%		>50%

13. DURING THE YEAR 2005 to CURRENT, HOW MANY KILOMETRES OF PIPELINES WERE INSTALLED/ REHABILITATED USING OPEN TRENCHING?

Length of pipelines:

km	Open trenching

14. WITH REFERENCE TO THE QUESTION ABOVE, HOW MUCH IN SOUTH AFRICAN RANDS DID THE INSTALLATION/ REHABILITATION USING OPEN TRENCHING COST?

Cost (South African Rands):

	under R500 000		R5mil. to under R10mil.
	R500 000 to under R1mil.		R10mil. to under R25mil.
	R1mil. to under R2.5mil.		Above R25mil.
	R2.5mil. to under R5mil.		

15. DURING THE YEAR 2005 to CURRENT, HOW MANY KILOMETRES OF PIPE WERE INSTALLED/REHABILITATED USING THE FOLLOWING TRENCHLESS TECHNOLOGIES (IF NOT APPLICABLE, PLEASE MENTION):

Trenchless technology length of pipe (in km's):

	Pipe bursting		Auger boring
	Close-fit lining for mains		Clos-fit lining for service connections
	Horizontal directional drilling		Microtunneling
	Pipe scanning & evaluation		Robotic spot repair
	Sliplining of pipe		Pipe jacking
	Other (Please specify):		

16. WITH REFERENCE TO THE QUESTION ABOVE, HOW MUCH IN SOUTH AFRICAN RANDS DID THE INSTALLATION/REHABILITATION USING TRENCHLESS TECHNOLOGIES COST?

Cost (South African Rands):

	under R500 000		R5mil. to under R10mil.
	R500 000 to under R1mil.		R10mil. to under R25mil.
	R1mil. to under R2.5mil.		Above R25mil.
	R2.5mil. to under R5mil.		

17. **ARE YOU FAMILIAR WITH THE TERMS "DIRECT COSTS" AND "INDIRECT COSTS"?**

	Yes		**No**

Direct Costs paid by the client:-

- Contractor costs;
- Bidding costs; and
- Project management costs.

Indirect costs paid by the client:-

- Compensation costs for claims submitted by the customer/consumer of the water supply; and
- Compensation claims for contingent damage to property e.g. asphalt driveways.

Socio-economic costs borne by the society:-

- Quantifiable:-
  - Traffic delay
  - Business disruption;
  - Early replacement of road infrastructure;
  - Accidental costs; and
  - Pollution.
- Non-Quantifiable:-
  - Environmental impact;
  - Quality of life; and
  - Dust control.

18. **WITH REFERENCE TO THE ABOVE COULD YOU LIST IN IMPORTANCE TO YOU THESE ITEMS:-**

(Scale: 1 – least important, 5 – most important)

	Direct costs		**Quantifiable socio-economic costs**
	Indirect costs		**Non-quantifiable socio-economic costs**

19. **COULD YOU ALSO LIST THEM ACCORDING TO WHAT YOU THINK THE END CONSUMER WOULD FIND MORE IMPORTANT?**

(Scale: 1 – least important, 5 – most important)

	Direct costs		**Quantifiable socio-economic costs**
	Indirect costs		**Non-quantifiable socio-economic costs**

20. **DO YOU THINK THAT HINDRANCE EXPOSURE IS IMPORTANT TO THE CONSUMER?**

	Yes		No

21. **HOW MANY COMPLAINTS (PER KILOMETRE OF PIPING) ARE RECEIVED BY CONSUMERS DURING THE PIPELINE REHABILITATION PROCESS?**

	under 50		300 under 400
	50 to under 100		400 to under 500
	100 to under 200		Above 500
	200 to under 300		

22. **WHERE DO YOU FORESEE THE MOST FUTURE GROWTH IN TRENCHLESS TECHNOLOGIES FOR MUNICIPAL/GENERAL APPLICATIONS?**

(Please rank each category in a scale from 1 – least promising, 10 - most promising)

	Pipe bursting		Auger Boring
	Close-fit lining for mains		Close-fit lining for service connections
	Horizontal directional drilling		Microtunneling
	Pipe scanning & evaluation		Robotic spot repair
	Sliplining of pipe		Pipe jacking
	Other (Please specify):		

23. **TO SUMMARISE, DO YOU FORESEE TRENCHLESS TECHNOLOGY TO BE THE BIGGER ROLE PLAYER THAN OPEN TRENCHING FOR PIPELINE REHABILITATION IN THE FUTURE?**

	Yes		No

24. WHICH OF THE FOLLOWING IS MORE IMPORTANT TO YOU?

	Cost	or		Creating work
	Speed of service delivery	or		Creating work
	Speed of service delivery	or		Cost

25. WHICH OF THE FOLLOWING DO YOU THINK IS MORE IMPORTANT TO THE CUSTOMER?

	Cost	or		Creating work
	Speed of service delivery	or		Creating work
	Speed of service delivery	or		Cost

26. WOULD YOU MIND PAYING A PREMIUM FOR TRENCHLESS TECHNOLOGY?

	Yes		No

27. HOW MUCH WOULD YOU PAY?

	10%		30%		50%		100%

28. SHOULD THE MUNICIPALITY CONSIDER 'DIRECT COSTS" ONLY?

	Yes		No

29. CONSIDER 'INDIRECT COSTS" AS WELL?

	Yes		No

30. DO YOU THINK THAT THE CUSTOMER WANTS THE FOLLOWING?

	Yes	**No**		**To pay a premium**
	Yes	**No**		**Consider direct costs**
	Yes	**No**		**Consider Indirect costs**

31. COULD YOU PLEASE REFER US TO THREE (3) PEOPLE IN OTHER MUNICIPALITIES OF THE SAME POSITION AS YOURSELF?

RETURN ADDRESS FOR QUESTIONNAIRE SUBMISSION

Thank you for taking the time to complete this questionnaire, for your valuable input and support with my thesis write-up.

Should you have any queries or would like to submit your completed questionnaire contact me on any of the details listed below.

Regards,

Shanley Hay

E-mail	:	hays@dut.ac.za	Cellular	:	073 715 4987
Landline	:	033 845 8960	Facsimile	:	033 845 8941

References:

Ariaratnam, S.T. Lueke, J.S., Allouche, E.N., 1999. *Utilization of trenchless construction methods by Canadian municipalities. Journal of Construction Engineering and Management* 125 (2), 76–86'

Ariaratnam, S.T. 2009. *Trenchless Technology Research. Survey questionnaire results of the current level of knowledge on trenchless technologies in China*, 808-810.

Zaneldin, E.K. 2006. *Trenchless construction: An emerging technology in United Arab Emirates*, 102-103.

Appendix C: MTSQ study areas

Table 28 Metropolitan municipalities

Name	Province
Buffalo City Metropolitan Municipality	Eastern Cape
City of Cape Town Metropolitan Municipality	Western Cape
City of Johannesburg Metropolitan Municipality	Gauteng
City of Tshwane Metropolitan Municipality	Gauteng
Ekurhuleni Metropolitan Municipality	Gauteng
eThekwini Metropolitan Municipality	KwaZulu-Natal
Mangaung Metropolitan Municipality	Free State
Nelson Mandela Bay Metropolitan Municipality	Eastern Cape

Table 29 presents the forty four (44) district municipalities that were invited to participate in the MTSQ.

Table 29 District municipalities

Name	Province
Alfred Nzo District Municipality	Eastern Cape
Amajuba District Municipality	KwaZulu-Natal
Amathole District Municipality	Eastern Cape
Bojanala Platinum District Municipality	North West
Cacadu District Municipality	Eastern Cape
Cape Winelands District Municipality	Western Cape
Capricorn District Municipality	Limpopo
Central Karoo District Municipality	Western Cape
Chris Hani District Municipality	Eastern Cape
Dr Kenneth Kaunda District Municipality	North West
Dr Ruth Segomotsi Mompati District Municipality	North West
Eden District Municipality	Western Cape
Central Karoo District Municipality	Western Cape
Ehlanzeni District Municipality	Mpumalanga
Fezile Dabi District Municipality	Free State
Frances Baard District Municipality	Northern Cape
Gert Sibande District Municipality	Mpumalanga

Table 29 District municipalities (continued…)

Name	Province
Joe Gqabi District Municipality	Eastern Cape
John Taolo Gaetsewe District Municipality	Northern Cape
Lejweleputswa District Municipality	Free State
Mopani District Municipality	Limpopo
Namakwa District Municipality	Northern Cape
Ngaka Modiri Molema District Municipality	North West
Nkangala District Municipality	Mpumalanga
OR Tambo District Municipality	Eastern Cape
Overberg District Municipality	Western Cape
Pixley ka Seme District Municipality	Northern Cape
Sedibeng District Municipality	Gauteng
Sekhukhune District Municipality	Limpopo
Sisonke District Municipality	KwaZulu-Natal
Siyanda District Municipality	Northern Cape
Thabo Mofutsanyana District Municipality	Free State
Ugu District Municipality	KwaZulu-Natal
uMgungundlovu District Municipality	KwaZulu-Natal
uMkhanyakude District Municipality	KwaZulu-Natal
uMzinyathi District Municipality	KwaZulu-Natal

Table 29 District municipalities (continued…)

Name	Province
uThukela District Municipality	KwaZulu-Natal
uThungulu District Municipality	KwaZulu-Natal
Vhembe District Municipality	Limpopo
Waterberg District Municipality	Limpopo
West Coast District Municipality	Western Cape
West Rand District Municipality	Gauteng
Xhariep District Municipality	Free State
Zululand District Municipality	KwaZulu-Natal

Appendix D: SESQ and MTSQ covering letter

ETHEKWINI MUNICIPALITY

In association with:

SINGAKWENZA NDAWONYE
ENGINEERING SERVICES
P.O. Box 13006 Cascades 3202 Tel: 082 5911 400 Fax: 0880 333 475 005

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01 November 2011

To: The Resident/ Business Owner/ Municipal Representative

Dear Sir/Madam

ASBESTOS CEMENT (AC) PIPE REPLACEMENT PROJECT: "TRENCHLESS VERSUS OPEN TRENCHING": QUESTIONNAIRE

I, **Shanley Hay** am undertaking a Masters Degree at the Durban University of Technology (DUT) at which I am also employed as a lecturer.

The topic of my thesis can be summarised as: "**Open Trenching versus Trenchless Technology for Water Pipeline Rehabilitation**"

Open trenching: Hand-dig or machine dig of ground, roads, drive-ways etc and laying a new pipe.

Trenchless: Laying a new pipe with advanced machines with little to no digging of the ground, roads, drive-ways etc.

There has been a water pipe replacement project in your area in the last 18 months to provide better water delivery service by the eThekwini Municipality for the years to come.

Please would you take ten (10) minutes of your time to complete a questionnaire (that I developed) which one of my field assistants (Singakwenza Ndawonye staff or student with identification badge) will gladly assist you with regarding the abovementioned project in your area?

Your completion of the questionnaire will help to achieve the following:-

- Assist me in completing part of my thesis;
- Assist the eThekwini Municipality in compiling a Feasibility Study which will detail your (the customers) feelings and concerns when undertaking a project of a similar nature in the future.

Should you have any queries please do not hesitate to contact me on 073 715 4987 or any of the other contacts listed.

Yours Sincerely,

[redacted]

[redacted]

Shanley Hay
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DUT Lecturer
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Alan Kee
eThekwini Municipality
Water and Sanitation Unit
Project Executive
031 311 8557 (L)
031 311 8747 (F)
alanke@dmws.durban.gov.za

Makhosi Maphumulo
Executive Secretary to Alan Kee
031 311 8557 (L)
031 311 8747 (F)
082 547 0439 (C)
makhosma@dmws.durban.gov.za

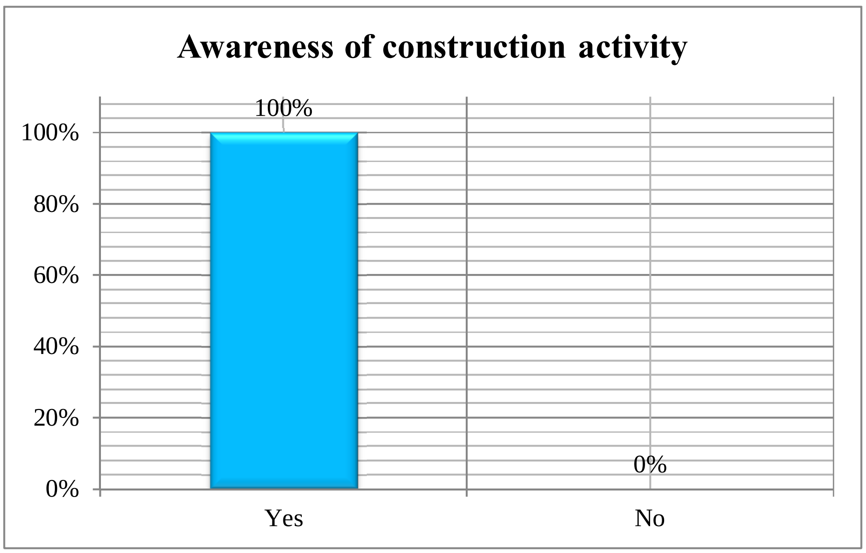
Jeroen Bosboom
Your Man on Site (working on eThekwini AC Project)
082 733 4550 (C)
jeroen@yourmanonsite.com

Appendix E: SESQ – Results of analyses

1. There has been a water pipe replacement project in your area in the last 18 months to provide better water delivery service for the years to come.

WERE YOU AWARE OF THIS CONSTRUCTION ACTIVITY?

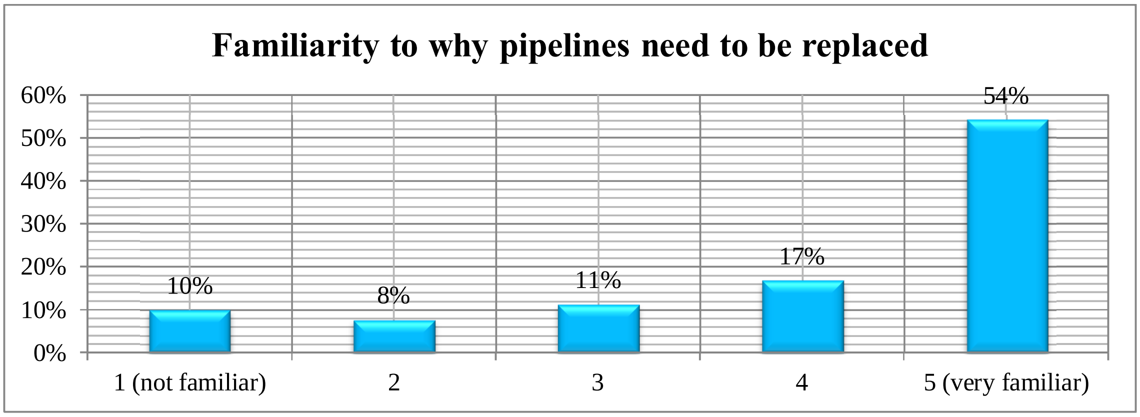
Percentage	Number	Category
100%	380	Yes
0%	0	No
100%	**380**	**Total**



2. **ARE YOU FAMILIAR WITH WHY WATER PIPES NEED TO BE REPLACED OVER TIME?**

(**Scale: 1 – not familiar, 5 – very familiar**)

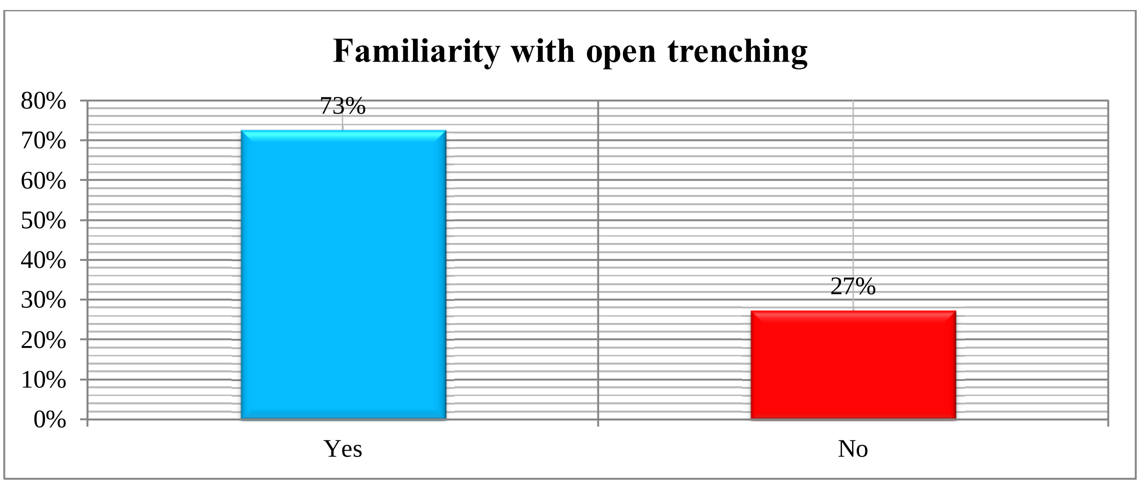
Percentage	Number	Category
10%	38	1 (not familiar)
8%	29	2
11%	43	3
17%	64	4
54%	206	5 (very familiar)
100%	**380**	**Total**



3. ARE YOU FAMILIAR WITH THE TERM 'OPEN TRENCHING'?

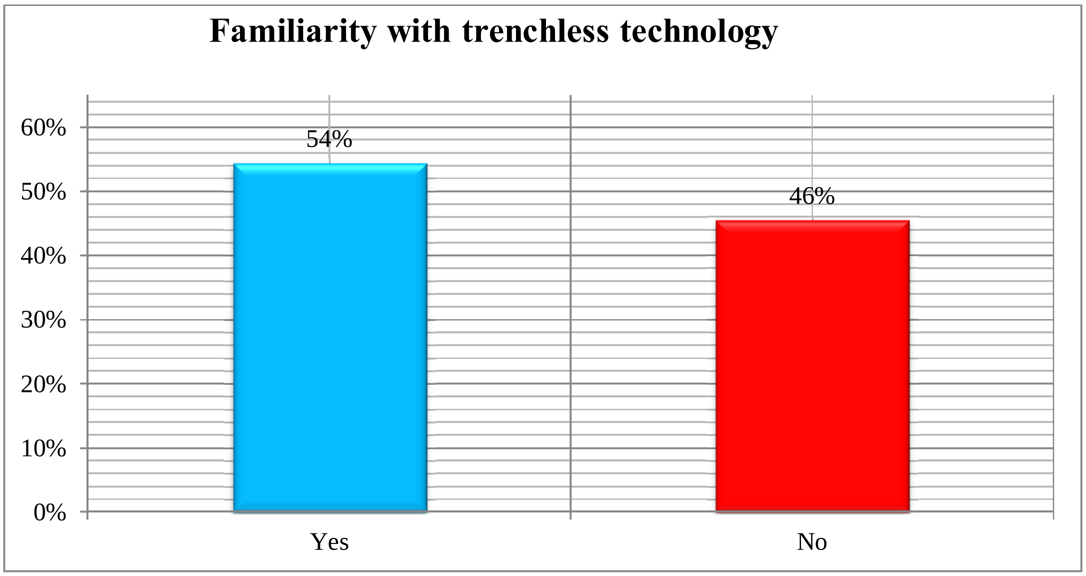
Open trenching refers to the laying of a new water pipe by excavating with a TLB or by hand.

Percentage	Number	Category
73%	276	Yes
27%	104	No
100%	**380**	**Total**



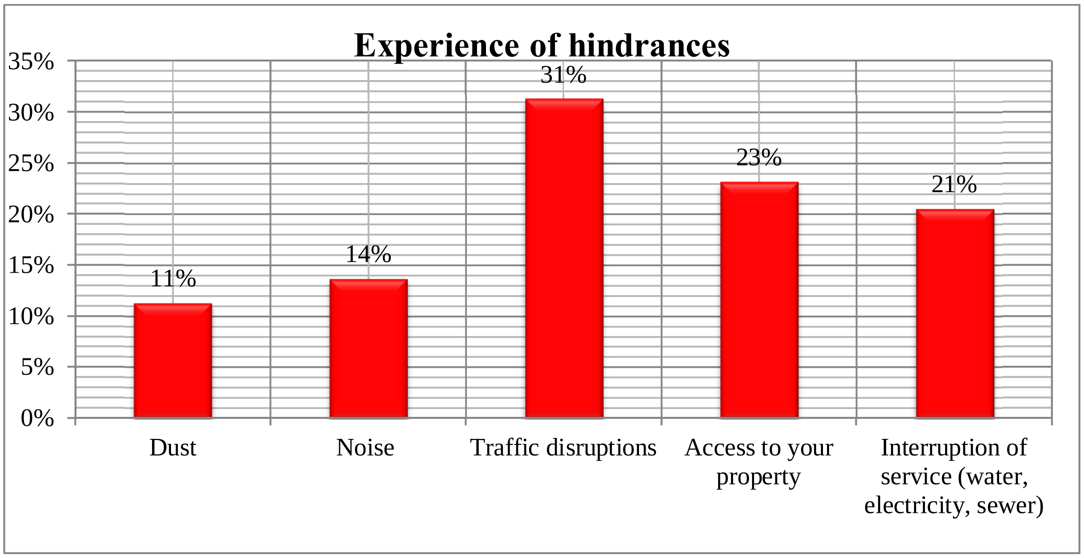
4. ARE YOU FAMILIAR WITH THE TERM 'TRENCHLESS TECHNOLOGY'?

Percentage	Number	Category
54%	207	Yes
46%	173	No
100%	**380**	**Total**



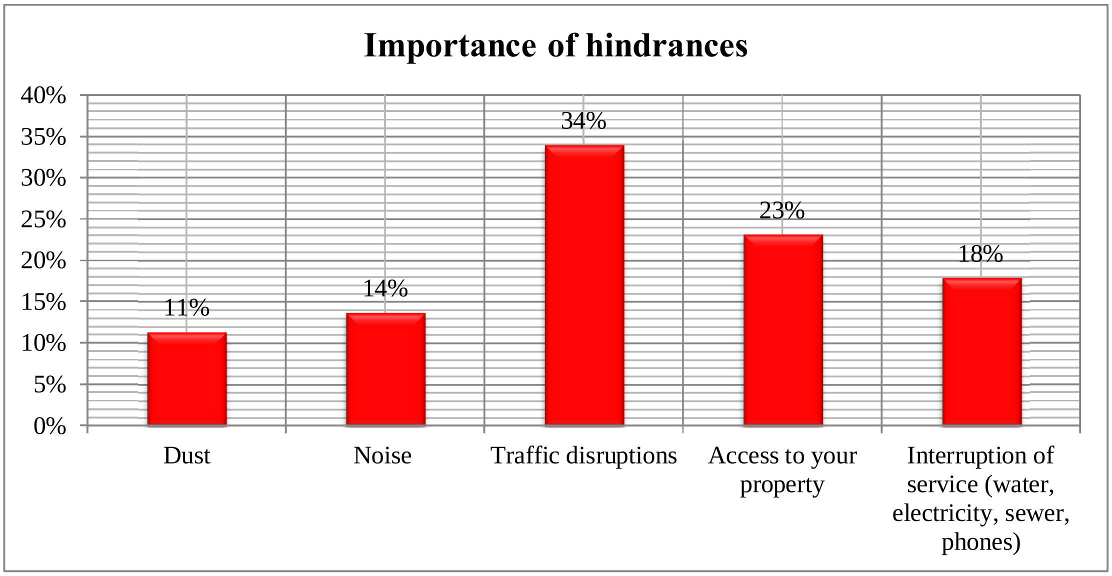
5. BASED ON THE PIPE REPLACEMENT PROJECT IN YOUR AREA, DID YOU EXPERIENCE ANY OF THE FOLLOWING HINDRANCES:

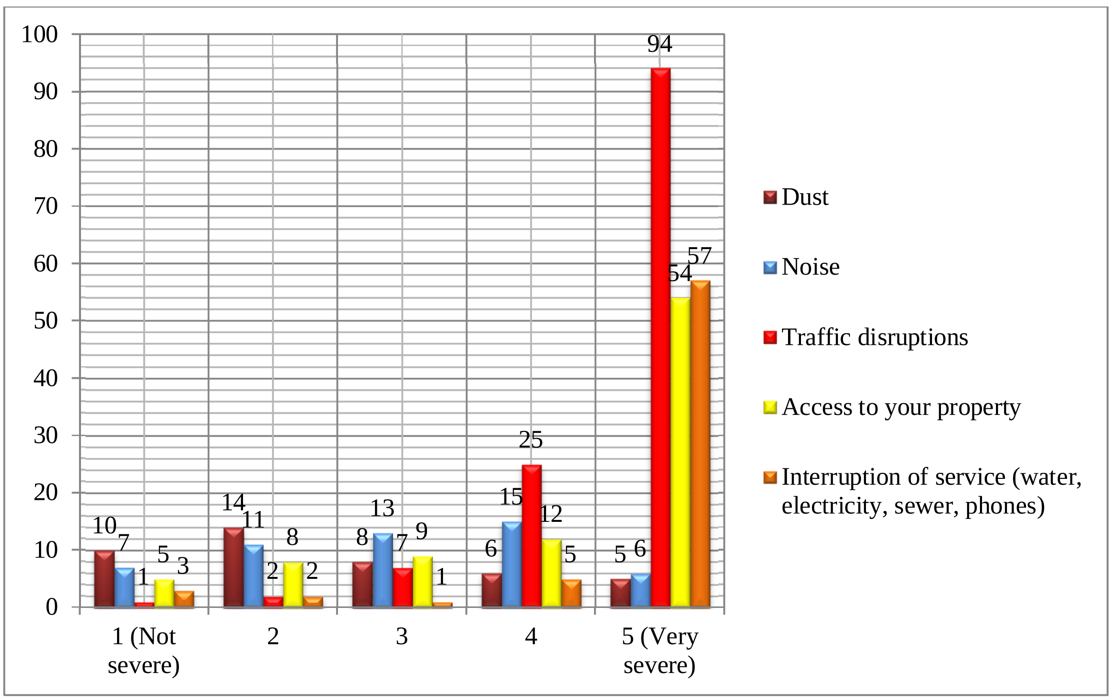
Percentage	Number	Category
11%	43	Dust
14%	52	Noise
31%	119	Traffic disruptions
23%	88	Access to your property
21%	78	Interruption of service (water, electricity, sewer)
100%	**380**	**Total**



6. **ON A SCALE OF 1 TO 5 (SCALE: 1 – NOT SEVERE, 5 – VERY SEVERE) WHICH OF THE FOLLOWING HINDRANCES ARE MOST IMPORTANT?**

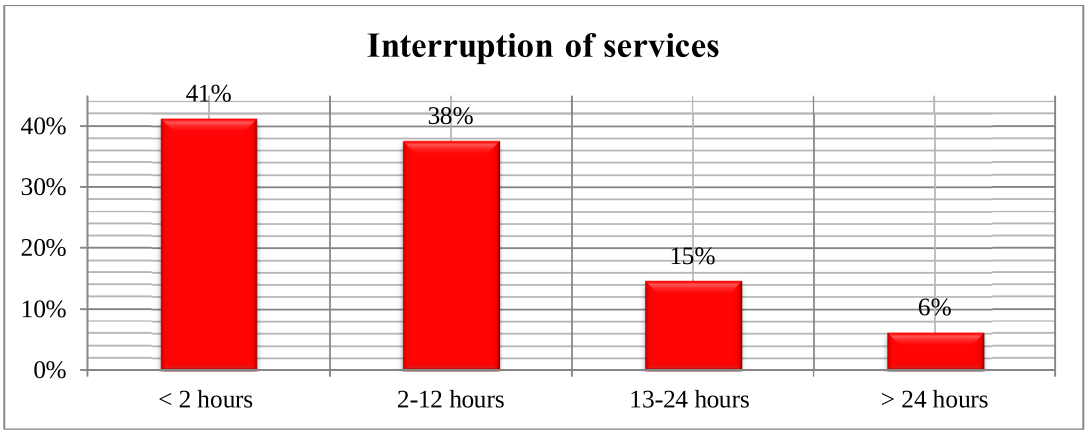
1 (Not severe)	2	3	4	5 (Very severe)	Total	%	Category
10	14	8	6	5	43	11%	Dust
7	11	13	15	6	52	14%	Noise
1	2	7	25	94	129	34%	Traffic disruptions
5	8	9	12	54	88	23%	Access to your property
3	2	1	5	57	68	18%	Interruption of service (water, electricity, sewer, phones)
26	**39**	**41**	**67**	**216**	**380**	**100%**	**Total**


Importance of hindrances
40%
35%
30%
25%
20%
15%
10%
5%
0%
11%
14%
34%
23%
18%
Dust
Noise
Traffic disruptions
Access to your property
Interruption of service (water, electricity, sewer, phones)


100
90
80
70
60
50
40
30
20
10
0
10
7
1
5
3
14
11
2
8
2
8
13
7
9
1
6
15
25
12
5
5
6
94
54
57
1 (Not severe)
2
3
4
5 (Very severe)
Dust
Noise
Traffic disruptions
Access to your property
Interruption of service (water, electricity, sewer, phones)

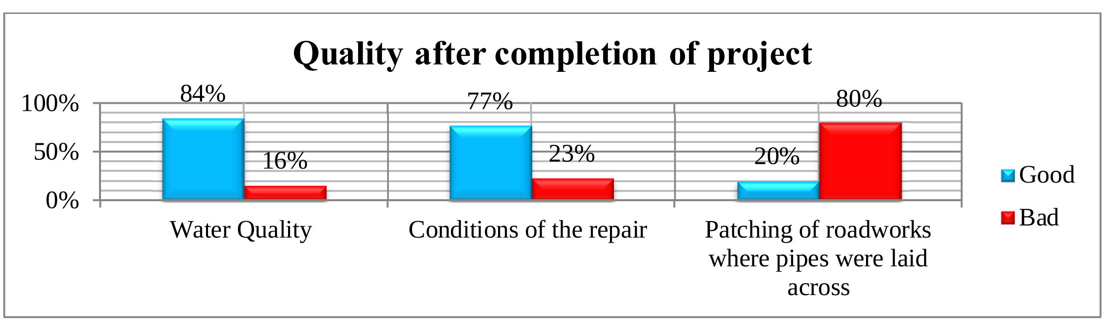
7. HOW LONG WAS THE INTERRUPTION OF SERVICE, IF ANY?

Percentage	Number	Category
41%	157	< 2 hours
38%	143	2-12 hours
15%	56	13-24 hours
6%	24	> 24 hours
100%	**380**	Total



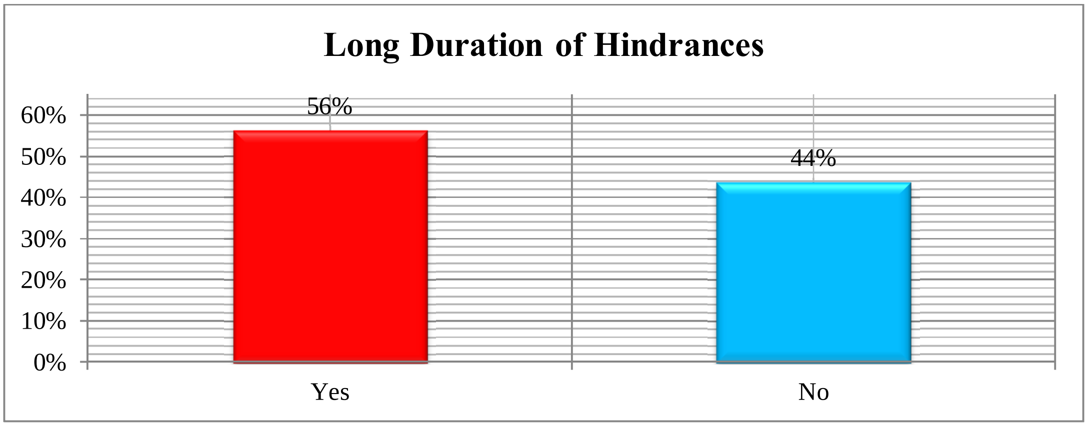
8. HOW WOULD YOU RATE THE QUALITY OF THE FOLLOWING AFTER THE PROJECT WAS COMPLETED?

Good	Bad	Good	Bad	Category
84%	16%	321	59	Water Quality
77%	23%	293	87	Conditions of the repair
20%	80%	77	303	Patching of roadworks where pipes were laid across



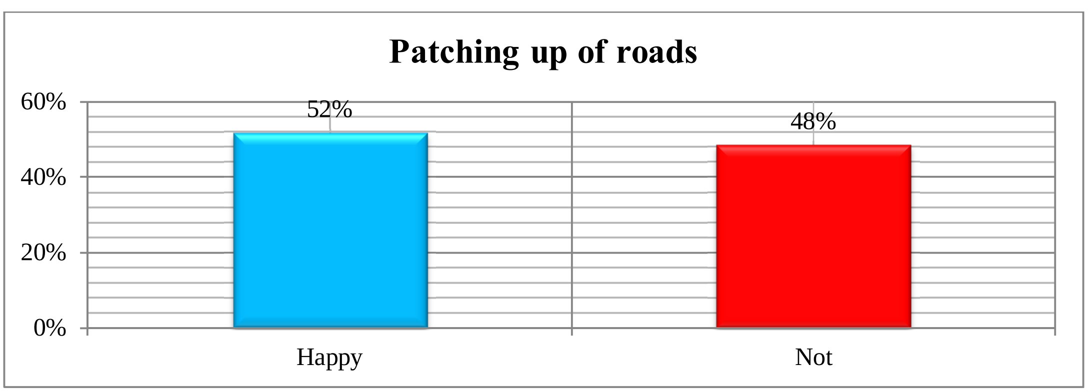
9. IN YOUR VIEW, DID THE HINDRANCES TAKE TOO LONG?

Percentage	Number	Category
56%	214	Yes
44%	166	No
100%	**380**	**Total**



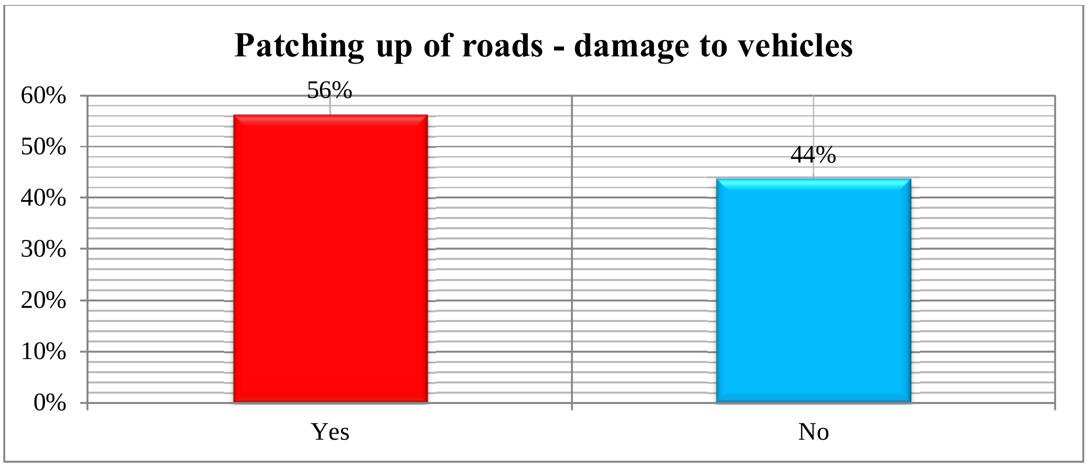
10. ARE YOU HAPPY OR NOT HAPPY WITH THE ROADS WHICH WERE PATCHED UP AND NEED TO BE PROPERLY REPAIRED AFTER THE LAYING OF THE NEW PIPE?

Percentage	Number	Category
52%	196	Happy
48%	184	Not
100%	**380**	**Total**



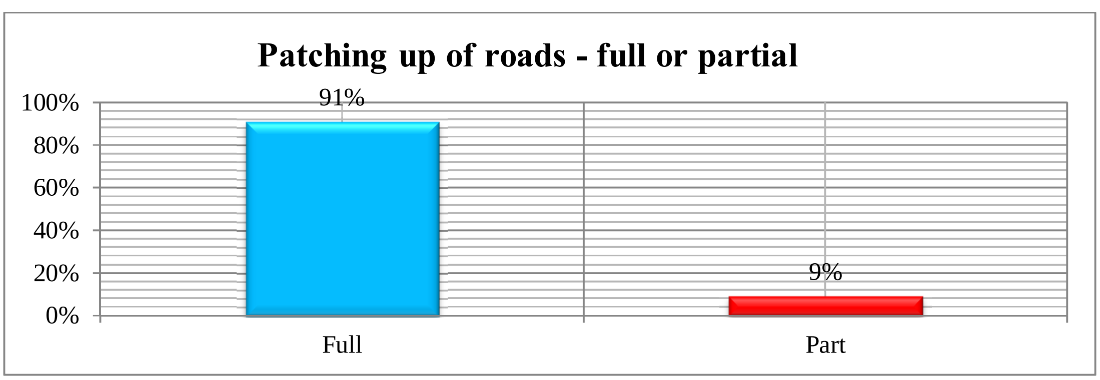
11. AS A RESULT OF THE PATCHING UP OF THE ROADS, IS IT CAUSING DAMAGE TO YOUR VEHICLE?

Percentage	Number	Category
56%	214	Yes
44%	166	No
100%	**380**	**Total**



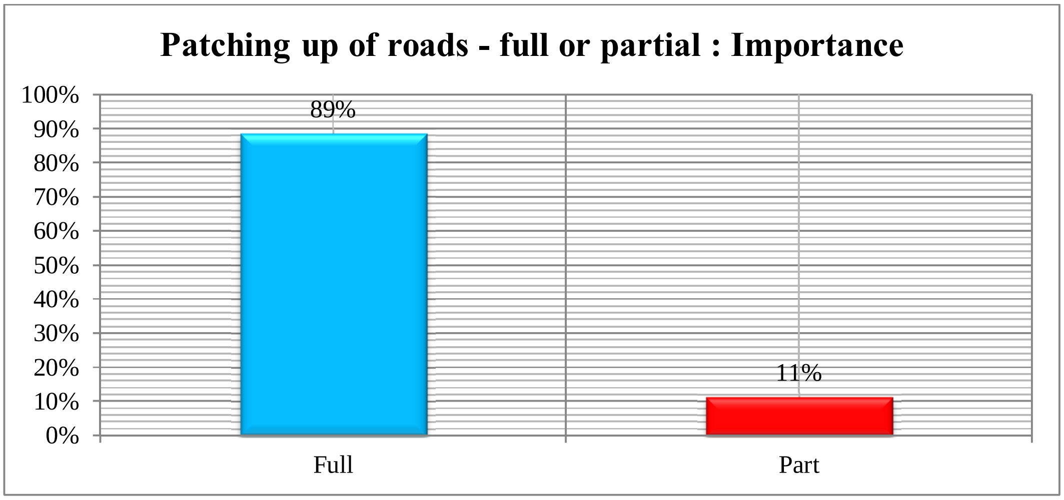
12. SHOULD THE FULL SECTION OF ROAD OR PART OF THE ROAD BE RESTORED?

Percentage	Number	Category
91%	346	Full
9%	34	Part
100%	**380**	**Total**



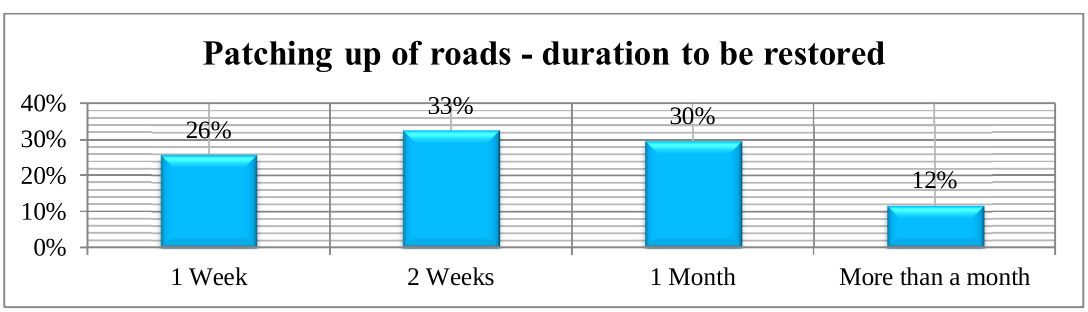
13. WHICH OF THE ABOVE (FULL ROAD OR PART) IS MORE IMPORTANT?

Percentage	Number	Category
89%	337	Full
11%	43	Part
100%	**380**	**Total**



14. HOW LONG DID IT TAKE FOR THE ROAD TO BE FULLY RESTORED

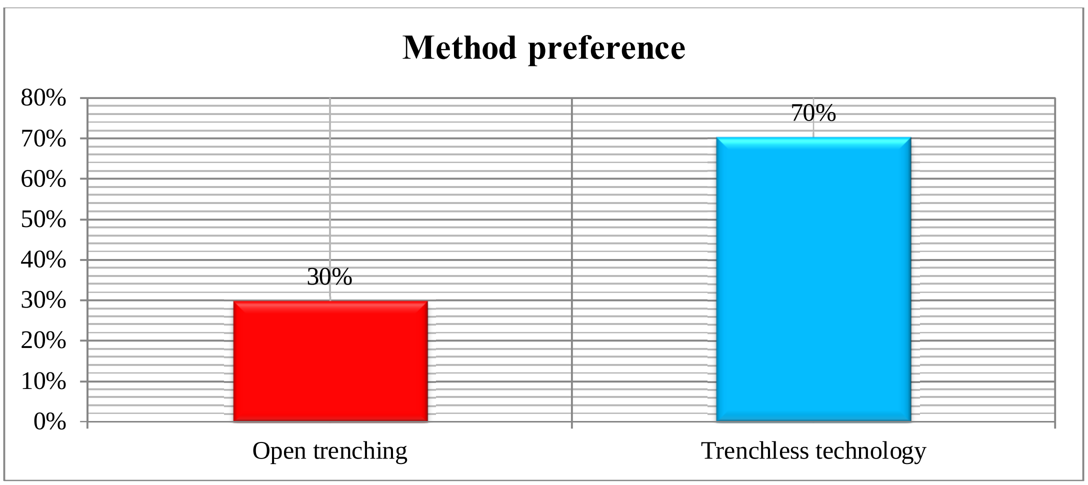
Percentage	Number	Category
26%	98	1 Week
33%	124	2 Weeks
30%	113	1 Month
12%	45	More than a month
100%	**380**	**Total**



15. Trenchless technology is in principle the faster method of replacing the water pipes and causes less damage and inconvenience as it uses more machines and is a precision job. Open trenching is more labour intensive and results generally in more damage to the surface, creates more inconvenience and takes longer.

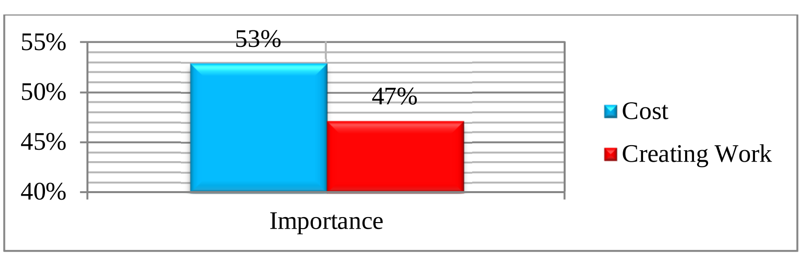
WHICH METHOD WOULD YOU PREFER?

Percentage	Number	Category
30%	113	Open trenching
70%	267	Trenchless technology
100%	**380**	**Total**

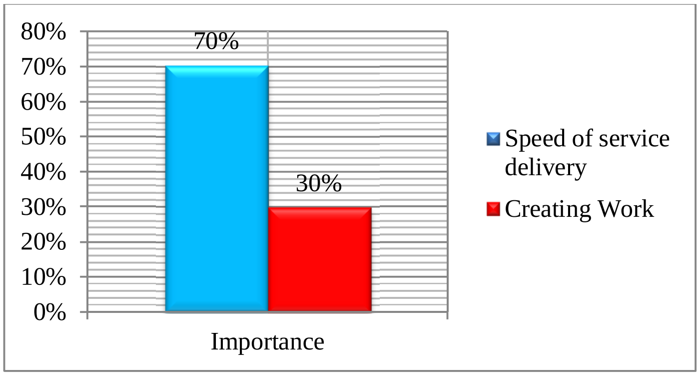


16. WHAT IS MORE IMPORTANT?

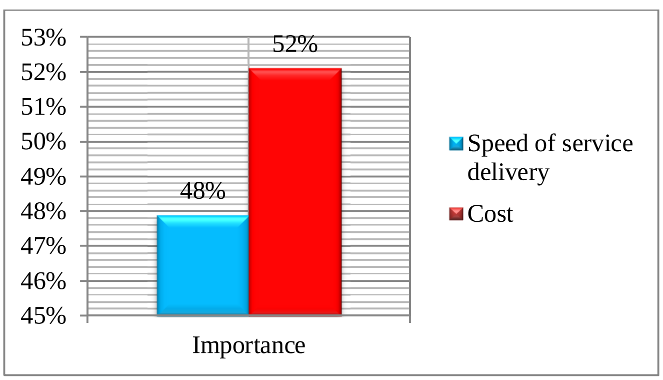
Percentage	Number	Category		Percentage	Number	Category
53%	201	Cost	or	47%	179	Creating Work



Percentage	Number	Category	or	Percentage	Number	Category
70%	267	Speed of service delivery		30%	113	Creating Work

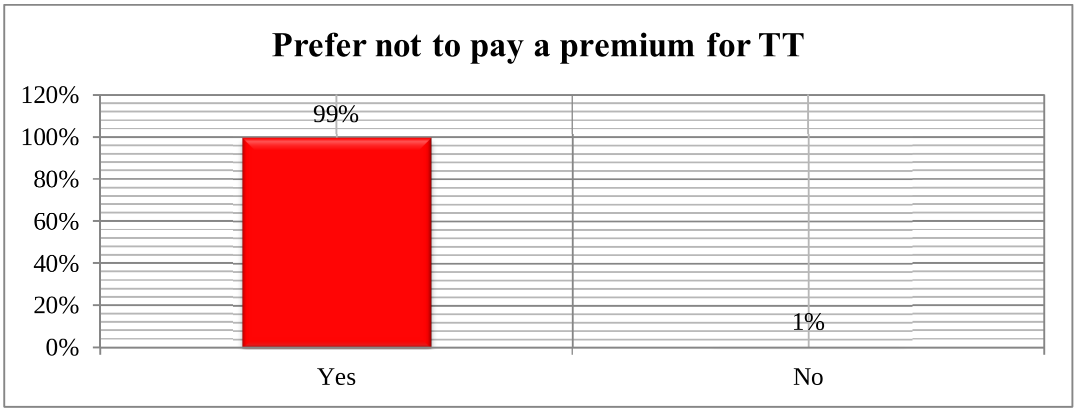


Percentage	Number	Category	or	Percentage	Number	Category
48%	182	Speed of service delivery		52%	198	Cost



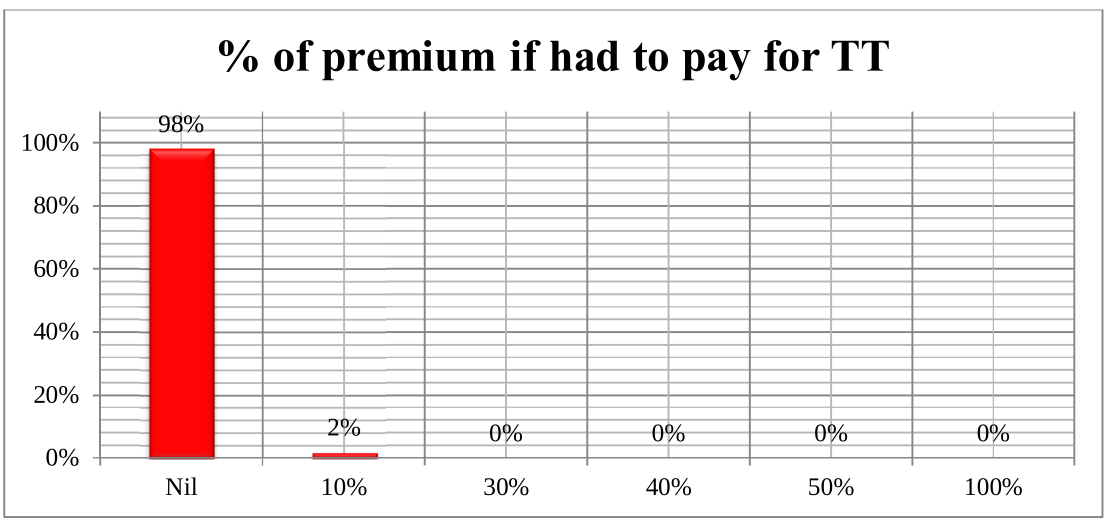
17. WOULD YOU MIND PAYING A PREMIUM FOR THE USE OF TRENCHLESS TECHNOLOGY RATHER THAN OPEN TRENCHING?

Percentage	Number	Category
99%	378	Yes
1%	2	No
100%	**380**	**Total**



18. HOW MUCH OF A PREMIUM WOULD YOU PAY?

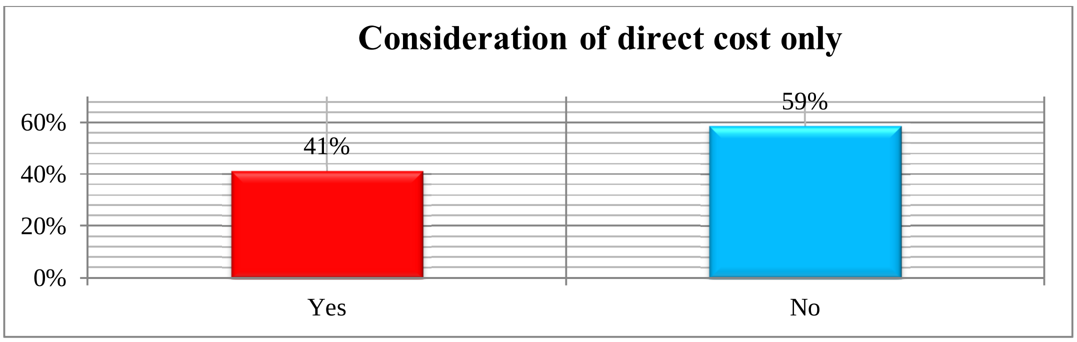
Percentage	Number	Category
98%	373	Nil
2%	7	10%
0%	0	30%
0%	0	40%
0%	0	50%
0%	0	100%
100%	**380**	**Total**



19. In principle, direct costs of rehabilitation are ±30%. 70% is more or less ñindirect costsò like road repairs after and inconvenience etc, which comes from a different budget (e.g. roads agency) or is directly endured by the customer (length of inconvenience).

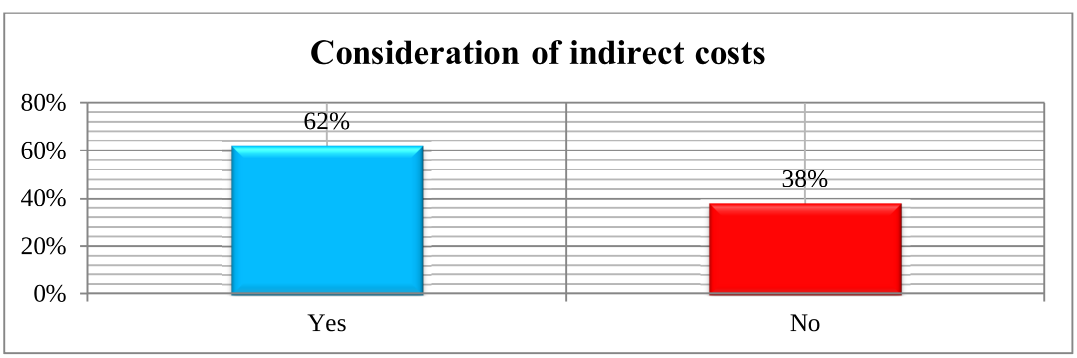
SHOULD THE MUNICIPALITY CONSIDER DIRECT COSTS ONLY?

Percentage	Number	Category
41%	157	Yes
59%	223	No
100%	**380**	**Total**



CONSIDER INDIRECT COSTS AS WELL?

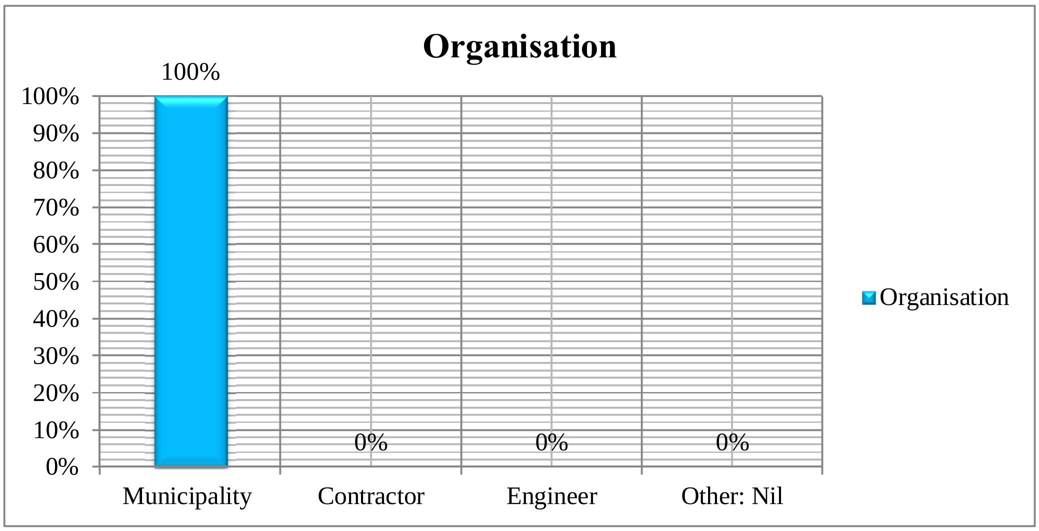
Percentage	Number	Category
62%	236	Yes
38%	144	No
100%	**380**	**Total**



Appendix F: MTSQ – Results of Analyses

1. YOUR ORGANIZATION:

Percentage	Number	Category
100%	32	Municipality
0%	0	Contractor
0%	0	Engineer
0%	0	Other: Nil
100%	**32**	**Total**



2. CITY:

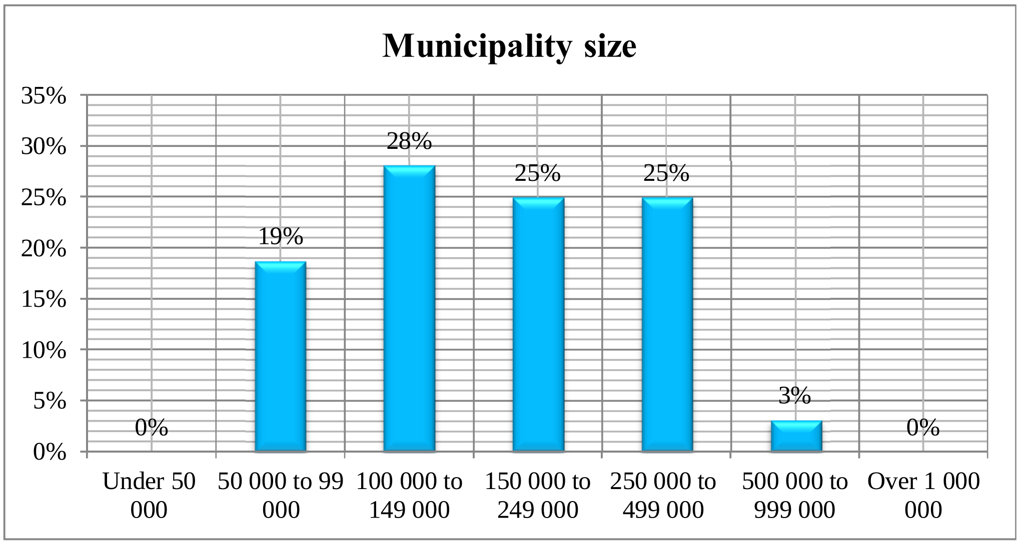
Please state the city/town in which your organisation is situated?

Names not specified - Confidential Information

3. MUNICIPALITY SIZE

a) What is the population of the municipality/city/region that you are responsible for?

Percentage	Number	Category
0%	0	Under 50 000
19%	6	50 000 to 99 000
28%	9	100 000 to 149 000
25%	8	150 000 to 249 000
25%	8	250 000 to 499 000
3%	1	500 000 to 999 000
0%	0	Over 1 000 000
100%	**32**	**Total**

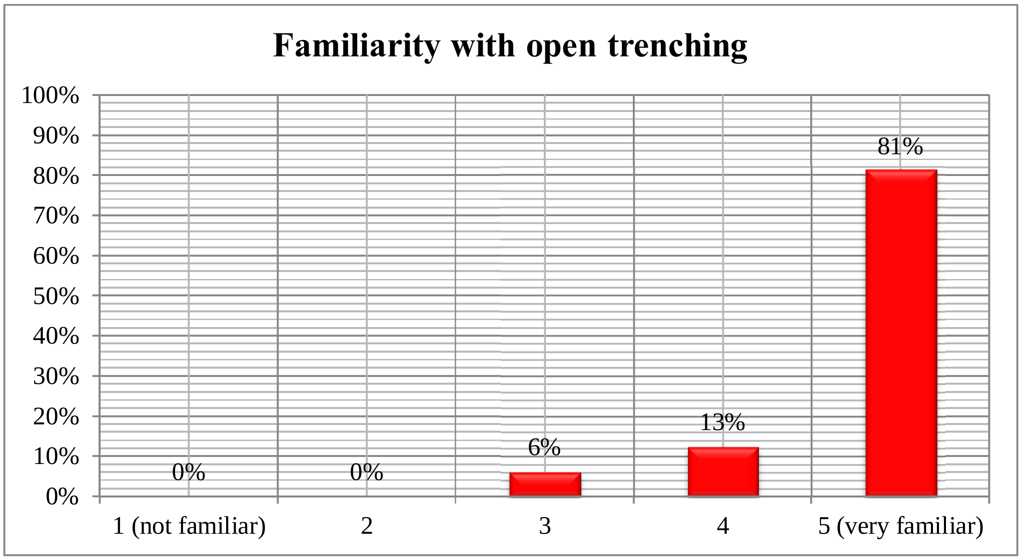


4. FAMILIARITY WITH "OPEN TRENCHING" FOR PIPELINE REHABILITATION

(**Scale: 1 – not familiar, 5 – very familiar**)

a) How familiar are you with the term ópen trenchingô for the rehabilitation of ageing deteriorating potable water pipelines?

Percentage	Number	Category
0%	0	1 (not familiar)
0%	0	2
6%	2	3
13%	4	4
81%	26	5 (very familiar)
100%	**32**	**Total**

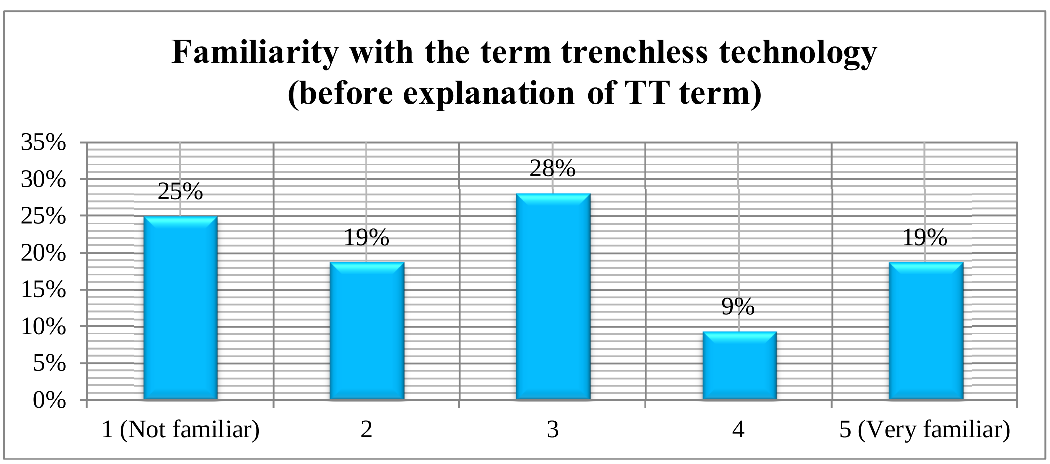


5. FAMILIARITY WITH "TRENCHLESS TECHNOLOGY" FOR PIPELINE REHABILITATION

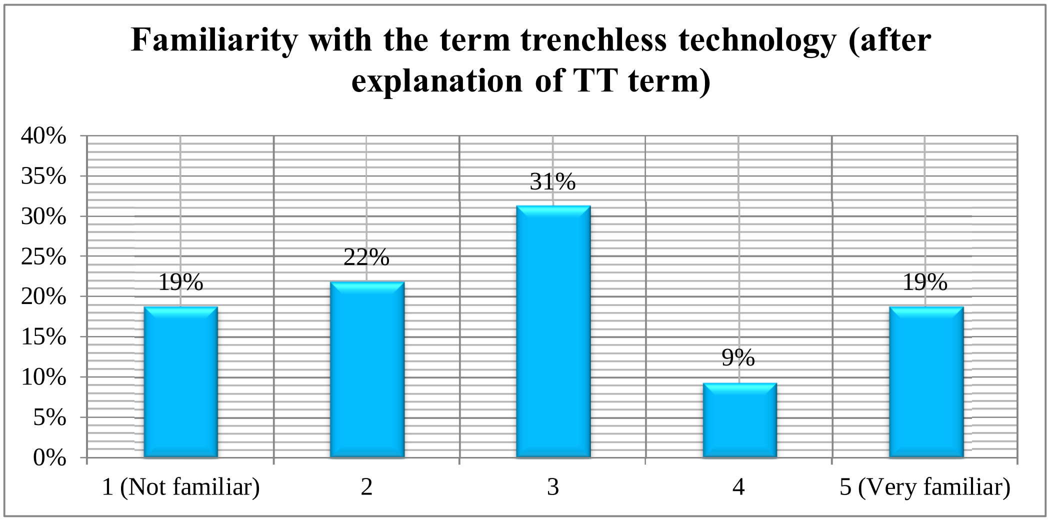
(Scale: 1 – not familiar, 5 – very familiar)

a) How familiar are you with the term ótrenchlessô for the rehabilitation of ageing deteriorating potable water pipelines?

1 (Not familiar)	2	3	4	5 (Very familiar)	Total	Category
8	6	9	3	6	32	Trenchless
25%	**19%**	**28%**	**9%**	**19%**	**100%**	**Total**



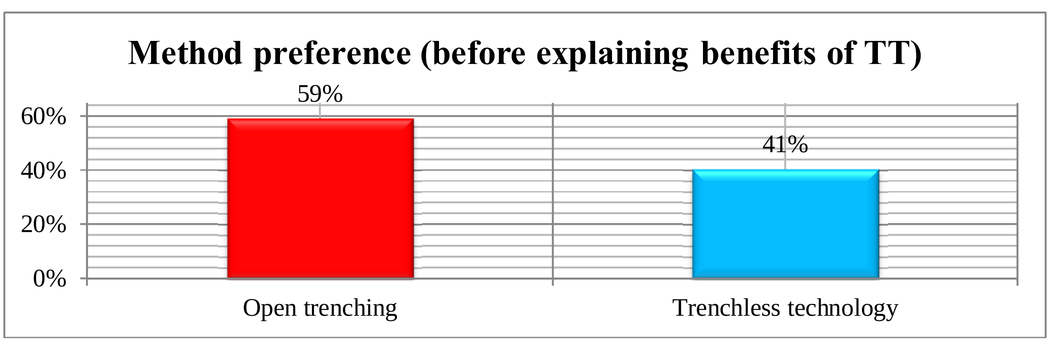
1 (Not familiar)	2	3	4	5 (Very familiar)	Total	Category
6	7	10	3	6	32	Trenchless
19%	**22%**	**31%**	**9%**	**19%**	**100%**	**Total**



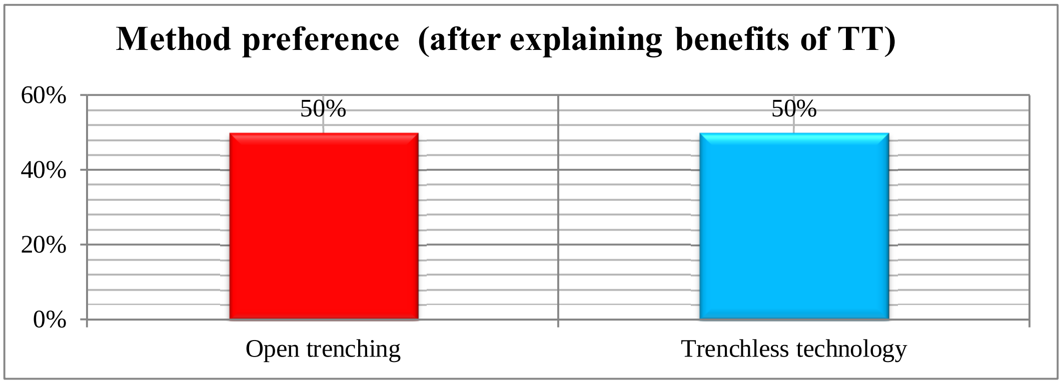
6. **PREFERENCE**

a) Would you prefer open trenching or trenchless technology for pipeline replacement/rehabilitation?

Percentage	Number	Category
59%	19	Open trenching
41%	13	Trenchless technology
100%	**32**	**Total**



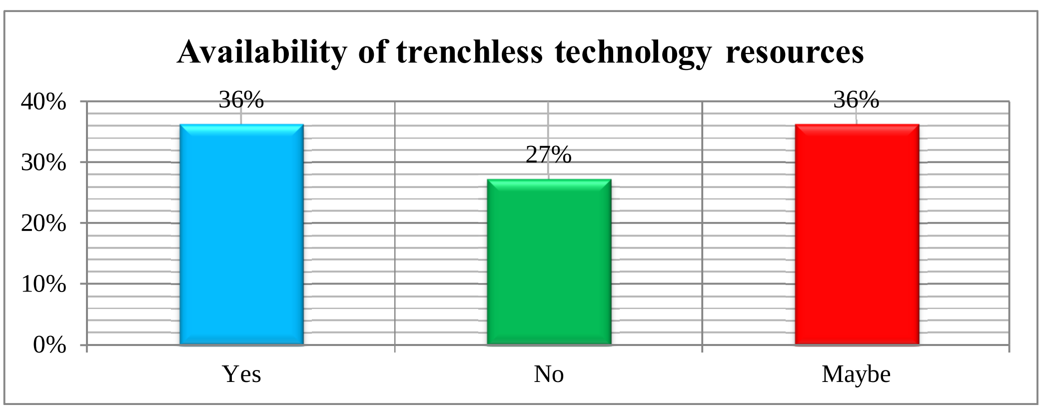
Percentage	Number	Category
50%	16	Open trenching
50%	16	Trenchless technology
100%	**32**	**Total**



7. **AVAILABILITY OF TRENCHLESS TECHNOLOGY RESOURCES**

a) To your knowledge, is the use of trenchless technological services readily available within your municipal jurisdiction?

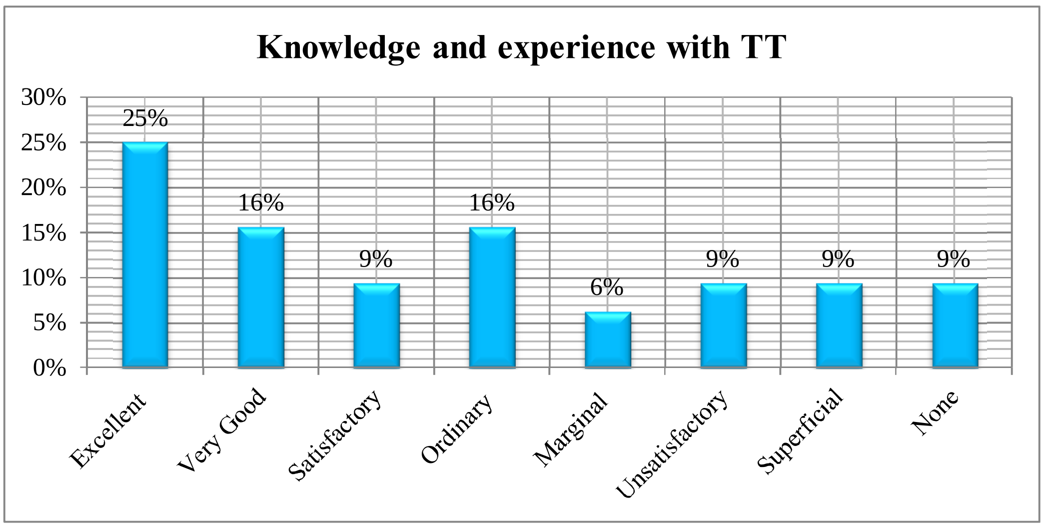
Percentage	Number	Category
36%	12	Yes
27%	9	No
36%	12	Maybe
100%	**33**	**Total**



8. KNOWLEDGE AND EXPERIENCE WITH TRENCHLESS TECHNOLOGY

a) How would you rate your knowledge and experience with trenchless technologies?

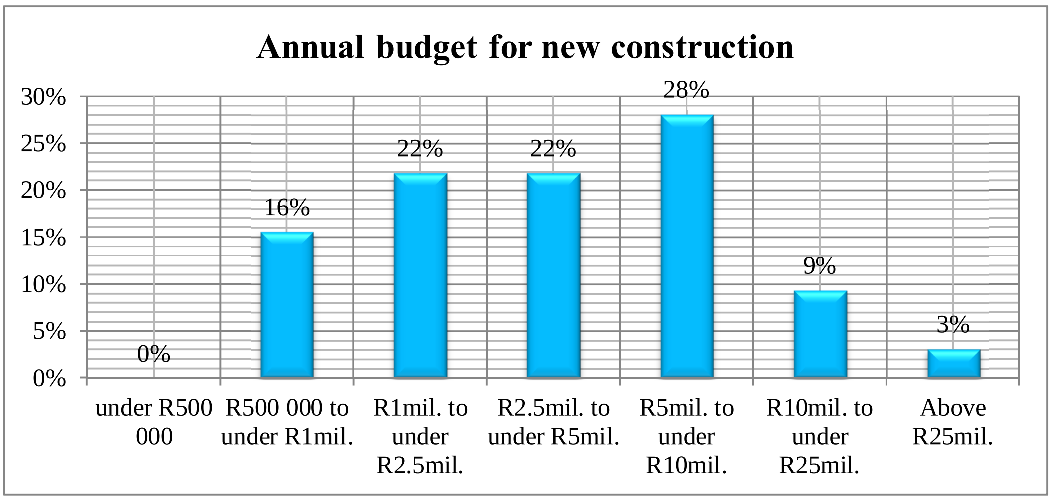
Percentage	Number	Category
25%	8	Excellent
16%	5	Very Good
9%	3	Satisfactory
16%	5	Ordinary
6%	2	Marginal
9%	3	Unsatisfactory
9%	3	Superficial
9%	3	None
100%	**32**	**Total**



9. IF APPLICABLE, WHAT IS YOUR ORGANISATION'S ANNUAL UTILITY INFRASTRUCTURE BUDGET FOR:

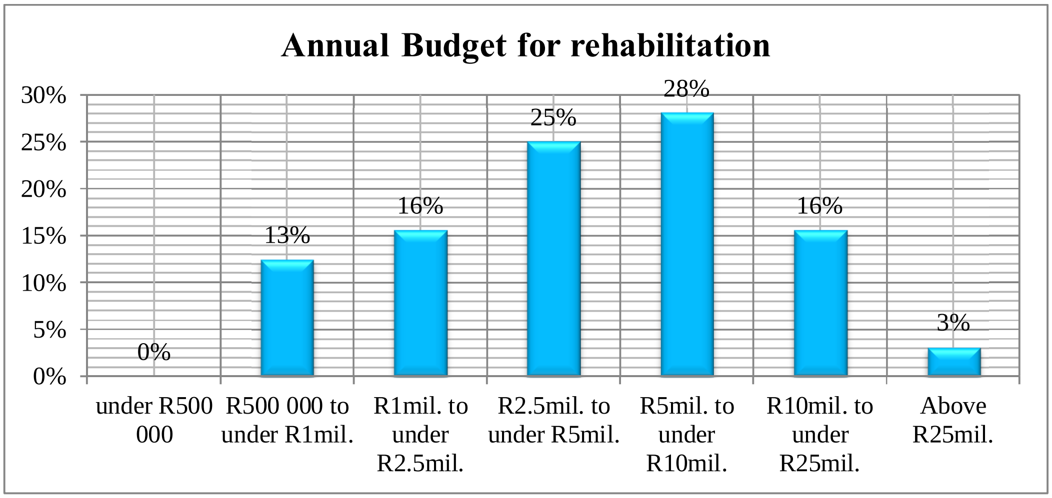
New Construction (in South African Rands):

Percentage	Number	Category
0%	0	under R500 000
16%	5	R500 000 to under R1mil.
22%	7	R1mil. to under R2.5mil.
22%	7	R2.5mil. to under R5mil.
28%	9	R5mil. to under R10mil.
9%	3	R10mil. to under R25mil.
3%	1	Above R25mil.
100%	**32**	**Total**



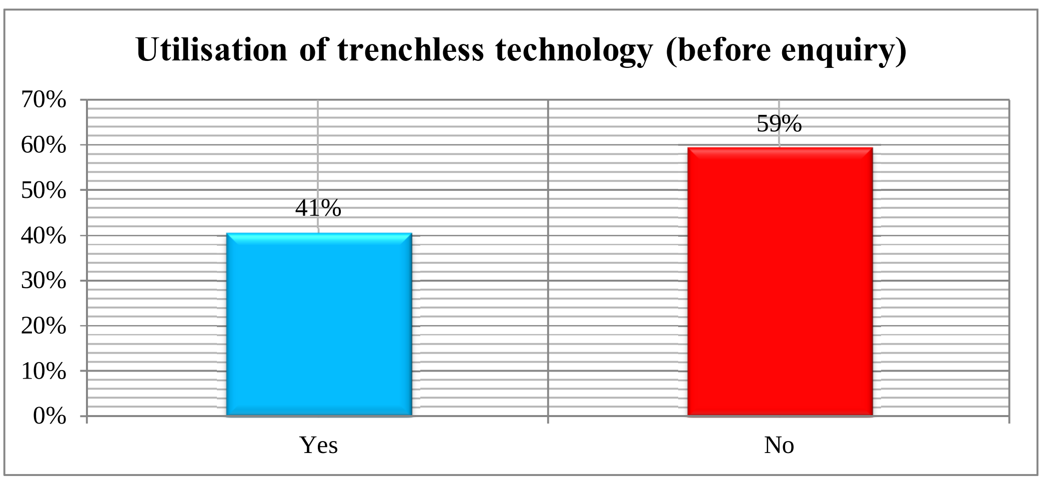
Rehabilitation (in South African Rands):

Percentage	Number	Category
0%	0	under R500 000
13%	4	R500 000 to under R1mil.
16%	5	R1mil. to under R2.5mil.
25%	8	R2.5mil. to under R5mil.
28%	9	R5mil. to under R10mil.
16%	5	R10mil. to under R25mil.
3%	1	Above R25mil.
100%	**32**	**Total**

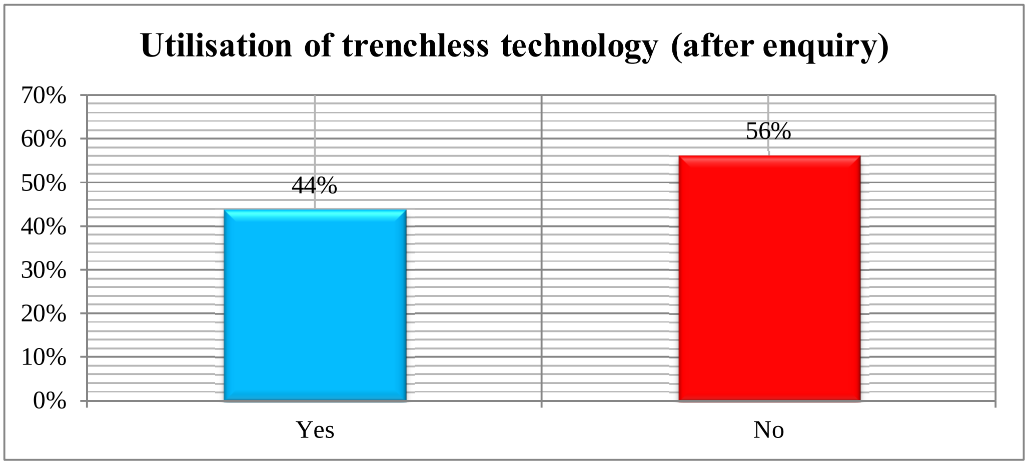


10. HAS YOUR COMPANY/ORGANIZATION EVER UTILISED TRENCHLESS TECHNOLOGIES FOR WATER AND SANITATION PIPELINE REPLACEMENT AND REHABILITATION?

Percentage	Number	Category
41%	13	Yes
59%	19	No
100%	**32**	**Total**

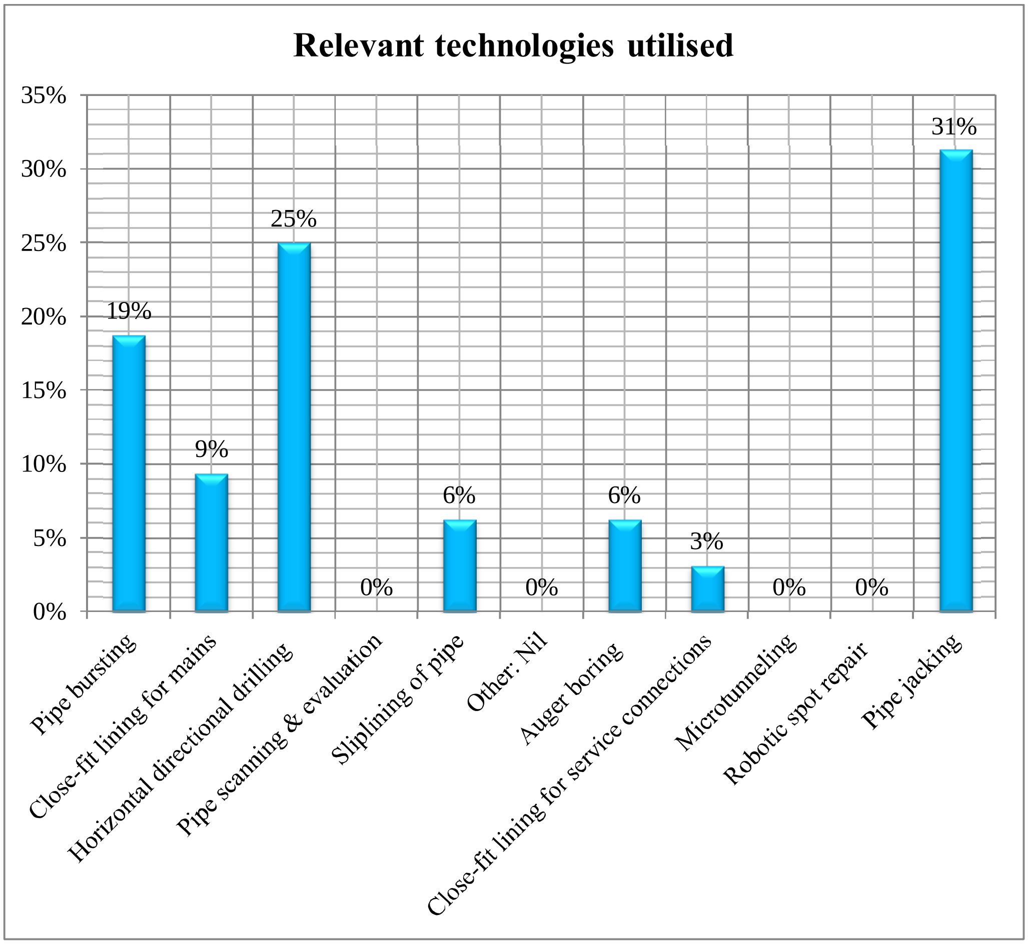


Percentage	Number	Category
44%	14	Yes
56%	18	No
100%	**32**	**Total**



If yes, please indicate all relevant technologies:

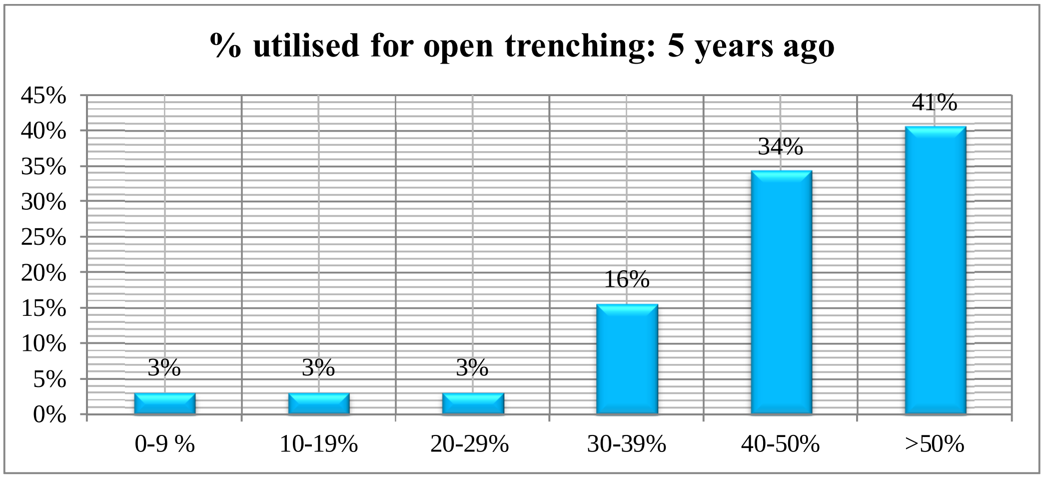
Percentage	Number	Category
19%	6	Pipe bursting
9%	3	Close-fit lining for mains
25%	8	Horizontal directional drilling
0%	0	Pipe scanning & evaluation
6%	2	Sliplining of pipe
0%	0	Other: Nil
6%	2	Auger boring
3%	1	Close-fit lining for service connections
0%	0	Microtunneling
0%	0	Robotic spot repair
31%	10	Pipe jacking
100%	**32**	**Total**



11. WHAT PERCENTAGES (APPROXIMATELY) OF ALL NEW PIPELINE AND UTILITY CONDUIT CONSTRUCTION EXECUTED BY YOUR COMPANY/ORGANIZATION EMPLOY TRADITIONAL OPEN TRENCHING METHODS FOR PIPELINE REHABILITATION

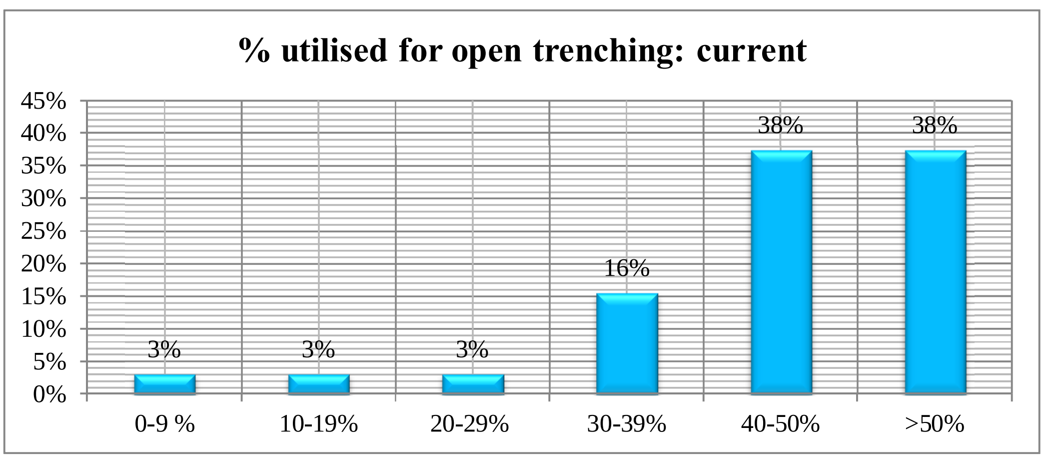
Five years ago:

Percentage	Number	Category
3%	1	0-9 %
3%	1	10-19%
3%	1	20-29%
16%	5	30-39%
34%	11	40-50%
41%	13	>50%
9%	**32**	**Total**



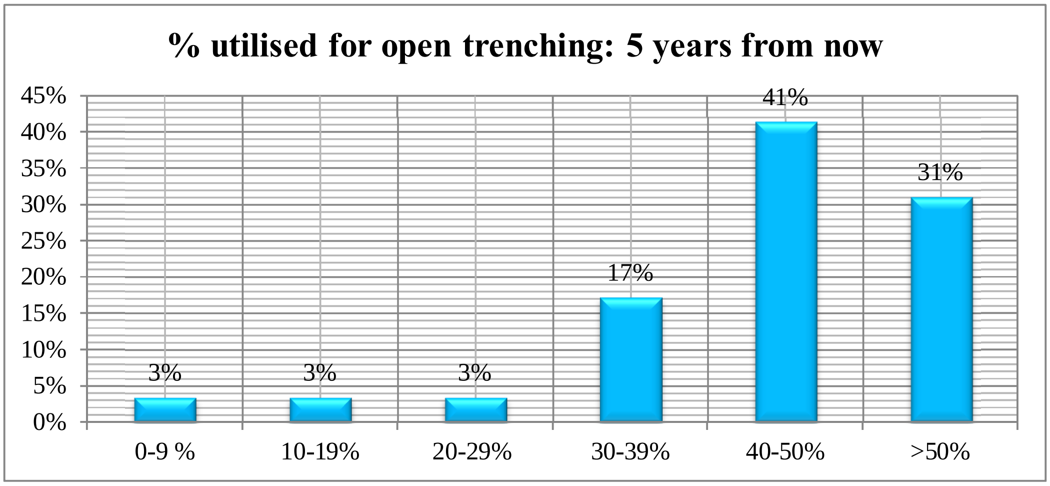
Today:

Percentage	Number	Category
3%	1	0-9 %
3%	1	10-19%
3%	1	20-29%
16%	5	30-39%
38%	12	40-50%
38%	12	>50%
9%	**32**	**Total**



Five years from now:

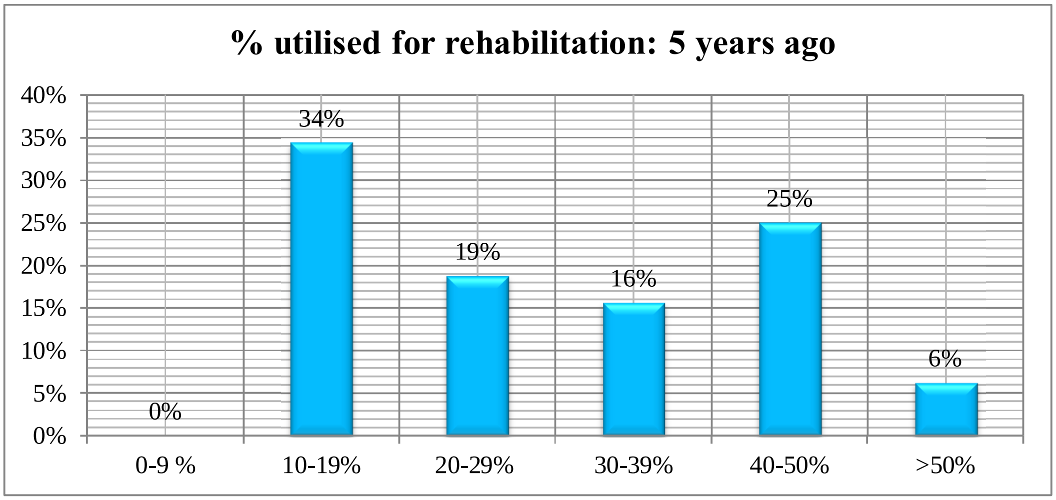
Percentage	Number	Category
3%	1	0-9 %
3%	1	10-19%
3%	1	20-29%
17%	5	30-39%
41%	12	40-50%
31%	9	>50%
10%	**29**	**Total**



12. WHAT PERCENTAGE OF ALL REPAIRS AND REHABILITATION TO PIPELINE AND UTILITY CONDUIT CONSTRUCTION EXECUTED BY YOUR COMPANY/ORGANIZATION EMPLOY TRENCHLESS TECHNOLOGIES?

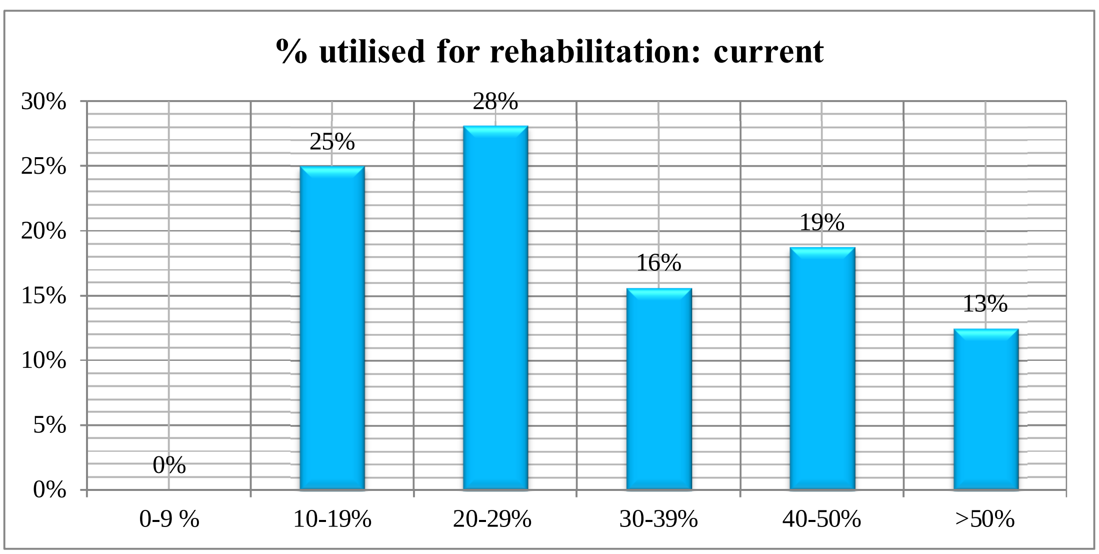
Five years ago:

Percentage	Number	Category
0%	0	0-9 %
34%	11	10-19%
19%	6	20-29%
16%	5	30-39%
25%	8	40-50%
6%	2	>50%
100%	**32**	**Total**



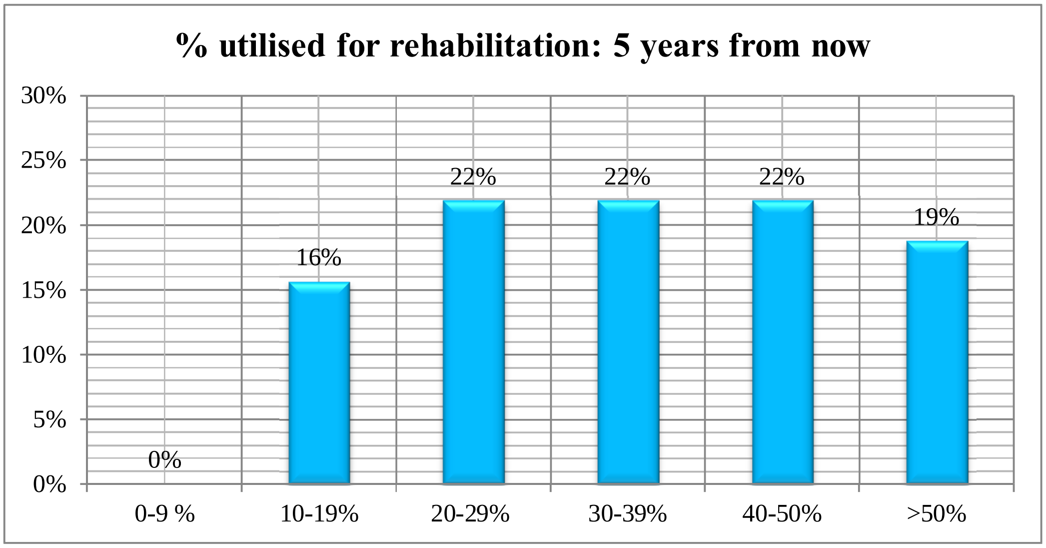
Today:

Percentage	Number	Category
0%	0	0-9 %
25%	8	10-19%
28%	9	20-29%
16%	5	30-39%
19%	6	40-50%
13%	4	>50%
100%	**32**	**Total**



Five years from now:

Percentage	Number	Category
0%	0	0-9 %
16%	5	10-19%
22%	7	20-29%
22%	7	30-39%
22%	7	40-50%
19%	6	>50%
100%	**32**	**Total**



13. DURING THE YEAR 2005 to CURRENT, HOW MANY KILOMETRES OF PIPELINES WERE INSTALLED/ REHABILITATED USING OPEN TRENCHING?

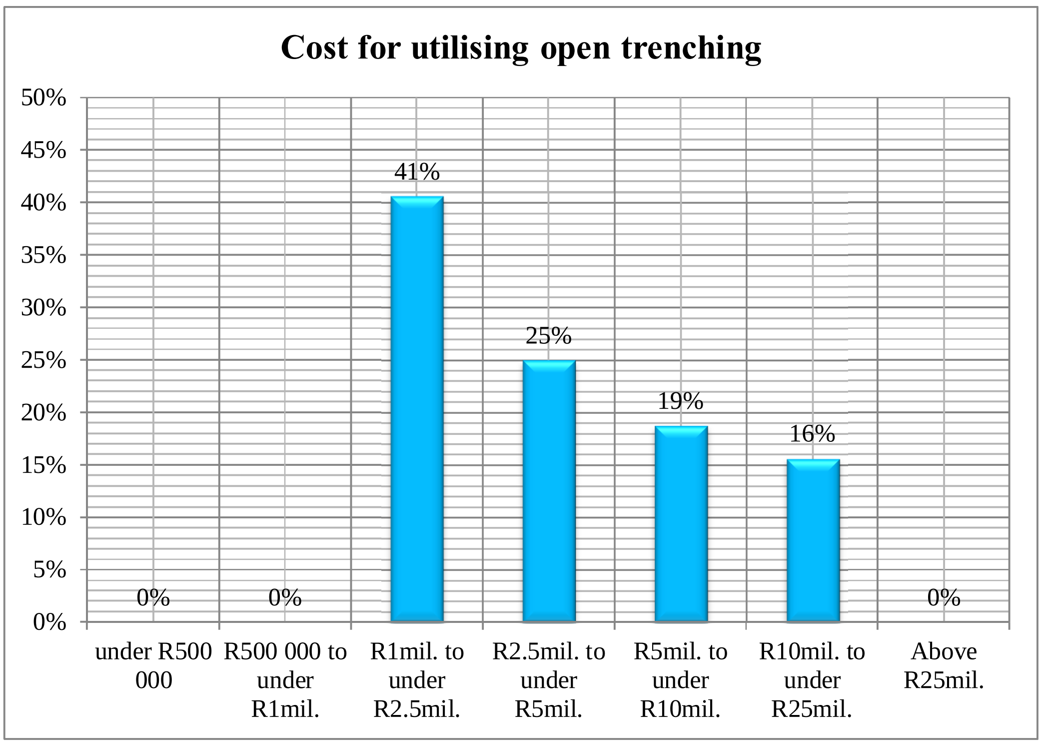
Length of pipelines:

Percentage	km	Category
100	2380	Open trenching
100%	**2380**	**Total**

14. WITH REFERENCE TO THE QUESTION ABOVE, HOW MUCH IN SOUTH AFRICAN RANDS DID THE INSTALLATION/ REHABILITATION USING OPEN TRENCHING COST?

Cost (South African Rands):

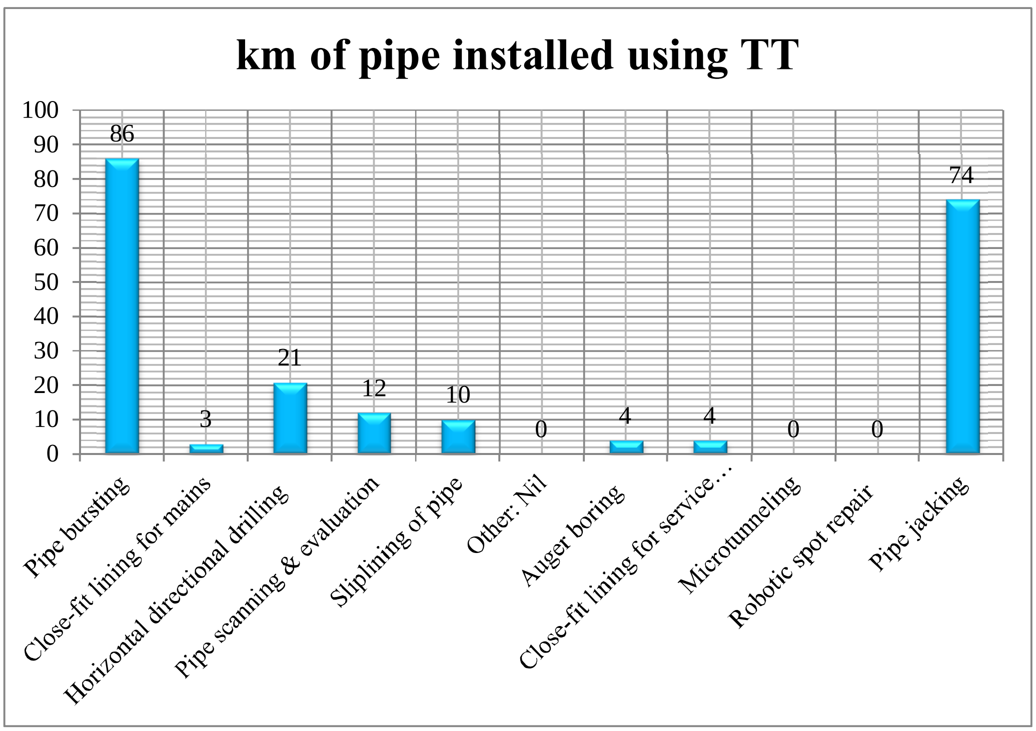
Percentage	Number	Category
0%	0	under R500 000
0%	0	R500 000 to under R1mil.
41%	13	R1mil. to under R2.5mil.
25%	8	R2.5mil. to under R5mil.
19%	6	R5mil. to under R10mil.
16%	5	R10mil. to under R25mil.
0%	0	Above R25mil.
34%	**32**	**Total**



15. DURING THE YEAR 2005 to CURRENT, HOW MANY KILOMETRES OF PIPE WERE INSTALLED/REHABILITATED USING THE FOLLOWING TRENCHLESS TECHNOLOGIES (IF NOT APPLICABLE, PLEASE MENTION):

Trenchless technology length of pipe (in km's):

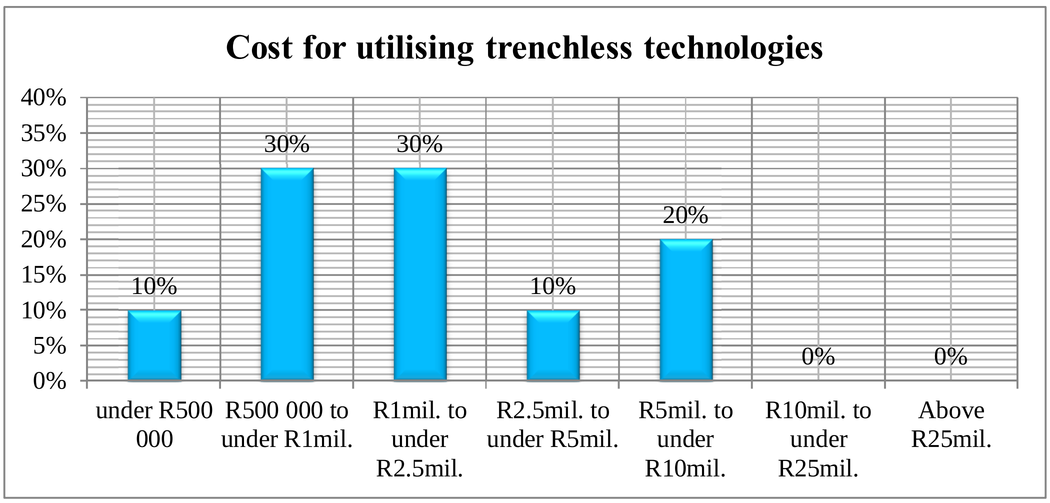
Percentage	km	Category
40%	86	Pipe bursting
1%	3	Close-fit lining for mains
10%	21	Horizontal directional drilling
6%	12	Pipe scanning & evaluation
5%	10	Sliplining of pipe
0%	0	Other: Nil
2%	4	Auger boring
2%	4	Close-fit lining for service connections
0%	0	Microtunneling
0%	0	Robotic spot repair
35%	74	Pipe jacking
100%	**214**	**Total**



16. WITH REFERENCE TO THE QUESTION ABOVE, HOW MUCH IN SOUTH AFRICAN RANDS DID THE INSTALLATION/REHABILITATION USING TRENCHLESS TECHNOLOGIES COST?

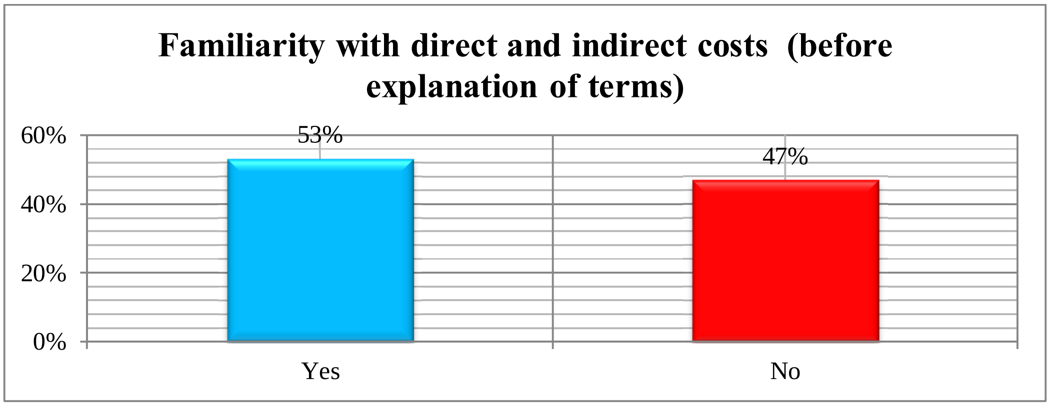
Cost (South African Rands):

Percentage	Number	Category
10%	1	under R500 000
30%	3	R500 000 to under R1mil.
30%	3	R1mil. to under R2.5mil.
10%	1	R2.5mil. to under R5mil.
20%	2	R5mil. to under R10mil.
0%	0	R10mil. to under R25mil.
0%	0	Above R25mil.
100%	**10**	**Total**

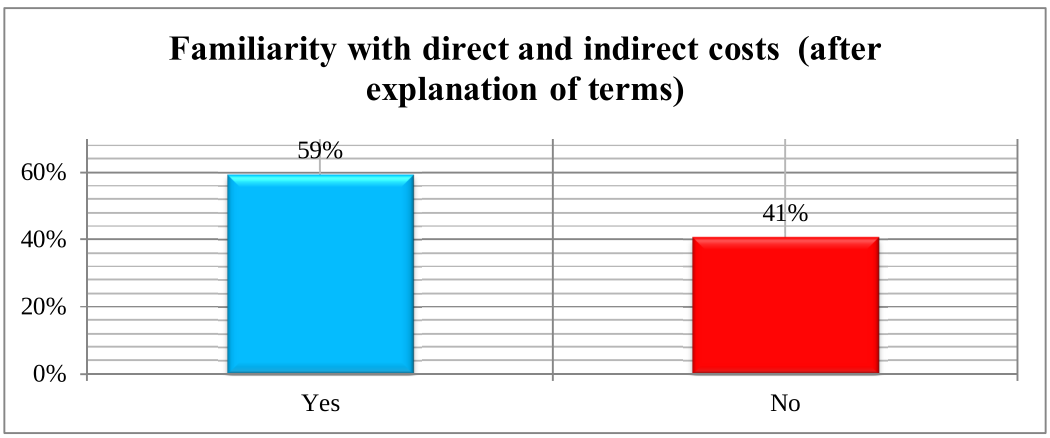


17. ARE YOU FAMILIAR WITH THE TERMS "DIRECT COSTS" AND "INDIRECT COSTS"?

Percentage	Number	Category
53%	17	Yes
47%	15	No
100%	**32**	**Total**



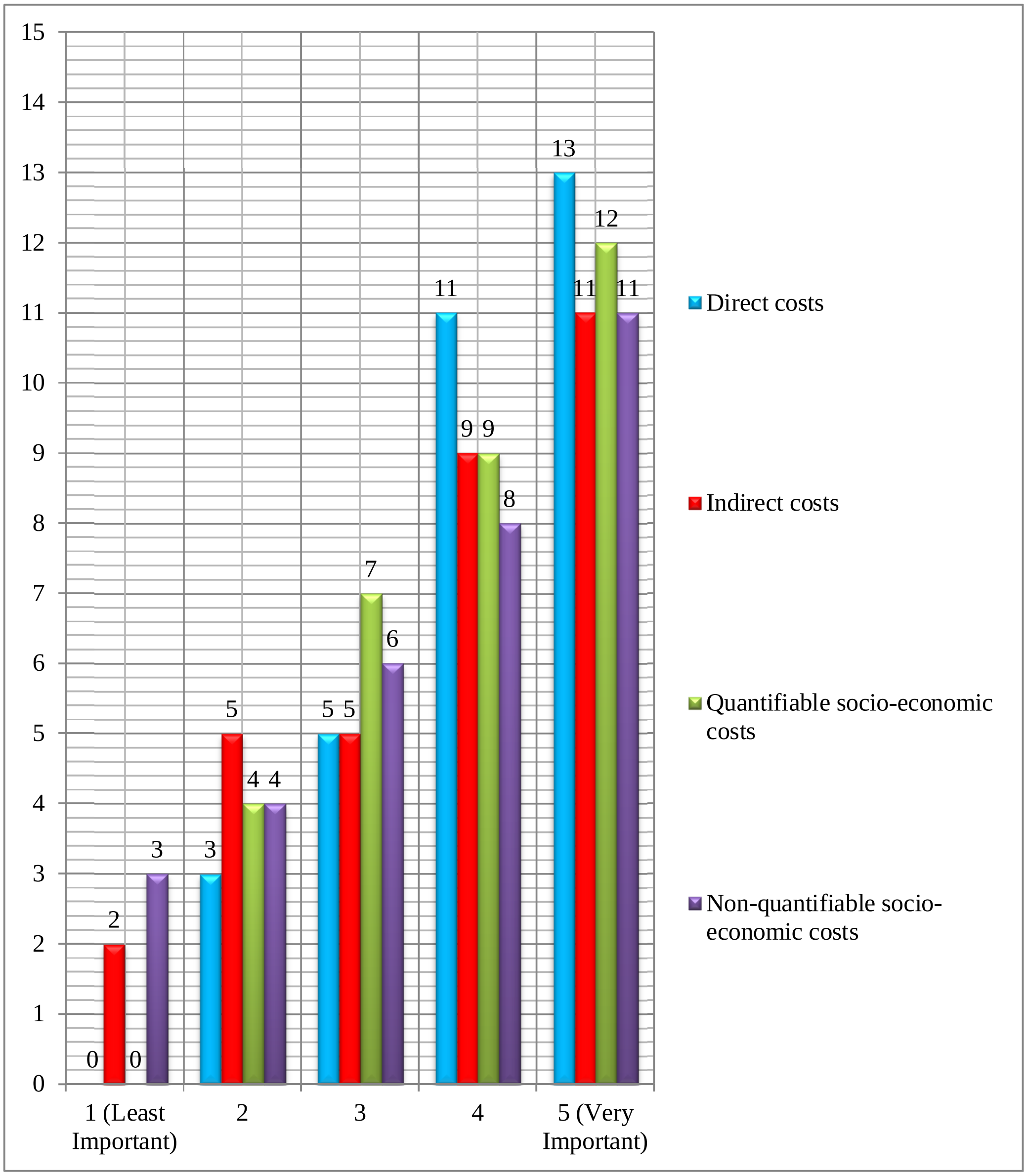
Percentage	Number	Category
59%	19	Yes
41%	13	No
100%	**32**	**Total**



18. WITH REFERENCE TO THE ABOVE COULD YOU LIST IN IMPORTANCE TO YOU THESE ITEMS:-

(Scale: 1 – least important, 5 – most important)

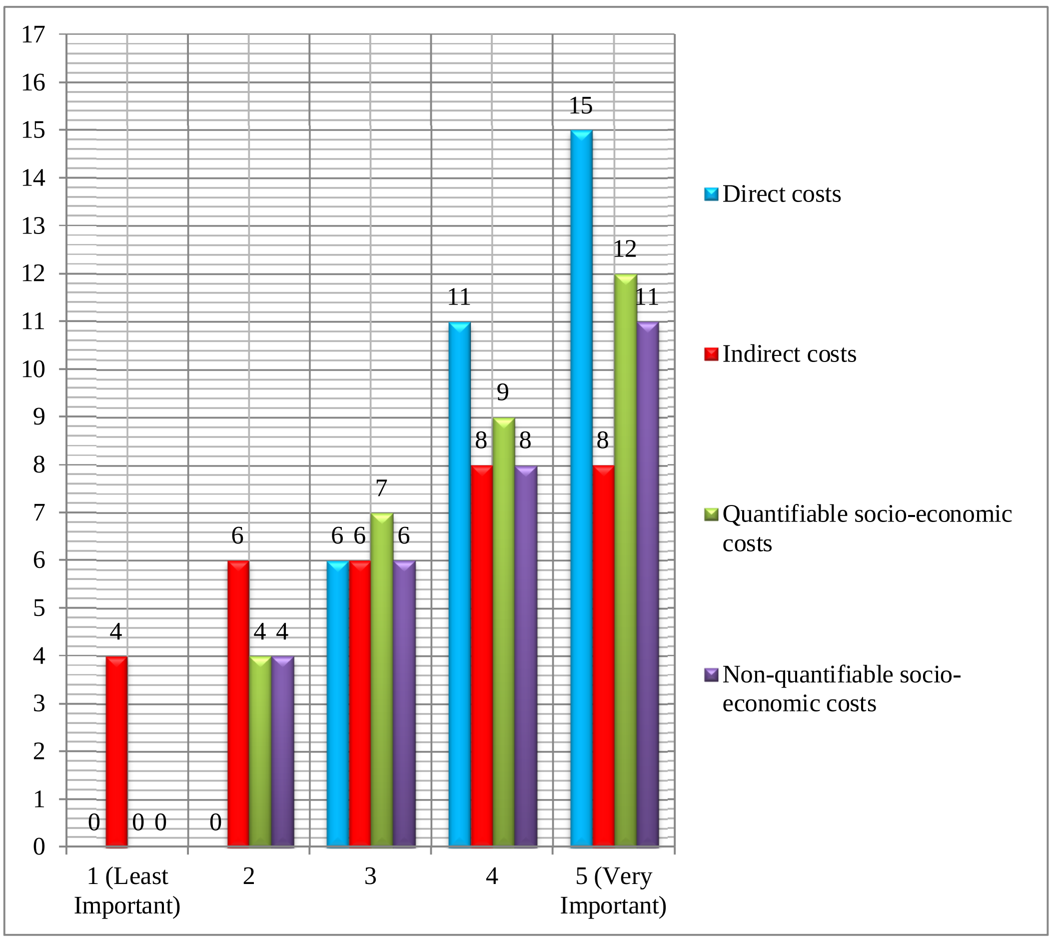
1 (Least Important)	2	3	4	5 (Very Impo rtant)	Total	Category
0	3	5	11	13	32	Direct costs
2	5	5	9	11	32	Indirect costs
0	4	7	9	12	32	Quantifiable socio-economic costs
3	4	6	8	11	32	Non-quantifiable socio-economic costs



19. COULD YOU ALSO LIST THEM ACCORDING TO WHAT YOU THINK THE END CONSUMER WOULD FIND MORE IMPORTANT?

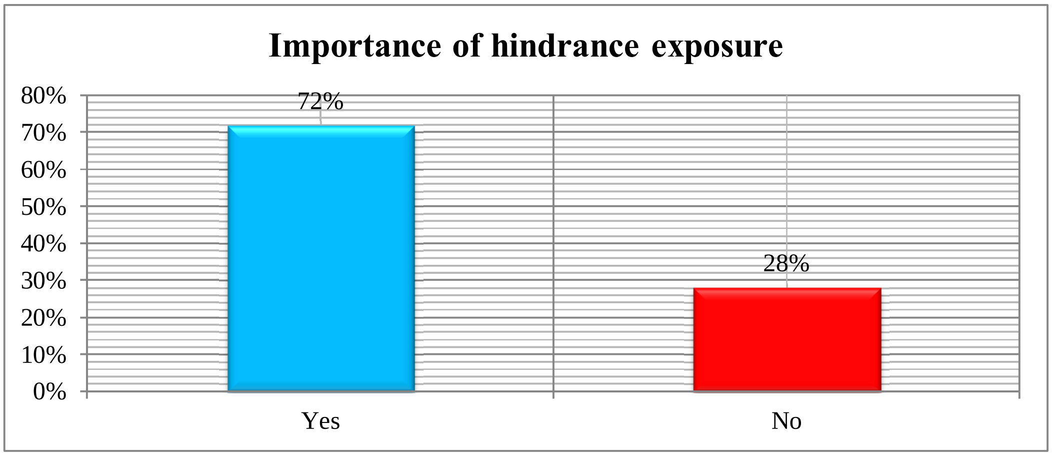
(Scale: 1 – least important, 5 – most important)

1 (Least Important)	2	3	4	5 (Very Important)	Total	%	Category
0	0	6	11	15	32	26%	Direct costs
4	6	6	8	8	32	26%	Indirect costs
0	4	7	9	12	32	26%	Quantifiable socio-economic costs
0	4	6	8	11	29	23%	Non-quantifiable socio-economic costs
0	**14**	**25**	**36**	**46**	**125**	**100%**	**Total**



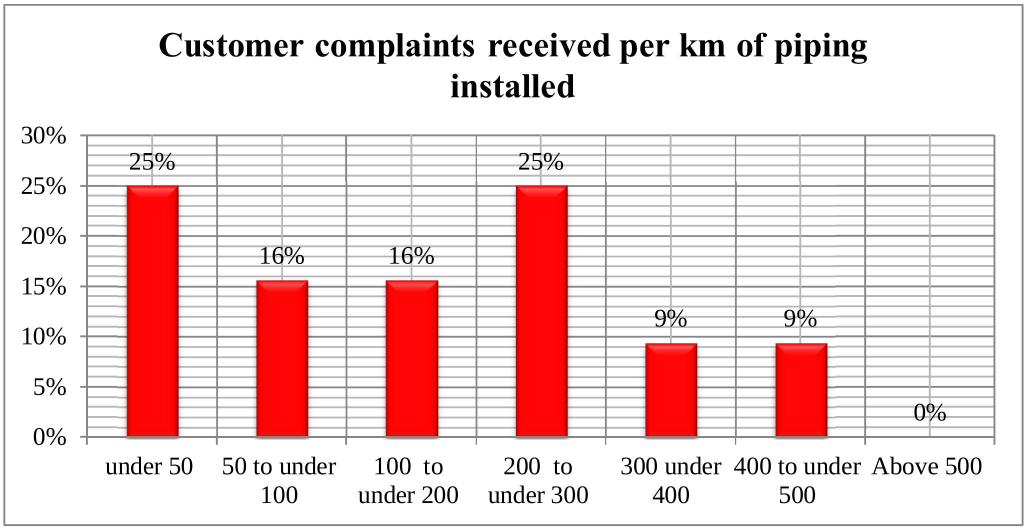
20. DO YOU THINK THAT HINDRANCE EXPOSURE IS IMPORTANT TO THE CONSUMER?

Percentage	Number	Category
72%	23	Yes
28%	9	No
100%	**32**	**Total**



21. HOW MANY COMPLAINTS (PER KILOMETRE OF PIPING) ARE RECEIVED BY CONSUMERS DURING THE PIPELINE REHABILITATION PROCESS?

Percentage	Number	Category
25%	8	under 50
16%	5	50 to under 100
16%	5	100 to under 200
25%	8	200 to under 300
9%	3	300 under 400
9%	3	400 to under 500
0%	0	Above 500
100%	**32**	**Total**

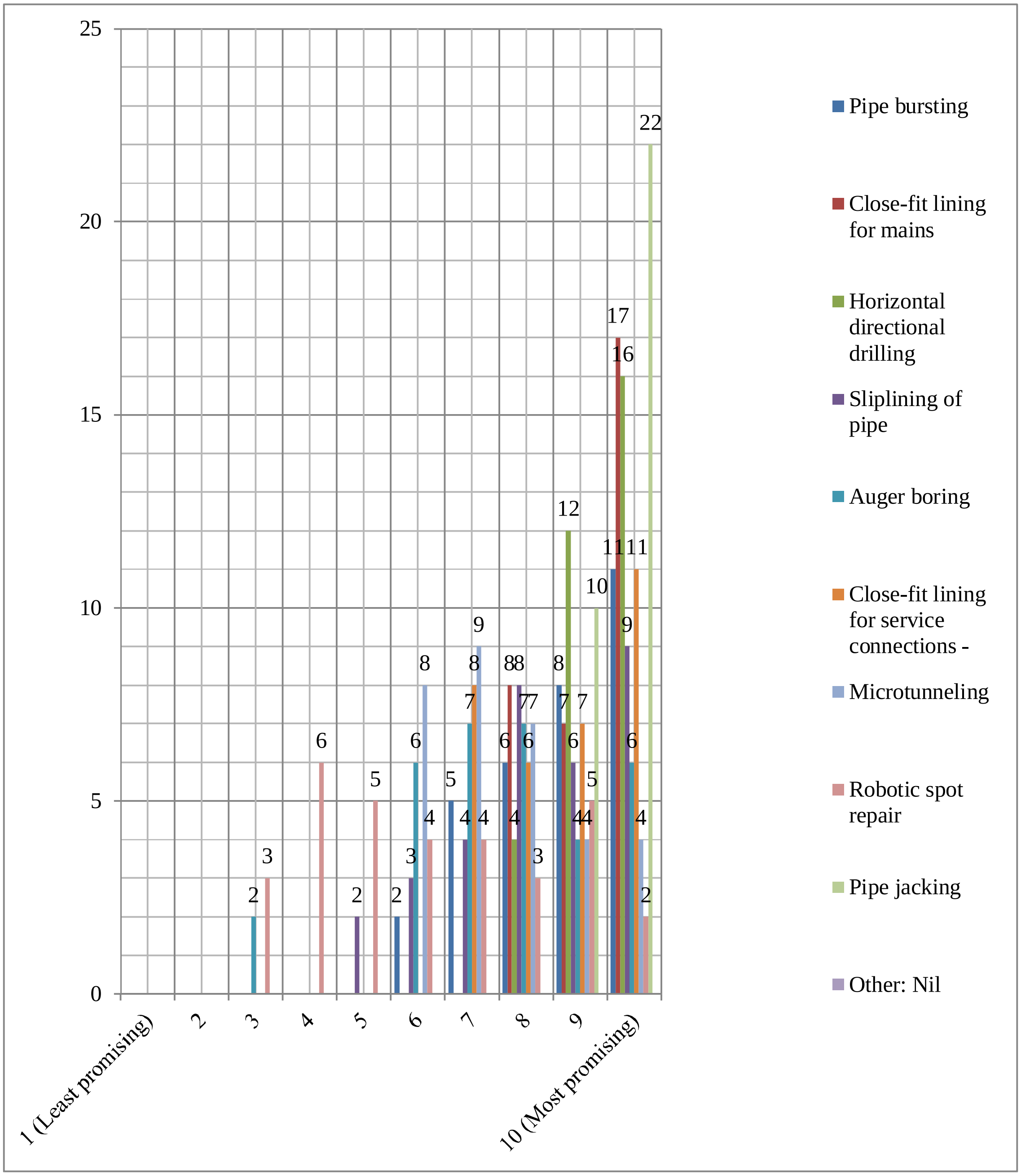


22. WHERE DO YOU FORESEE THE MOST FUTURE GROWTH IN TRENCHLESS TECHNOLOGIES FOR MUNICIPAL/GENERAL APPLICATIONS?

(Please rank each category in a scale from 1 – least promising, 10 - most promising)

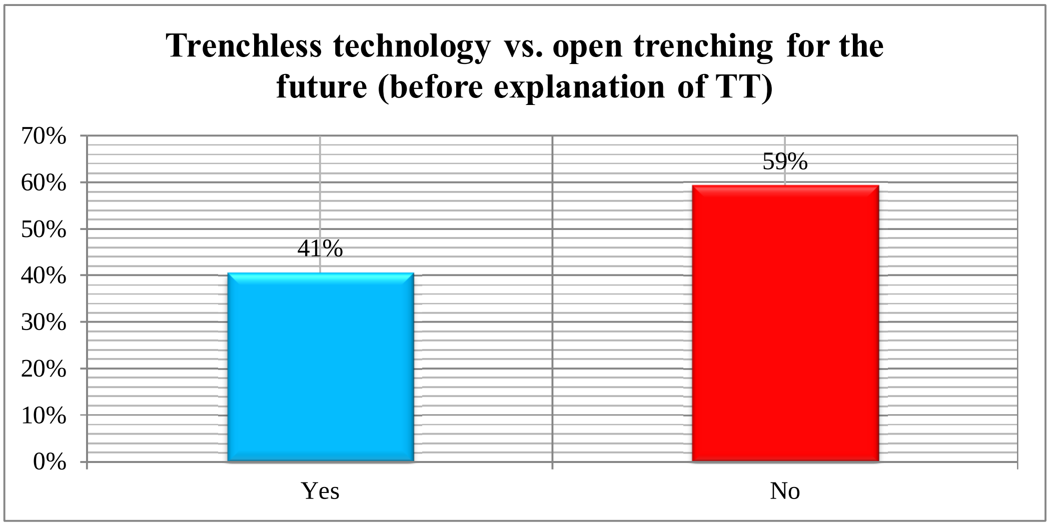
1 (Least promising)	2	3	4	5	6	7	8	9	10 (Most promising)	Total	Category
					2	5	6	8	11	32	Pipe bursting
							8	7	17	32	Close-fit lining for mains
							4	12	16	32	Horizontal directional drilling
					5	4	7	5	11	32	Pipe scanning & evaluation
				2	3	4	8	6	9	32	Sliplining of pipe
		2			6	7	7	4	6	32	Auger boring
						8	6	7	11	32	Close-fit lining for service connections -
					8	9	7	4	4	32	Microtunneling

1 (Least promising)	2	3	4	5	6	7	8	9	10 (Most promising)	Total	Category
		3	6	5	4	4	3	5	2	32	Robotic spot repair
								10	22	32	Pipe jacking
											Other: Nil

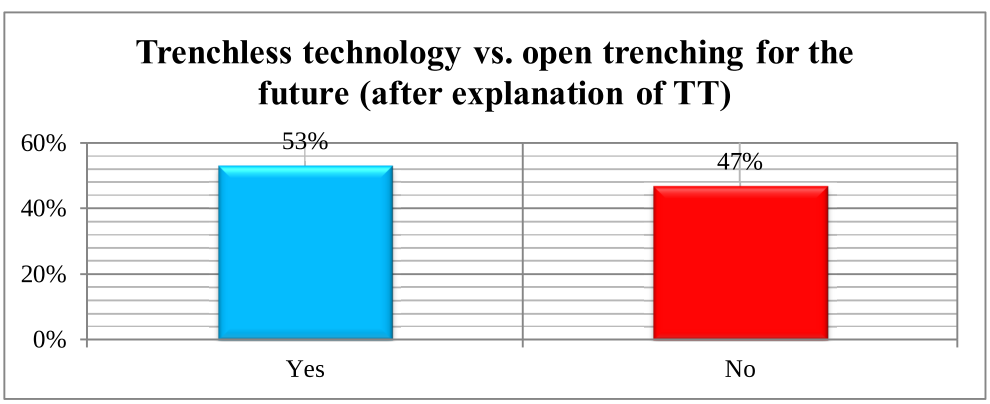


23. TO SUMMARISE, DO YOU FORESEE TRENCHLESS TECHNOLOGY TO BE THE BIGGER ROLE PLAYER THAN OPEN TRENCHING FOR PIPELINE REHABILITATION IN THE FUTURE?

Percentage	Number	Category
41%	13	Yes
59%	19	No
100%	**32**	**Total**



Percentage	Number	Category
53%	17	Yes
47%	15	No
100%	**32**	**Total**

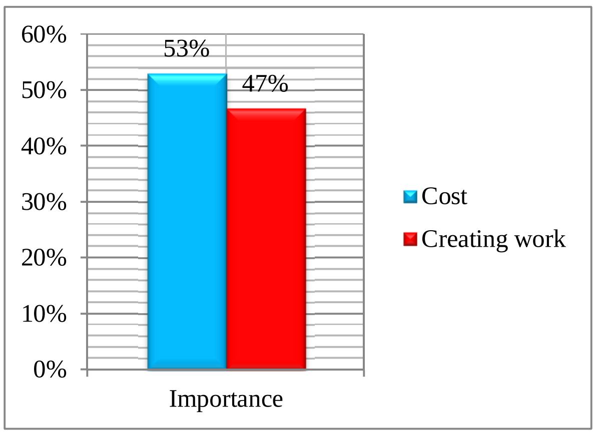


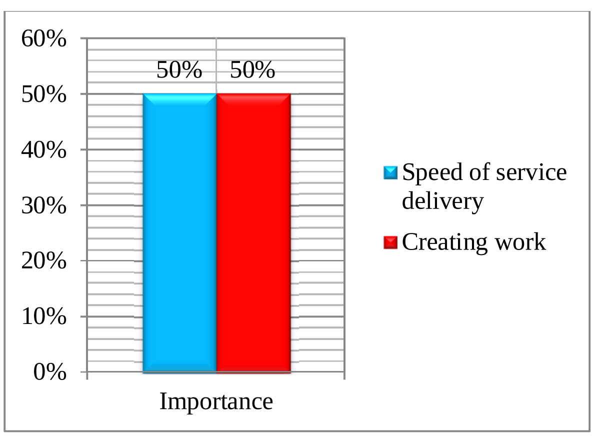
24. WHICH OF THE FOLLOWING IS MORE IMPORTANT TO YOU?

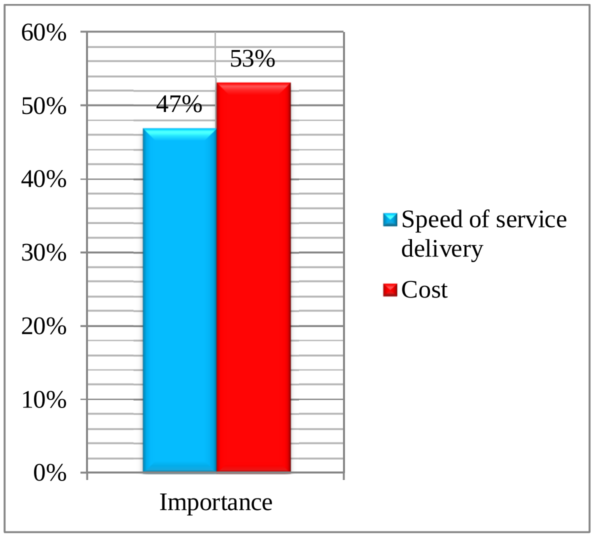
Percentage	Number	Category		Percentage	Number	Category
53%	17	Cost	or	47%	15	Creating work

Percentage	Number	Category		Percentage	Number	Category
50%	16	Speed of service delivery	or	50%	16	Creating work

Percentage	Number	Category		Percentage	Number	Category
47%	15	Speed of service delivery	or	53%	17	Cost





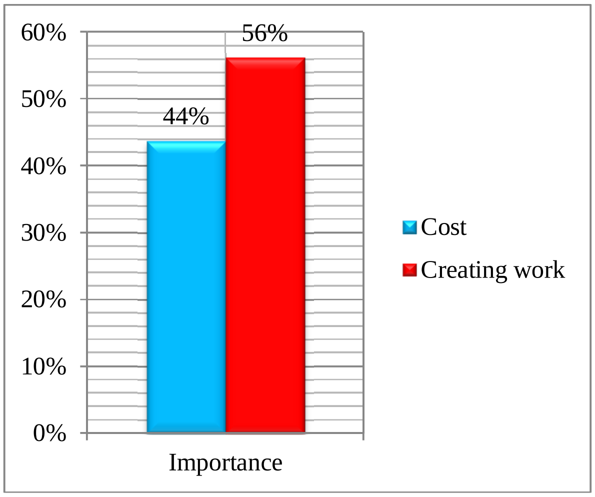


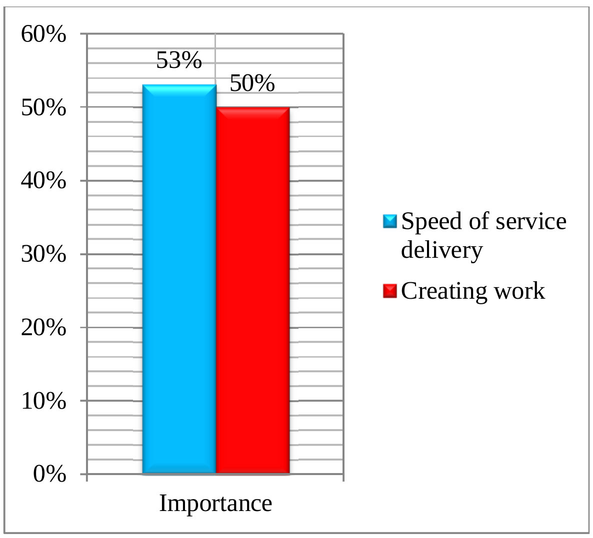
25. WHICH OF THE FOLLOWING DO YOU THINK IS MORE IMPORTANT TO THE CUSTOMER?

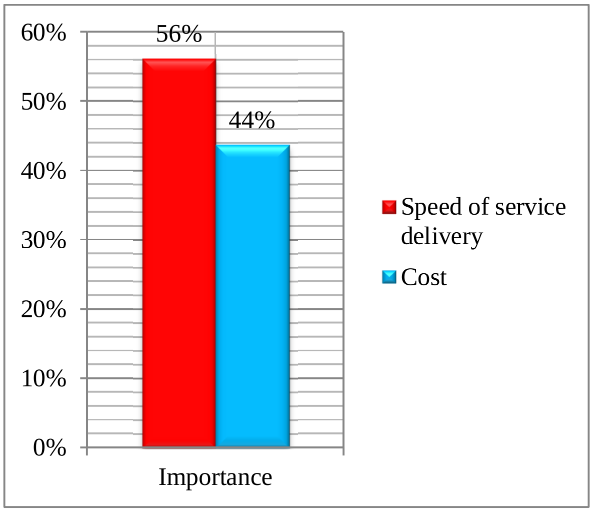
Percentage	Number	Category		Percentage	Number	Category
44%	14	Cost	or	56%	18	Creating work

Percentage	Number	Category		Percentage	Number	Category
53%	17	Speed of service delivery	or	47%	15	Creating work

Percentage	Number	Category		Percentage	Number	Category
56%	18	Speed of service delivery	or	44%	14	Cost

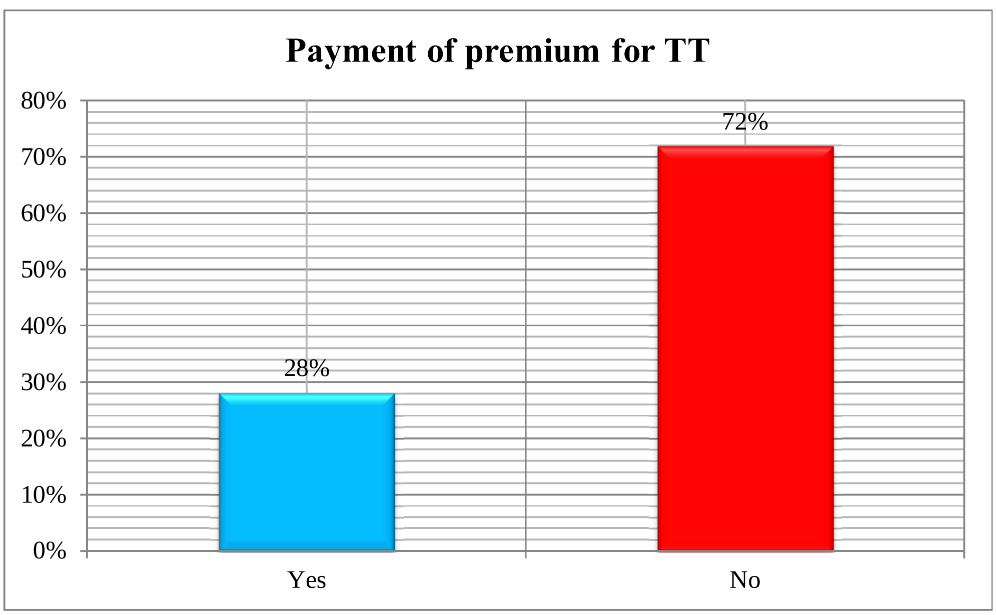

60%
50%
40%
30%
20%
10%
0%
56%
44%
Importance
Cost
Creating work


60%
50%
40%
30%
20%
10%
0%
53%
50%
Importance
Speed of service delivery
Creating work



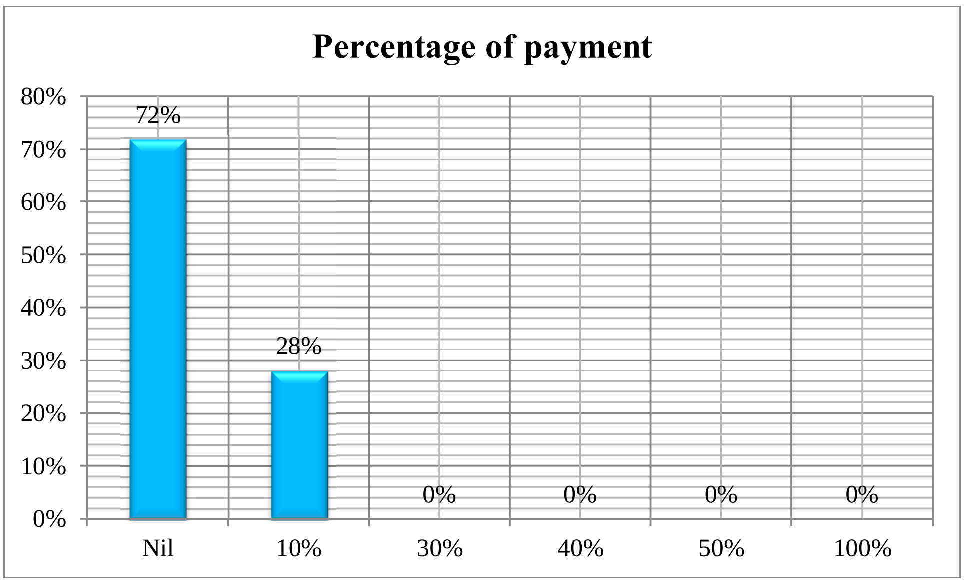
26. **WOULD YOU MIND PAYING A PREMIUM FOR TRENCHLESS TECHNOLOGY?**

Percentage	Number	Category
28%	9	Yes
72%	23	No
100%	**32**	**Total**



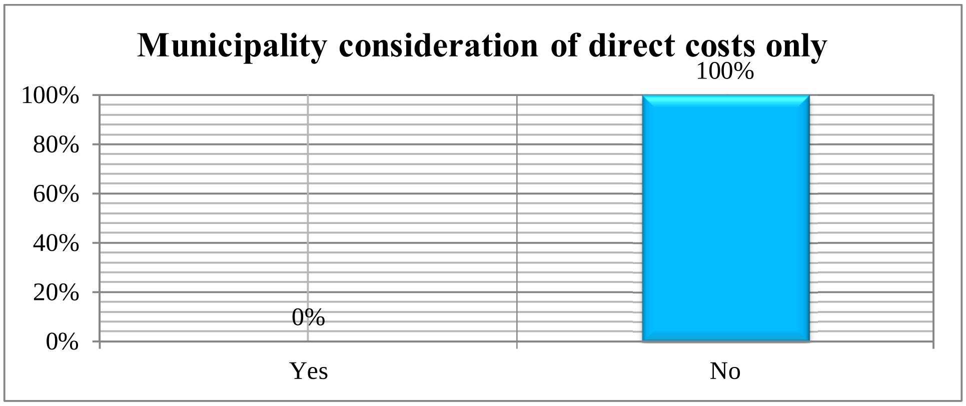
27. HOW MUCH WOULD YOU PAY?

Percentage	Number	Category
72%	23	Nil
28%	9	10%
0%	0	30%
0%	0	40%
0%	0	50%
0%	0	100%
100%	**32**	**Total**



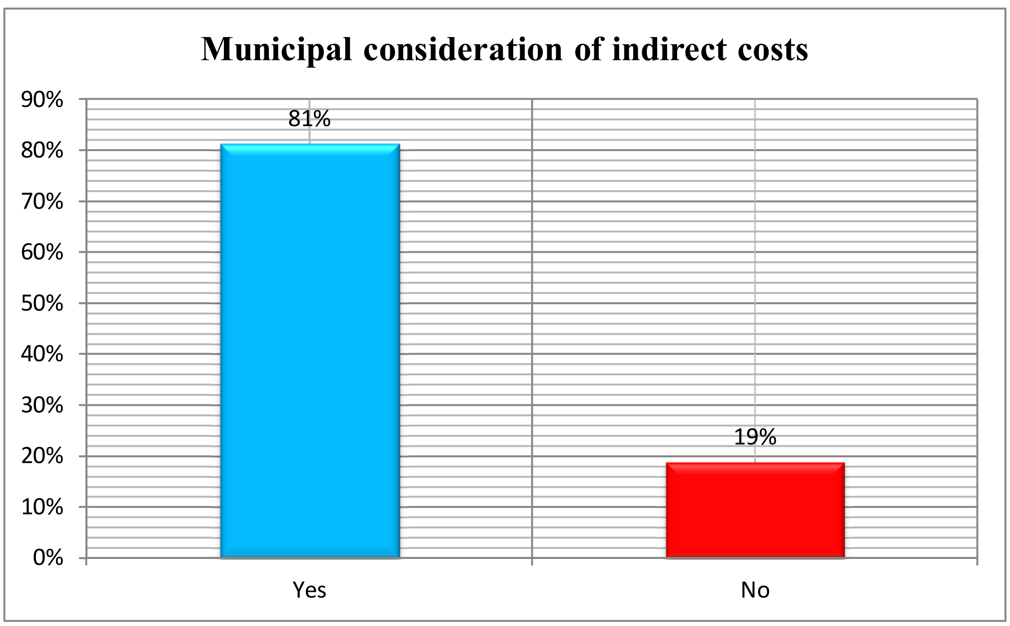
28. SHOULD THE MUNICIPALITY CONSIDER 'DIRECT COSTS" ONLY

Percentage	Number	Category
0%	**0**	Yes
100%	**32**	No
100%	**32**	**Total**



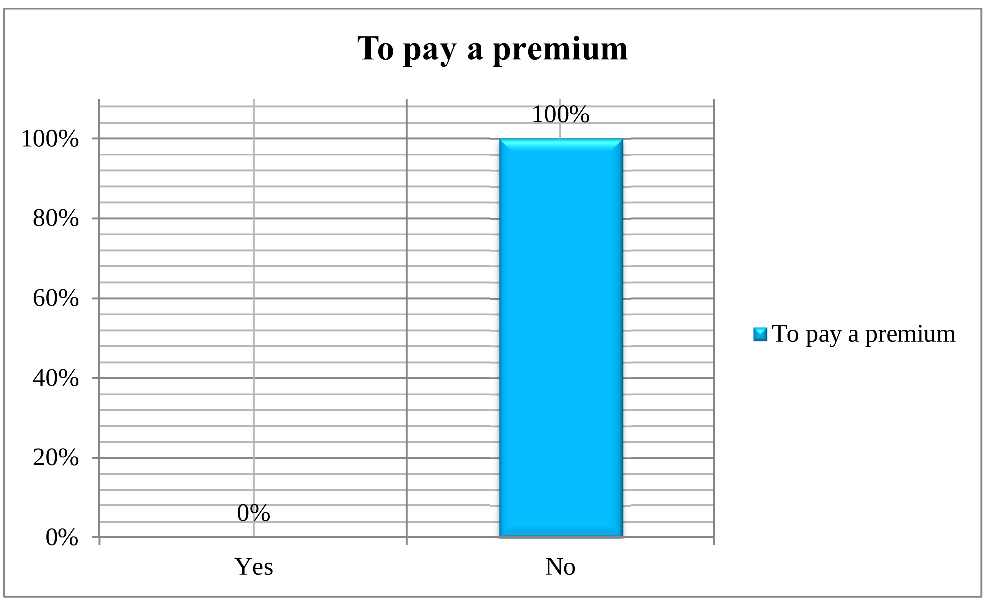
29. CONSIDER 'INDIRECT COSTS" AS WELL?

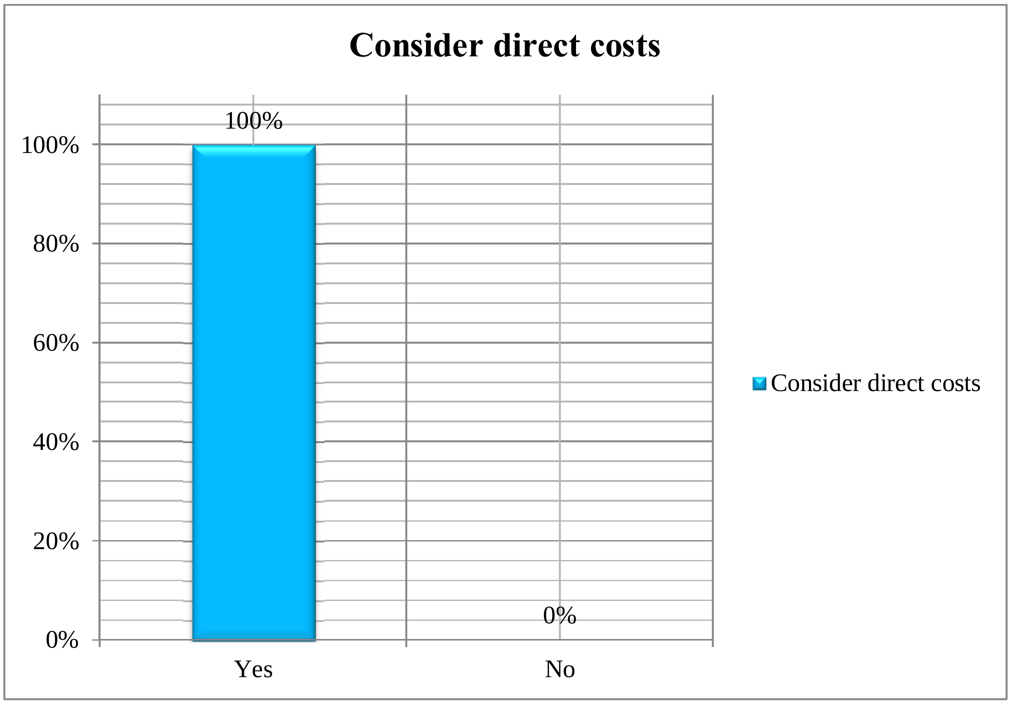
Percentage	Number	Category
81%	**26**	Yes
19%	**6**	No
100%	**32**	**Total**

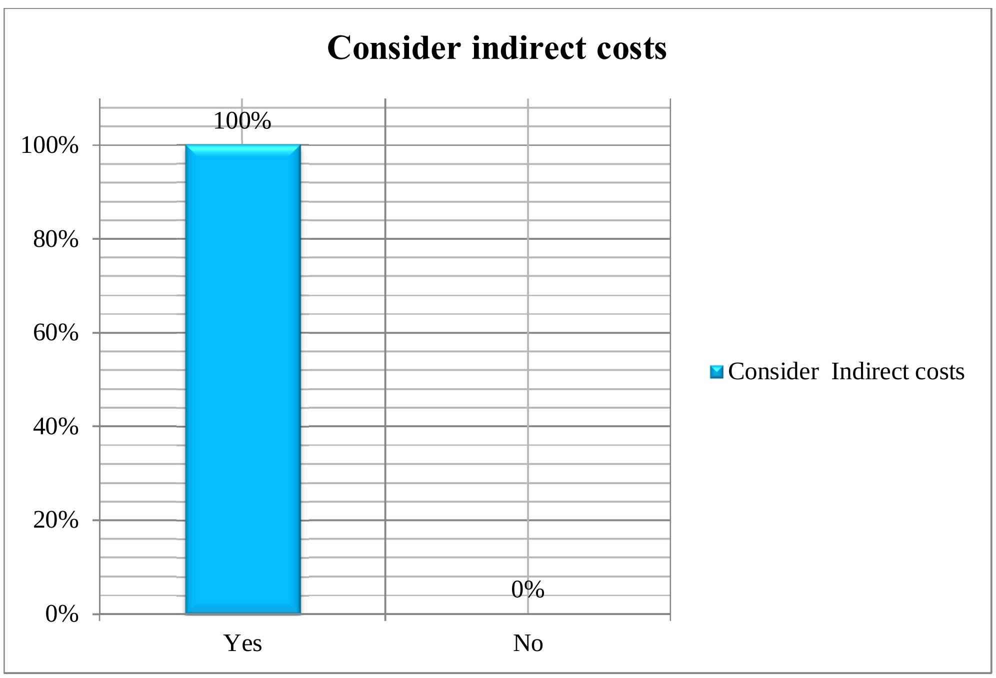


30. DO YOU THINK THAT THE CUSTOMER WANTS THE FOLLOWING?

Percentage	Number	Category	Category
0%	0	Yes	To pay a premium
100%	32	No	
100%	**32**	**Total**	
100%	32	Yes	Consider direct costs
0%	0	No	
100%	**32**	**Total**	
100%	32	Yes	Consider Indirect costs
0%	0	No	
100%	**32**	**Total**	




Consider direct costs
100%
0%
100%
80%
60%
40%
20%
0%
Yes
No
Consider direct costs


Consider indirect costs
100%
0%
100%
80%
60%
40%
20%
0%
Yes
No
Consider Indirect costs