Spatial Modelling of Water Pipe Bursts in Harare, Zimbabwe.

By

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Dissertation submitted to the Department of Geography and Environmental Science in Partial Fulfillment of the Requirements for the Master of Arts Degree in Environmental Policy and Planning.

June 2008

University of Zimbabwe

Abstract

Water is a scarce commodity whose availability and utilisation requires diligent planning, distribution and management to ensure its proper use and protection in the interest of humankind and other ecological balances. Currently, Zimbabwe is facing problems of persistent droughts, increasing competition within and between sectors due to increasing demand, imbalances in access to water between consumers and industrial activities, commercial farmers. Therefore, water conservation policy and planning procedures need to be to backed by strong scientific research findings. It is in this context that the main objective of this study was to model pipe burst hazard in the Harare fresh water supply pipe systems as a function of pipe related and terrain factors. Specifically, the study identified pipe leaks and used logistic regression to test whether the leak locations were a statistically significant of pipe age, water pressure, pipe material, as well as terrain factors such as slope. The study also spatially modelled the pipe leak hazard, that is, probability of a leak occurring at a place as a function of factors that significantly explain pipe leaks using logistic regression in a GIS environment. Harare water pipes were digitized in a GIS based system, burst points were collected using GPS and non-burst points were randomly sampled in a GIS based system. A Digital Elevation Model (DEM) of the study area was generated from the map of 1:2500. Map gaps were filled using 90m by 90m DEM using co-Kriging. Pipe age, material, location, type of material and other relevant information was obtained through interviews from Zimbabwe National Water Authority (ZINWA) staff. Results of the research indicated that there was a significant relationship ($p<0.05$) between pipe related factors such as pressure, slope terrain, pipe material and age.

Dedications

To my father and mother Cletus and Eleonar Punungwe- I love you.

Acknowledgements

My thanks go to my supervisors Dr. A. Murwira and Mr. S. Kusangaya. I thank also the following people with their academic help, ZINWA staff, Mr Tagwireyi, G.Mutowo, Mbulisi Sibanda, ‘Chief’ Maruziva, ‘Prof’ Courage Mutema and friends. I would like to extend my gratitude to my parents Baba naMaiPunungwe for nurturing me up to this age. To my brothers and sisters (Lovemore, Shepherd, Sally, Clever, Shelly and Miriam), I thank you for your unwavering support. Lastly, I thank Chirume Primary School teachers for teaching me some of the basic skills.

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CHAPTER 1: INTRODUCTION

1.1 Introduction

Inadequate water and poor sanitation facilities constitute some of the most critical problems faced by developed and developing countries (Schmugge, Jackson and McKim, 1998). Agriculture, industry and domestic water demands requirements are increasing, showing water as one of the most important resources for sustainable physical, social and economic development (Manzungu, 2002, United Nations Environmental Programme, (UNEP), 1997). Human use of water has increased more than 35-fold over the past three centuries and water withdrawals have been increasing about 4-8% per year with most of that occurring in the developing world (Sontheiner, 1991). There is therefore the need for present generations to utilise this scarce, finite and precious resource to meet future needs (Manzungu, 2002). In Zimbabwe conservation and sustainability use of water is met in the following guidelines of the Rio-Dublin Principles of 1992, Environmental Management Act (EMA), and Agenda 21 as some of the legal and policy instruments that advocate for the need to conserve water (Chenje, Sola and Paleney, 1996). All this shows the demand and the importance of water.

Much of the Sub-Saharan Africa in particular Zimbabwe, has low conversion of rainfall to runoff, a precarious balance between available water resources and water demand (Mazvimavi, 2003), a factor which puts stress on urban water supply system. Rapid population, which is a characteristic of Sub-Saharan Africa region, has increased water demand for domestic, agricultural and industrial purposes, is causing water scarcity. It is forecasted that by 2025, Malawi and South Africa will be facing absolute water scarcity and Lesotho, Tanzania and Zimbabwe will be water stressed (Wilson, 1990). In water scarce Namibia, demand for state supplied water increased from 37 000 000 cubic meters per year to 95 000 000 cubic meters per year (Chenje, Sola and Paleney, 1996). All this shows the demand and importance of water.

In many water distribution systems, a significant percentage of water is lost while in transit from treatment plants to consumers. According to The Water Wheel, (2007), the amount of lost ''unaccounted for'' water is typically in the range of 20-30% of production. In South Africa and Zimbabwe, 29% and 20% of pumped water respectively, is lost through pipe leakages (The Water Wheel, 2007). In Zimbabwe, Harare and Bulawayo are currently having high water shortages, a problem attached to water pipe bursts that take long to be repaired.

Furthermore, in Harare, the outbreaks of water borne diseases like cholera, dysentery, diarrhoea have been reported. The bursting pipes pose a public health risk as leaks are potential entry points for contaminants if a pressure drop occurs in a system. Given high water demands in industry, agriculture and domestic uses, poor water supplies in these areas have contributed to the slowdown of economic activities. Of particular interest is the loss of treated water through pipe water bursts that take very long to be detected. In short, the loss of water culminates to numerous other environmental costs thus a loss not only to people but also the economy. Generally the overall problem will be the failure to provide enough and clean water to the consumers.

The Harare water supply falls under the jurisdiction of Zimbabwe national Water Authority (ZINWA). ZINWA deal with matters relating to water, participate in water resources development planning, conserve and manage water resources, promote efficient, equitable and sustainable allocation and use of water. However the major problem that still persists is the failure to early repair and detection of leakages in the treated piped water.

1.2 Problem Statement

Detecting and repairing pipe bursts is one of the main components of water conservation strategies meant to ensure adequate water supply. Various studies have focused on ways of water conservation in dambos and wetlands (Mazvimavi, 2003). In urban areas studies have mainly focussed on dams, pollution of water, inter alia, but less with Harare urban piped water supply system. Above all methods of water pipe burst detection have dealt more with water that rise above ground surface, ignoring the fact that water pipe bursts continue for long periods under the ground before rising to the surface (Mahachi, 1994). Pipe bursts that manage to rise to the surface continue for days creating ‘artificial streams’ because of slow and poor methods of repairing pipe bursts. All this leads to loss of expensive treated water. The bursting pipes pose a public health risk as leaks are potential entry points for contaminants creating health hazards. Available literature shows that little attention has been given to the monitoring and maintenance of water pipes and more so to specifically detect pipe water bursts (O’Dwyer and Partners 1994). Pipe burst detection has historically assumed that all, if not most, leaks rise to the surface and are visible. However many pipe bursts continue below the surface for longer periods of time and remain undetected until such a time they rise to the surface. Above all, water lost after treatment and pressurisation, but before delivered for the intended use is water, money and energy wasted. It is because of the above gaps and problems that have aroused interest to the need to spatially model water pipe bursts.

1.3 Justification of the study

Little work has been done on spatial modelling of pipe water supply and bursts in urban areas specifically Harare. It is in Harare where government's administrations, heavy industries and highest concentration of population are found and as a result Harare has high water use compared to other cities. It is in the same city where there are higher water pipe bursts, water cuts and shortages are impacting negatively on economic and social sectors. Water shortages in Harare are affecting the Harare Municipality to effectively provide sanitation facilities. In many suburbs of Harare the health of people is at risk mainly due to poor water supply for example the outbreak of cholera in Mbare, Mabvuku among other cities. This study goes in line with Rio-Dublin and ZINWA principles on the need to conserve water. This study will therefore contribute scientific knowledge to various water bodies. It will also help in the conservation of treated pipe water and assist in Urban Water Policy formulations such as water rationing.

1.4 Objectives

1.4.1 Main Objective

The main objective of the study is to model the pipe burst hazard in the Harare fresh water supply pipe systems as a function of pipe related and terrain factors.

1.4.2 Specific objectives

1. To identify pipe leaks and test whether the leak locations are a statistically significant function of pipe age, water pressure, pipe material, as well as terrain factors such as slopes
2. To spatially model the pipe leak hazard (i.e., probability of a leak occurring at a place as a function of factors that significantly explain pipe leaks).

1.4.3 Research Question

- Can pipe leaks and bursts be significantly explained by pipe age, water pressure and pipe material as well as terrain factors such as slopes?

1.5 Hypothesis

- There is a significant relationship between pipe age, water pressure, pipe material, slope and water pipe bursts

CHAPTER 2: WATER SUPPY NETWORKS: A LITERATURE REVIEW

2.1 Introduction

Water is a subject which has been widely covered by many research scientists. The need to conserve natural wetlands and dambos, participation and gender, health and sanitation are some of the topics which have been covered. This chapter is mainly going to look at what has been done and what does the literature say concerning urban water piped system, in this case the capital Harare.

2.2 The Harare water supply network

The Harare water supply system that is being controlled by ZINWA gets its water from four water sources. These water sources are Manyame River, Harava, Manyame and Chivero dams with a safe yield of 447 mega litres of water per day. It also compromises of two treatment plants which are Morton Jaffrey and Prince Edward with a total design output of 740 mega litres per day. The supply system comprises of 12 bulk water pumping stations, approximately 200km of bulk transmissions mains, 28 water storage reservoirs with a total of about 850ML and over 2600km of primary and secondary distribution pipeline of different sizes. By 1992 the population grew to 1850 000 and there was the need to upgrade pumping stations to meet demands of the population. Due to high demands between 1993 and 2000 has seen Warren Control booster being upgraded to 700ML/day.

2.3Existing Situation

The areas within the existing boundaries of the City of Harare, some 540 square kilometres, are traversed by over 2500km of water mains ranging in size from 50mm to 1300mm (O’Dwyer and Partners, 1994). Records of these pipelines are maintained on 1:1250 scale mapping based on Surveyor-General’s maps in the Department of Water [ZNWA] offices. However, some pipes were replaced as they did not meet the municipal’s authority’s standards and no records of such works were given. The information in table 2.1 was abstracted by scaling for these drawings.

Table 2.1 Existing Pipe Sizes, Materials and Lengths

	Pipe Materials and Lengths		
Pipe Sizes (dia.mm)	Steel	AC	
50	4980	401309	406289
75	11578	428766	440344
100	8389	691920	700309
125	-	530	530
150	3576	421993	425569
225	8918	185504	194422
250	6168	15422	21590
300	14881	100325	115206
350	9884	1000	10 890
375/400	15270	28690	43 960
450	4070	22621	26691
500/575	16866	-	23311
600	10870	-	10870
750	19170	-	19170
800	9050	-	9050
975/1000	21276	-	21276
1300	12290	-	12290
Total	177233	2 303 531	2 484 767

Source: Mahachi (1994)

The above study showed that there were about 990 pipe bursts per year on average and most of these bursts took place on asbestos pipes. Burst in water mains are typically detected when water percolates upwards from the burst and inundates the adjacent surface. When these bursts in mains are detected, they are reported by the general public to ZNWA. The saturated are excavated to expose the damaged pipe and repairs are undertaken to suit the extent of damaged main.

2.4 Role of ZINWA

In the early 1990s, Zimbabwe was facing problems of persistent droughts competition within and between sectors due to increasing demand, imbalances in access to water between commercial and communal farmers, and the need to decentralise water resources management in line with the Economic Structural Adjustment Programme which was adopted in 1991. Furthermore the Dublin and Rio conferences emphasized the need to address gender and treat water as an economic good. In line with these, Zimbabwe embarked on a programme to reform its water sector and this saw the 1997 Water Bill and the birth of 2000 Water Act and ZINWA. The Harare water supply falls under the jurisdiction of the Zimbabwe National Water Authority (ZINWA). It is the duty of ZINWA to advise the Minister on matters relating to water, participate in water resources development planning, conserve and manage water resources, promote efficient, equitable and sustainable allocation and use of water. Above all, it is also the duty of ZINWA to maintain water supply in urban areas for 24 hours a day, plumbing to service lines so as to avoid wastage. A lot has been done to improve the capacity of ZINWA to carry out its duties and these include Environmental Management Agency, Waternet and the Institute of Water and Sanitation Development among other measures (Manzungu, 2000). However, the major problem that still persists is the failure to early detect leakage in the treated piped water system and repairing burst water pipes. However, it is historically known that the Harare water supply system that ZINWA took over had many problems which range from finance to effective management of water.

2.5 Factors contributing to water shortages

Population growth

Population growth is one of the major factors which are highly impacting the supply of piped water in urban areas as the demand will be high (Chenje, Sola and Paleney, 1998). The level of water stress grows with population increase leading to water shortages. In Harare before and soon after independence there were no major water woes compared to the current water shortages (Gary, 1991). Before independence there was less population due to colonial rules and in 1992 the population of Harare ballooned to 1850 000 and this posed a major threat on pipe water supply leading to water shortages. The situation of water supply in Harare has worsened due to population which has grown to over 2 000 000 and ZINWA is being faced with a big challenge of supplying enough water.

Infrastructure

Infrastructure is inadequate and unable to meet the growing demands for service (SARDC, SIDA, World Bank and IUCN, 2002). The development of water and sanitation infrastructure is a function of demand of services (Chenje, Sola and Paleney, 1998). This means low access and shortage to safe drinking water and adequate sanitation are as a result of inadequate infrastructure, and poor operation and maintenance of facilities (SARDC, SIDA, World Bank and IUCN, 2002). The infrastructure of many countries like Zimbabwe is old and it is now difficult for the pipes to adequately provide the service resulting in many pipes bursting causing water shortages (Tevera and Moyo, 2000).

Urbanisation

Rapid growth and expansion of urban areas especially around Harare has grossly contributed to water shortages as demand is now very high (Tevera and Moyo, 2000). The increase in water demand is outstripping the supply leading to perennial water shortages. A number of areas experience low water pressures during peak periods with some receiving no piped water at all. As the situation is, high rural-urban migration is contributing to water shortages in the capital of Harare.

Pipe bursts

Bursts in the pipe mains is a factor which is contributing to water shortages as a significant amounts of water are being lost in transit to consumers. In South Africa, of the 62 systems an estimation of 623 million cubic meters or 29% of the total water supplied is lost (Water Wheel, 2007). The extent of water losses, wastages and inefficient use of water is negatively affecting the ability of municipalities to provide sustainable services.

2.6 Causes of pipe bursts

Mains (pipes) bursts are caused by a variety of factors. Some of the common external factors relating to road opening activities are: direct damage of water mains and valves by indiscriminate or reckless use of construction plant, groundsettlement or movement caused by excavation work, disturbance of lateral or vertical support to water mainsand excessive stress or loading caused by piling, blasting, heavy mechanical plant or construction traffic.

Internal factors

There are various internal factors which contribute to water pipe bursts and these are age of the pipes, water pressure, type of material, composition, joining methods, quality of initial installation, and contact with other structures, stress from traffic, frost loads, freezing soil around the pipes and rusting through age.

2.7 Benefits of early burst detection and repair

Minimizing water pipe bursts in water systems has many benefits for water consumers and users. These include improved operational efficiency, lowered water systems operational costs, reduced potential for contamination, extended life of facilities, reduced potential property damage and water system liability, reduced water shortage events and improved public relation

CHAPTER 3: MATERIALS AND METHODS

3.1 Study Area

The study was carried out in the suburbs of Harare which is the capital city of Zimbabawe. Areas which were chosen constitute both old and new suburbs. It is in Harare where we have some of the oldest buildings for example Mbare, industrial locations like Rugare and it is in these areas where highest concentrations of populations are found. A study carried out by Mahachi (1994), indicated that most of oldest locations in Harare experience water shortage although the situation has changed as it is affecting both old and new due to different reasons. As already indicated above, the situation at hand indicates that both new and old suburbs are experience acute water shortages. This problem has been magnified by pipe bursts and people have been left with no other option other than fetching water in nearby rivers or digging wells at their places. Thus risking their lives as most of these waters are contaminated as they are close to sewages which run everywhere. Some of the places or locations in the study area are located in high and low areas like Highlands and Belvedere respectively as indicated in the study area (Fig.3.1).

3.2 Methods and Materials

In this research, field surveys such as interviews, GPS points collection, use of software such as Arc-View GIS, IWLWIS, SPSS and other methods as shall be indicated below were used. In digitizing pipes, a hard copy map showing water pipes distribution was acquired from ZINWA on scale 1:1250 based on surveyor's general map. The map was first scanned, geo-referenced and the pipes were digitised in GIS based system as indicated below (Fig 3.1).

The DEM of the study area was generated from the map of 1:2500 (higher resolution). However, the map had some gaps and these were filled using 90m by 90m DEM using co-Kriging. In this, the 1:2500 elevations were used as an independent variable while the 90m by 90m elevations were used as dependent variable. Details of co-Kriging as interpolation methods are treated in detail in Roland (2008) and the DEM is shown in Appendix 3.

Slope percentage was calculated using the following formula:

$$Slope\% = \frac{100 \times hyp(dx,dy)}{pixel\ size(DEM)}$$

Equation 1

Where: HYP is hypotenuse function, DX is change in x, DY is change in y and DEM is digital elevation model and Slope in degrees was calculated using the following formula:

$$Slope\ degree=\frac{RAADEG(ATAN(slope\%))}{100}$$

Equation 2

Where: RAADEG and ATAN internal map calculations as shown in Appendix 4. The digitized pipes were then overlaid with the slope and entrenched 2m Probability slope map was produced in a GIS as illustrated in Appendix 8. The map was sliced and crossed with the water pipe map as shown in Figure 10.

Pipe bursts points were obtained from ZINWA daily record book and their GPS points were identified using the geo-referenced map of Harare. The non-burst points were randomly sampled in the Arc-View (Fig.3.2).

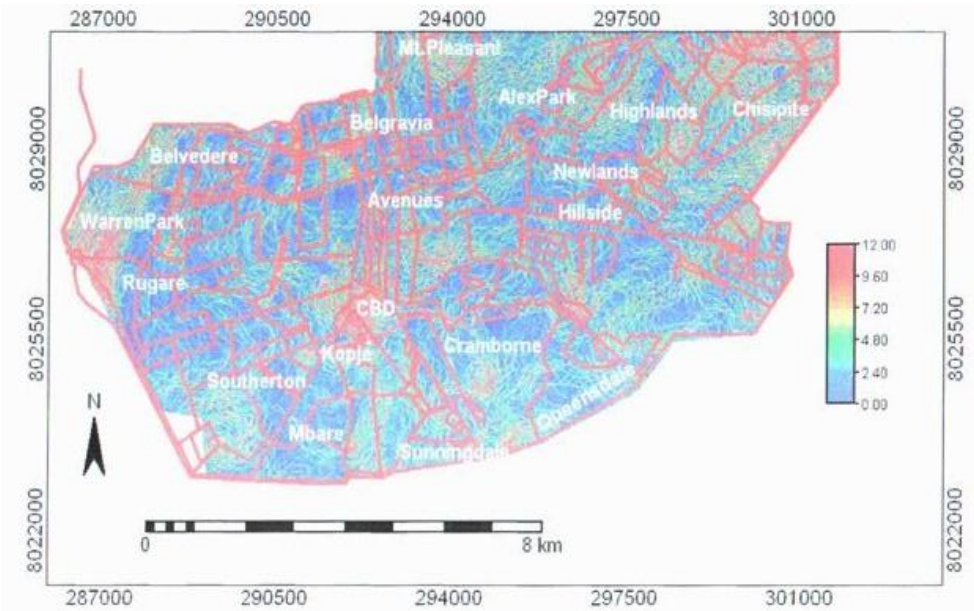


Figure 3.1: Digitized pipes of study area

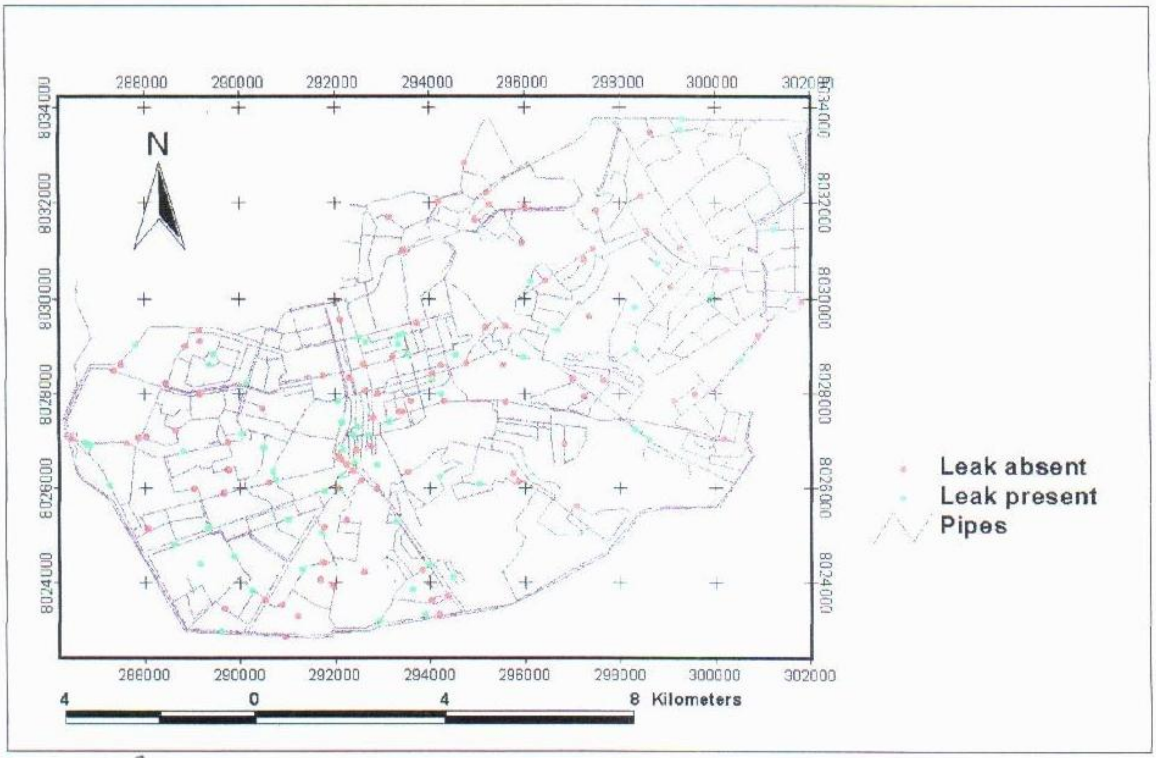


Figure 3.2: Burst and Non-Burst points

A hard copy of pipe material was obtained from ZINWA offices and this was mapped in Arc-View GIS and was assorted based on material as shown in Appendix 2. The age of the pipes was obtained by relating pipes to the time of construction. Age map was generated in a GIS and probability map for age was produced as shown in Appendix 6. The probability Age map was sliced and crossed as shown in Figure 9 for easy communication. The pipe lengths for material was calculated in GIS-Arc-View based system.

Pressure was calculated in GIS using the following formula:

$$V = \frac{k}{n} R^{2/3} h^{.S^{1/2}}$$

Equation 3

Where:V is the cross-sectional average water velocity; *k* is a conversion constant equal to 1.486, *n* is the Manning coefficient of roughness (independent of units), *Rh* is the pipe diameter, *S* is height of the tank. A Moody Chart was used to find friction factors and Reynolds Number for Darcy friction factor.

*Where :*is the head loss due to friction; L is the length of the pipe; D is the hydraulic diameter of the pipe (for a pipe of a circular section, this equals the internal diameter of the cross-sectional wetted area; *g* is the local acceleration due to gravity *f* is a dimensionless coefficient called the Darcy friction factor:

$$\mathrm{hf} = f.\frac{L}{D}.\frac{V^2}{2g}$$

Equation 4

Given that the head loss *hf* expresses the pressure loss *Δp*as height of column of fluid,

$$\Delta \mathrm{p} = \rho \mathrm{ghf}$$

Equation 5

Where: ρ is the density of the fluid, the Darcy-Weisbach equation can also be written in terms of pressure loss:

$$\Delta \mathrm{p} \alpha \frac{L}{D} x \frac{1}{2} \rho \mathrm{V}^2$$

Equation 6

Where: the pressure due to friction factor Δp is a function of length to diameter of pipe L/D; ρ is the density of fluid, *V*is the average velocity of flow, a dimensionless coefficient of laminar or turbulent flow λ. After calculating pressure of different pipe sizes a probability pressure map was produced as is shown in Fig. 7. The map was sliced and crossed with the pipe map to show variations in pressure as is shown in Fig.7

CHAPTER 4: RESULTS AND DISCUSSION

4.1 Results

Figure 4.1 shows a significant ($p<0.05$) relationship between terrain slope and the occurrence of water pipe bursts. It can be observed that there is a negative relationship between slope and the probability of leaks occurring. Most pipe bursts occur between 0-8 degrees (Fig.4.2). At 0 degrees the probability of water pipe burst is very high above 0.8. Probability of water pipe burst does not significantly at 12 degrees as the probability of water pipe burst is still above 0.5. It can also be observed that as the slope continues to increase the probability of water pipe bursts decrease. At a higher slope of about 40 degrees the chances of having water pipe burst is very low as it is less than 0.1 (Fig.4.1).

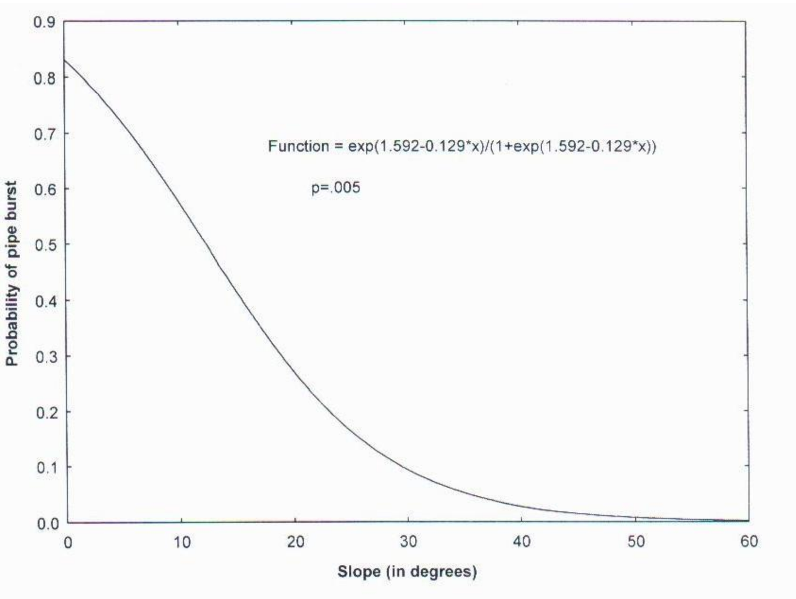


Figure 4.1: A significant ($p<0.05$) negative relationship between terrain slope and probability of pipe bursts

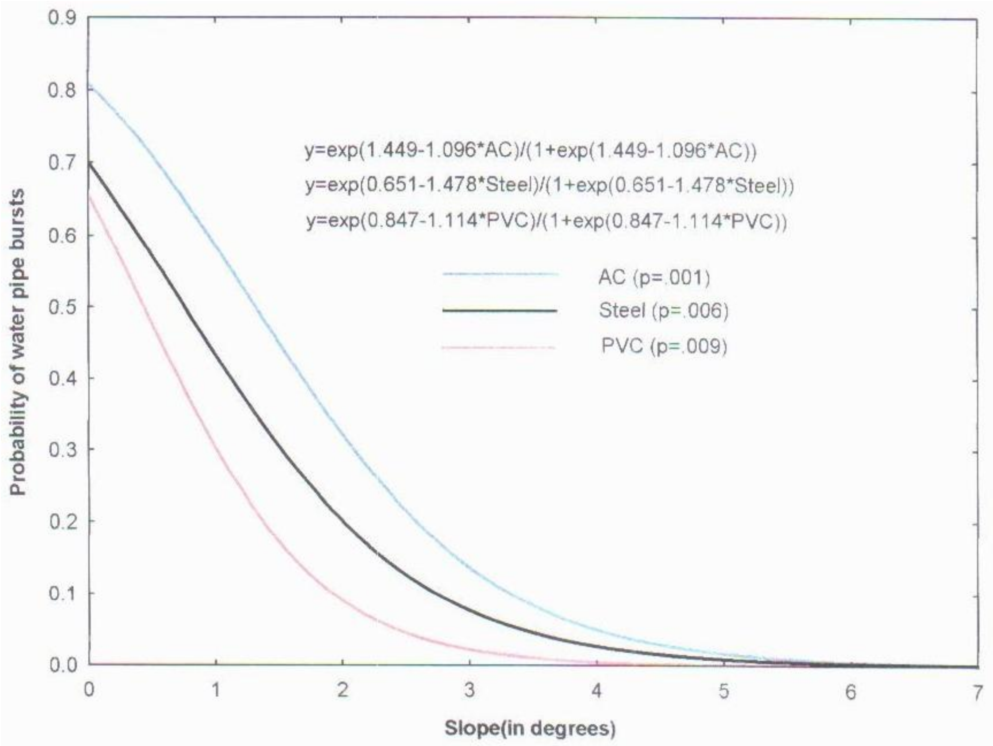


Figure 4.2: A significant (p<0.05) negative relationship between terrain slope and probability of pipe bursts based on material

Figure 4.2 illustrates a significant (p<0.05) relationship between terrain slope and the probability of pipe bursts based on material. It can be observed that there is negative relationship between the probability of pipe water burst based on material and terrain slope. At 0 degrees Asbestos Cement (AC) pipes have a high probability (0.8) of bursting, followed by Steel pipes (0.7) and lastly Polyvinyl chloride (PVC) pipes with a probability of about 0.65. The probability of water pipe burst at a slope of 1 degree shows a significant decrease in PVC (below 0.5) but for Steel and AC pipes remaining high (above 0.5 with AC recording the highest-0.65). It can be observed that as slope decreases, the probability of water pipe burst also reduces. At a slope height of 4 degrees the probability of PVC pipes shows a very minimal probability of bursting (close to 0), with Steel (0.5) and AC pipes (0.1) showing a probability of bursting. At a slope height of 5 degrees it can be observed that Steel pipes like PVC pipes no longer burst (0.0) and lastly AC pipes having a probability 0f (0.0) chance of water pipe bursting at about 6 degrees.

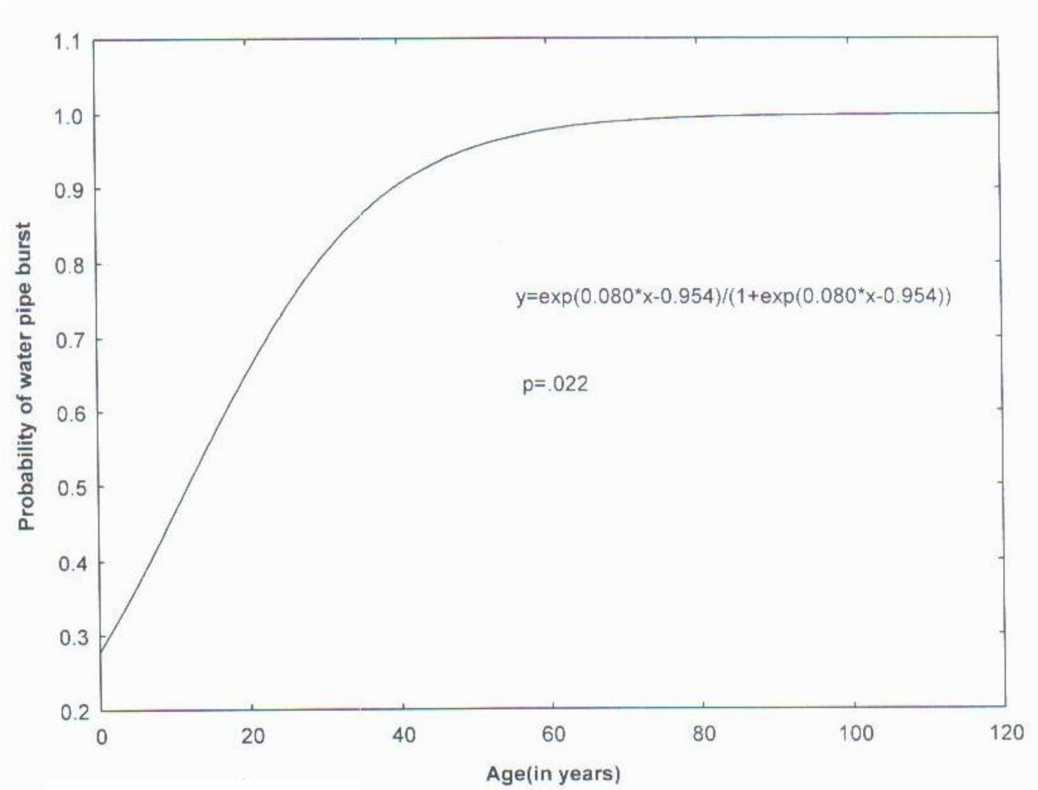


Figure 4.3: A significant (p<0.05) positive relationship between pipe age and probability of pipe bursts

Figure 4.3 illustrates a significant (p<0.05) relationship between age and the probability of pipe water burst. It can be observed that there is a positive relationship between the probability of water pipe burst and age. It can further be observed that as the age increases, the probability of water pipe bursts increase (Fig.4.3). All pipes show a high probability of water pipe burst (0.6) at 20 years. There is high probability of water pipe bursts between the ages of 40 and 60 as the probability ranges from 0.82 to 0.92 (Fig.4.3).

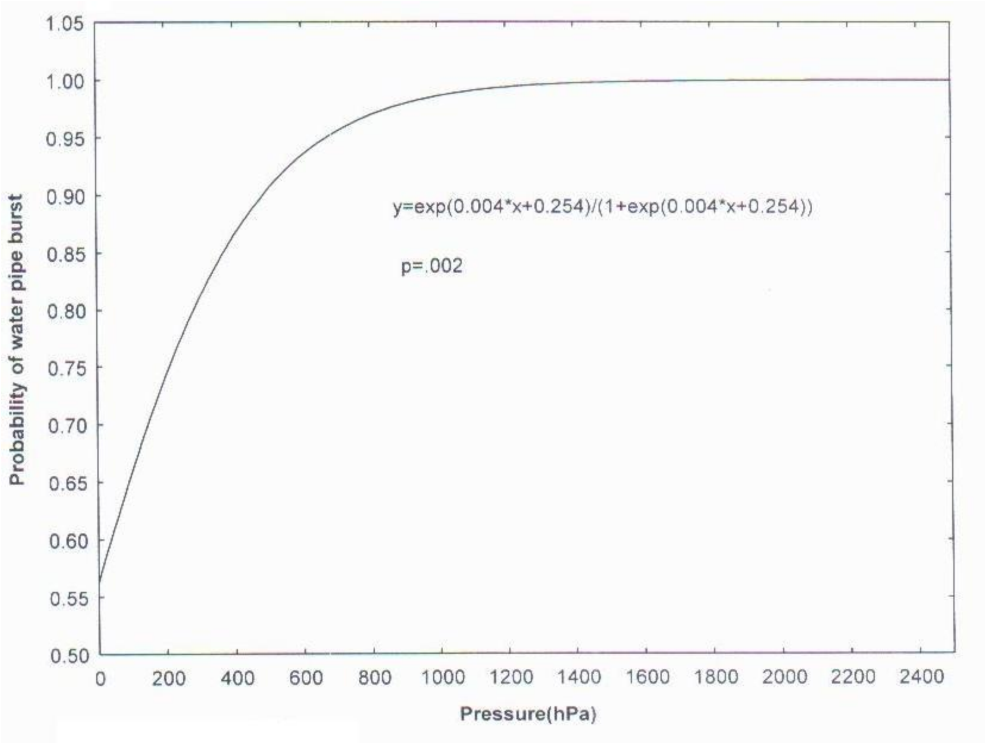


Figure 4.4: A significant ($p<0.05$) positive relationship between pressure and probability of pipe bursts

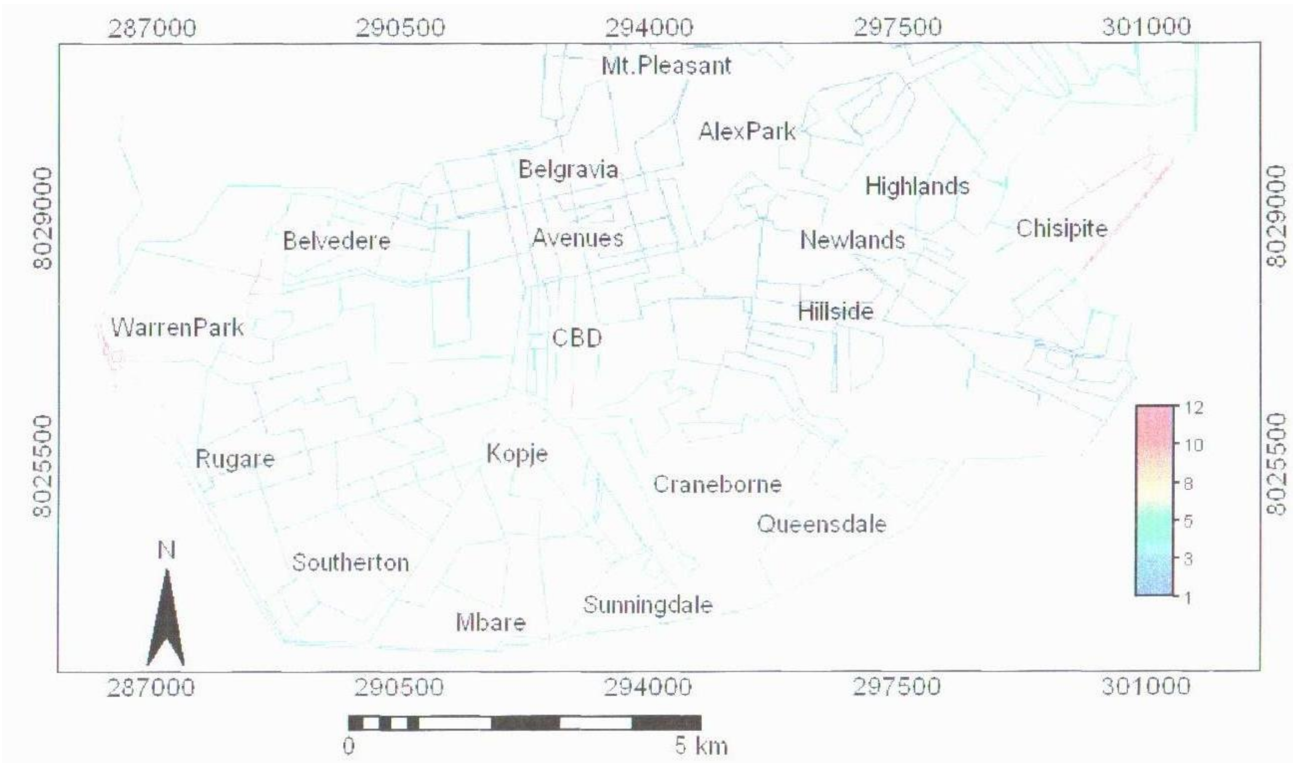
Table 4.1 Pressure results for different pipe sizes

Size	Class	Pressure (hPa)
100	18	900
150	12	600
225	18	900
300	6	300
225	6	300
750	30	1500
150	24	1200
300	18	900

Figure 4.4 illustrates a significant ($p<0.05$) relationship between pipe water pressure and the probability of water pipe bursts. It can be observed that there is a positive relationship between pressure and the probability of water pipe burst. It can further be observed as pressure increases, the probability of having water pipe bursts also increases. From 0 to 200 hPa the probability of water pipe burst is above 0.65 which is high. At 600hPa the probability of water pipe burst is above 0.9 which is very high and at 1000hPa the probability of water

pipe burst (0.96) does not significantly differ. As indicated in Fig.4.4 more water bursts occur between 600 and 1000hPa.

Figure 4.5: Age variations along pipes in the study area



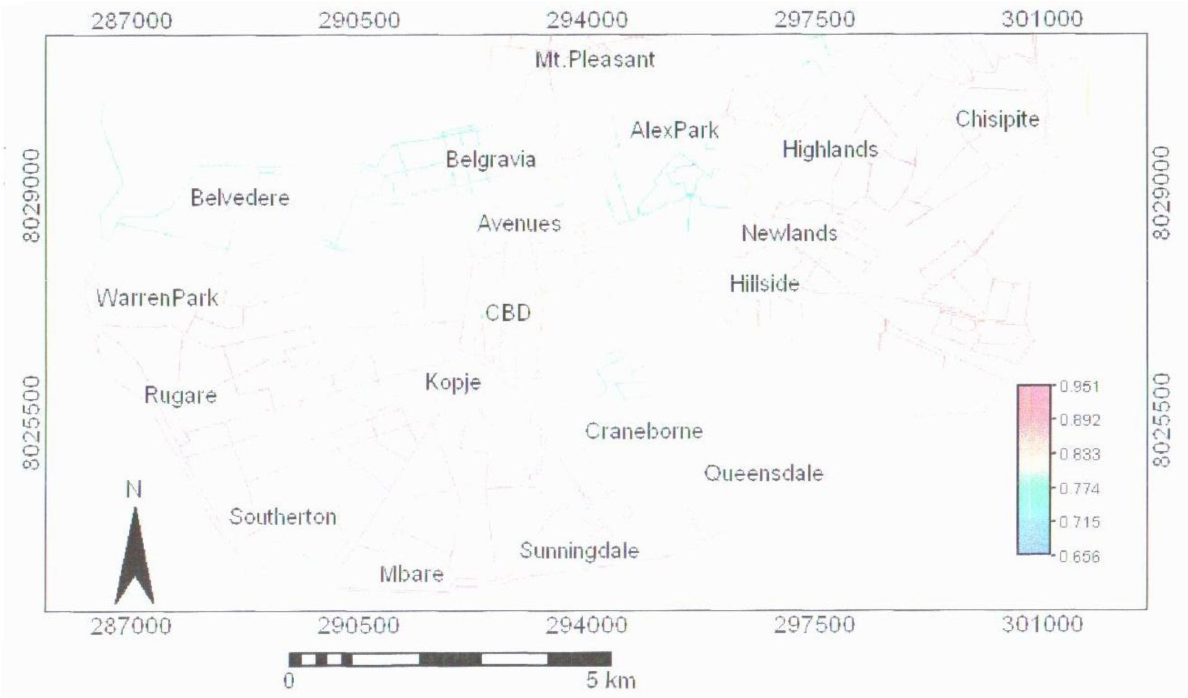


Figure4.6: Slope variations along pipes in the study area

4.2 DISCUSSION

Results in this study indicate an inverse relationship between water pipe bursts and slope (Fig.4). This means pipe water pressure increases with decrease in slope and increase in length of pipes. Results further indicate that water pipe bursts mostly occur between 0-5 degrees. This finding is supported by the findings of Mahachi (1994) which indicate that water pipes bursts are more in Hatfield, Mbare and Southerton suburbs, which are areas of predominantly low terrain slopes. Thus, it is deduced that lower areas in terrain result in higher water flow accumulations that result in higher probability of pipe bursts in these areas.

Moreover, findings indicate significant ($p<0.05$) contribution of different pipe materials to the probability of water pipe bursts. Results indicate that AC pipes have the highest probability of bursts, followed by Steel and then by PVC. This is because AC pipes are relatively weaker and brittle than Steel pipes in withstanding excessive external load or pressure. AC pipes are the dominant type in the study area, thus explaining the high frequency of water pipe bursts. The weakness of AC pipe is further compounded by the fact that it is also mostly found in low areas. This means that excessive external load or pressure from haulage trucks and vehicles is the reason why AC water pipe bursts are more than in Steel and PVC pipes.

Furthermore, results indicate that at a lower slope PVC pipes experience more frequent bursts than Steel and AC pipes. This may be attributed to the fact that PVC pipes are not resistant to solvents, aromatics and some chlorinated hydrocarbons make them prone to attacks from these chemicals. The bursts can be attributed to external pressures from vehicles and haulages trucks since they are along roads as explained above. However, PVC pipes have the least probability ($p<0.009$) because they are resistant to many acids, bases, salts, parrafinic hydrocarbons, halogens, alcohols and they are strong in withstanding excessive stresses than Steel and AC pipes. Above all, PVC pipes are a recent phenomenon (first laid in 1997) compared to Steel and AC pipes, a factor that makes them strong in withstanding pressure, chemical attacks better than the other two materials.

Findings in this study indicate that Steel pipes are weaker than Ac pipes because Steel pipes do not withstand internal water pressure and their corrosive nature make them have numerous bursts more than PVC (O'Dweyer, 1994). This weakness is further worsened by the fact that most Steel pipes are found along major roads where they experience a lot of pressure from heavy vehicles, as well as, release of chemical substances which attack steel pipes, wearing them down, thus increasing chances of bursts. Appendix 2 indicates water pipe materials based on each suburb. Many AC pipes have small pipe sizes which mainly range from 125mm-225mm as compared to Steel. This means the high probability of water pipe bursts in AC pipes is interplay of pipe size and pipe length and slope. However all pipes are highly influenced by slope as indicated in Fig.4

One of the major findings is that age is positively related with the probability of pipe bursts (Fig.5). Pipes that have the oldest age experience very high probability of water pipe bursts. Mbare, Southerton, Central Business District of Harare are among other suburbs which are very old, consequently they have the oldest pipes and as the result they experience high probability of water pipe bursts. More so, pipe rust and corrosion due to attacks from chemicals, breakages due to continuous stress, pressure due to everyday activities make water pipe bursts increase with each year. Furthermore AC and Steel pipes have a maximum durability of 10 years, rust on Steel pipes and corrosion and external pressures on both pipes may be factors that make them burst. Thus making age a major contributor to pipe water bursts in Harare (Fig.5).

A significant relationship ($p<0.05$) between pressure and probability of water pipe burst is indicated (Fig.6). Probability of water pipe bursts increase with pressure (Fig.6). Slope and pressure have a strong positive correlation in that areas which are low in slope experience high pressure due to flow accumulation. Size of pipes and length of pipes are some of the reasons why pressure significantly explains water pipe bursts. This is because pressure increase is a function of slope, pipe length and pipe size. Pipe contains large volumes of water more than the pressure they can withstand which results in them bursting. In addition pipes transport water for so long distances of about 2km, velocity increase with pipe length and slope make pressure high making it a major factor contributing to water pipe bursts. In overall, it should be noted that each material that is AC, Steel and PVC pipes has its weaknesses and this explains why water pipe bursts occur and why they are numerous.

CHAPTER 5: CONCLUSION AND POLICY IMPLICATIONS

5.1 Conclusion

The study revealed that there is significant relationship between water pipe related factors such and water pressure, slope, age, pipe material and probability of water pipe bursts. This explains that water pipe bursts are as a result of these factors specifically slope, pressure, pipe material and age as they significantly explain pipe water bursts. It has been found in this study that water pipe bursts frequency differs with material due to different factors as explained in the results section. In this study AC pipes have the highest chance bursting when compared to Steel and PVC. This is supported by a study which was carried by Mahachi (1994) which showed that 60% of water pipe bursts take place on AC pipes and about 40% on Steel pipes (by then there were no PVC pipes). It is also from the above research that pressure, age, type of material and slope contribute significantly to water pipe bursts as also supported by O'Dwyer (1996). This means that the durability, pressure and slope should be considered when water pipes are being installed. It can also be safely concluded that water pipe bursts can be modelled spatially in a GIS based system and this a cost effective measure in both space and time.

5.2 Policy Implications.

Water resources are vital for sustainable economic and social development in any country (SADC, 2005). It is because of this that the conservation of water across societies forms the cornerstone to physical, social and economic development. The need for present generations to use water in a sustainable is seen as the key to the development of future generations as many water bodies are now under threat (Mazvimavi, 2000). This study is backed by international, regional and local policies and principles on the conservation of water. The Rio-Dublin principles of 1992 emphasized the need for present generations to protect and conserve water for future generations. Thus the principles of equal access, participatory approach, women taking key positions in water management related issues and the need to treat water as an economic good, aim at conserving water. At a global level there are various water policies and principles such as those stipulated in Dublin principles. Principle No.1-

There should GIS and Remote Sensing Department which monitors pipe water bursts. Principle No.2- water development and management should be based on a participatory approach involving users, planners and policy makers at all levels. Principle No.3- water has an economic value in all its competing users and should be recognised as an economic good. Water is the first basic right of all human beings to have access to clean water and sanitation at affordable price. Managing water as an economic good is an important way of achieving efficient and equitable use and of encouraging conservation and protection of water resources (Miguel and Gonzalez-Villarreal, 1990).

At regional level there is The SADC Revised Protocol on shared Watercourses, SADC Water Policy, SADC Water Strategy and SADC Indicative Strategy Action Plan, which outline policies and principles of water resource management. Among them are water for poverty alleviation, environment, peace and cooperation and Integrated Water Resources Management.

At local level, Zimbabwe has its water policies and principles that are backed by legal instruments. In early 1990s, Zimbabwe was facing persistent droughts, increasing competition within and between sectors due to increasing demand, imbalances in access to water between commercial and communal farmers, and the need to decentralise water resources management in line with Economic Structural Adjustment Programme-ESAP. The Zimbabwean water reformations for example 1998 Water Act and 2000 ZINWA Act were meant to address some these problems. The study meets Zimbabwean water policies on Water conservation and Demand management, Water pricing, Water resource allocation and ZINWA principles of supplying clean and enough water to consumers and helps on matters relating to water resources, promote efficient, equitable and sustainable allocation and use of water. It is also in the context of water supply that the National Environmental Health Policy of Zimbabwe on water supply and sanitation was formulated. The study helps in the advancement of the field in contributing with scientific knowledge and helps conscientise people and water bodies. The study helps water sectors on the conservation of water and water authorities on urban water policy formulations such as water rationing and water pricing. As indicated the need to conserve fresh urban water supply through effective monitoring of pipe water bursts. It is because of this that the study is supported by international, regional and local policies and principles as indicated above.

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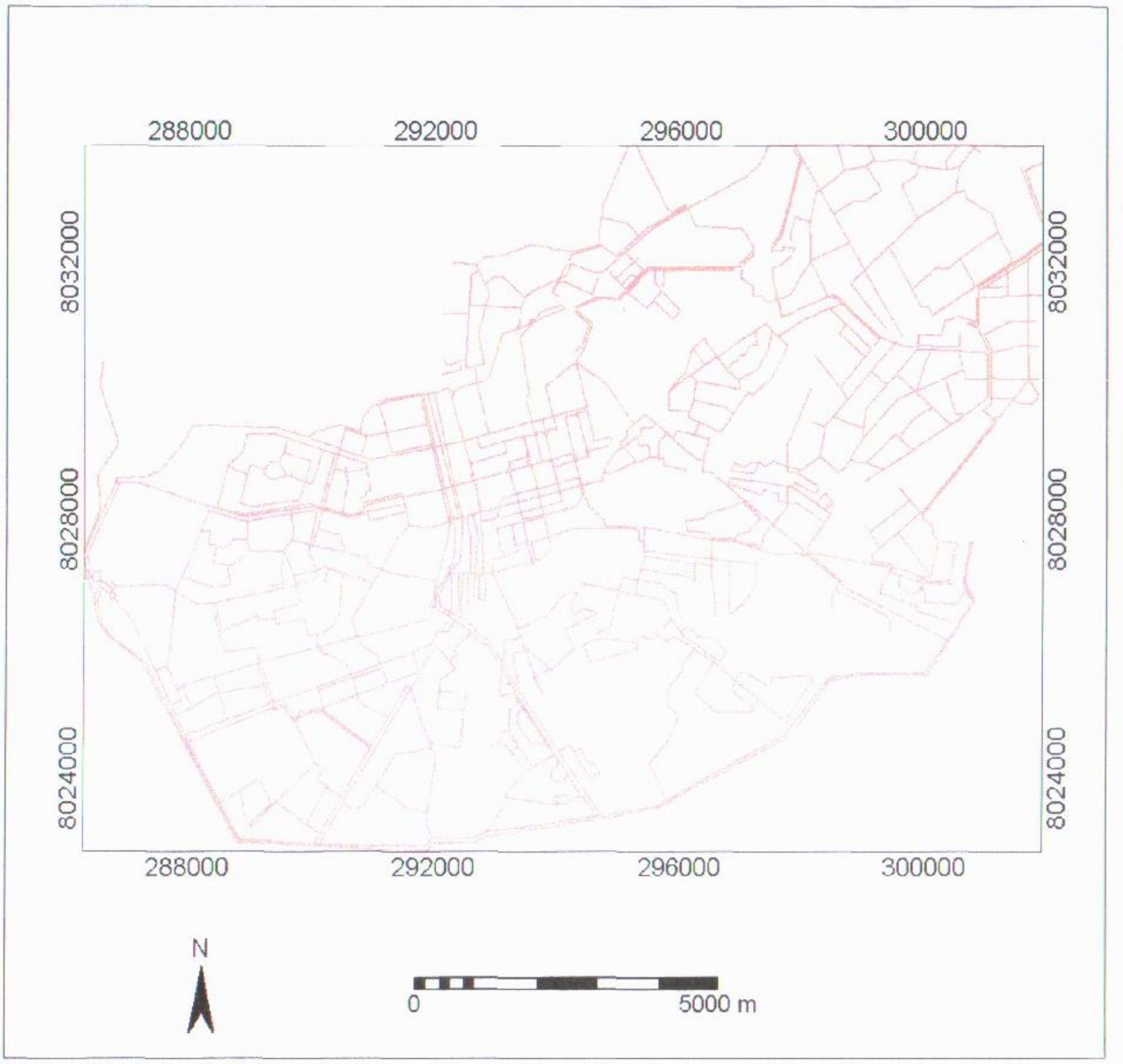
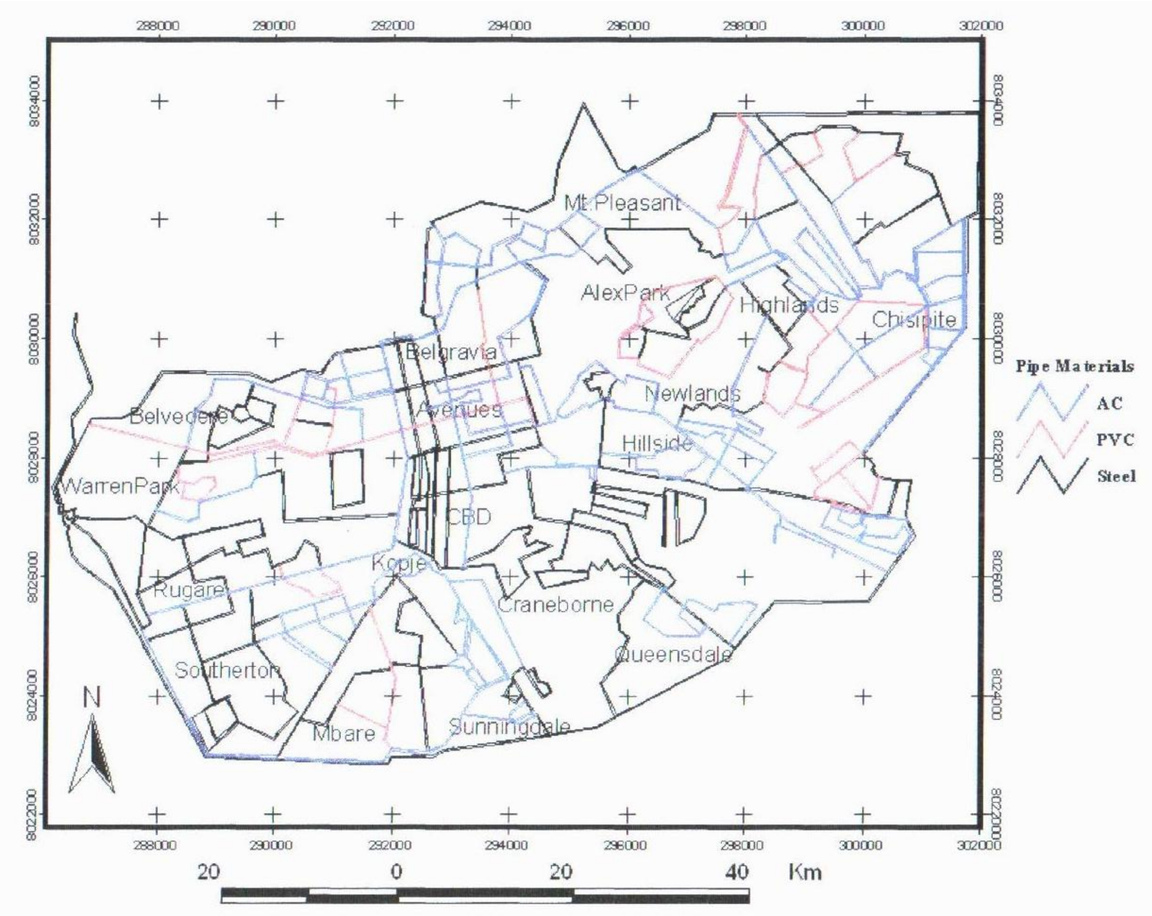
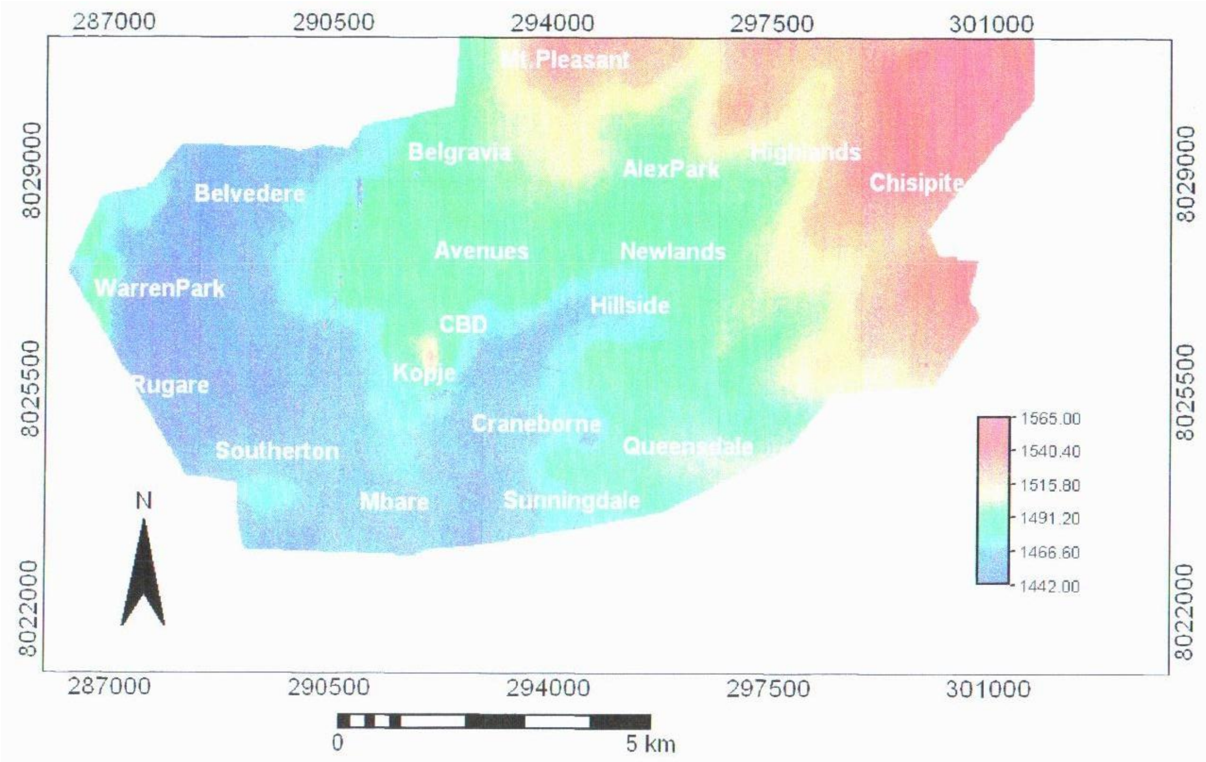
LIST OF APPENDICES



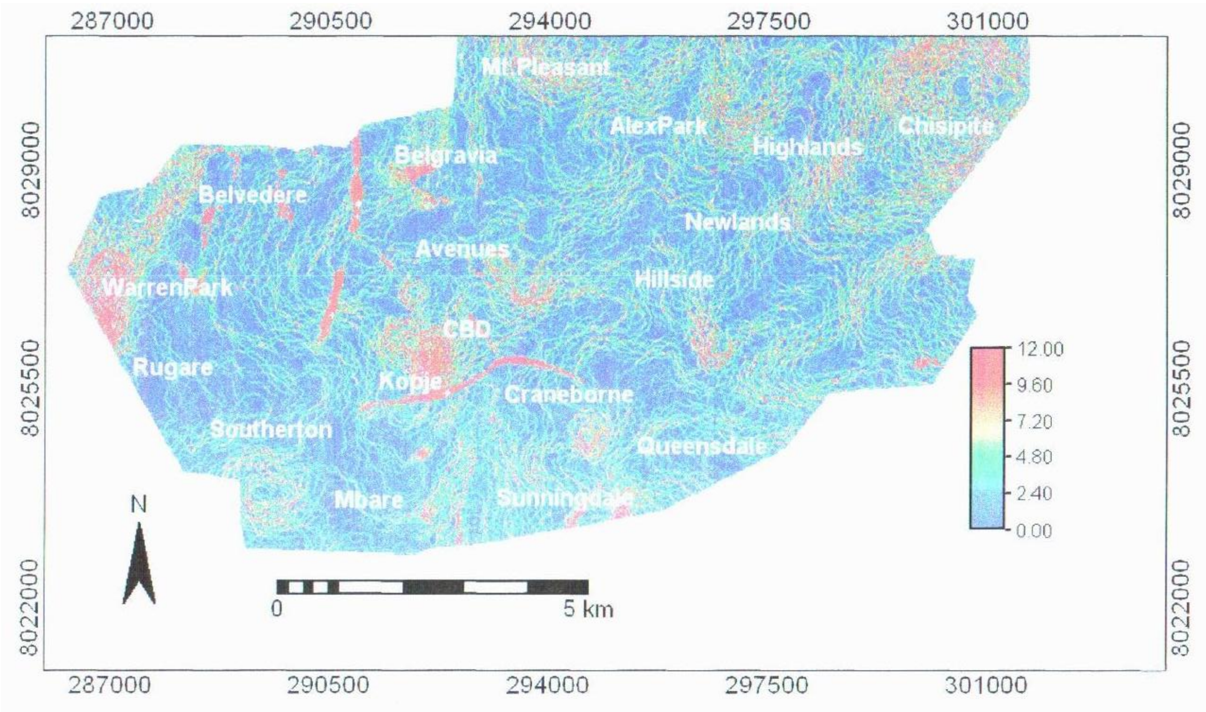
Appendix 1: Digitized water pipes of Harare



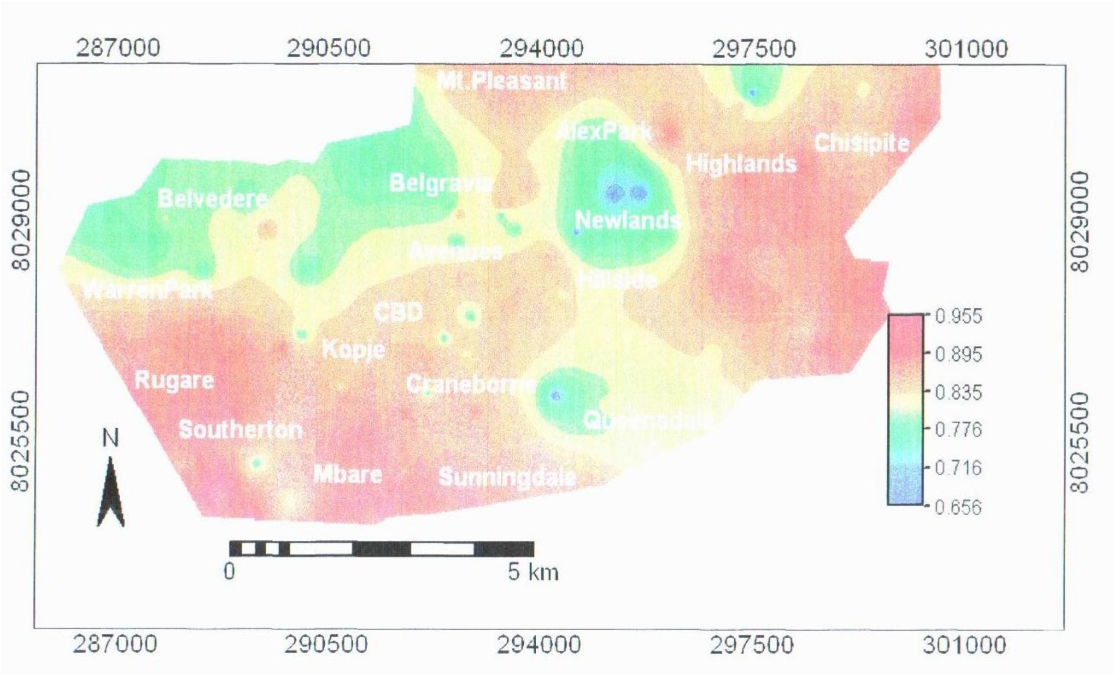
Appendix 2: Harare water pipe material



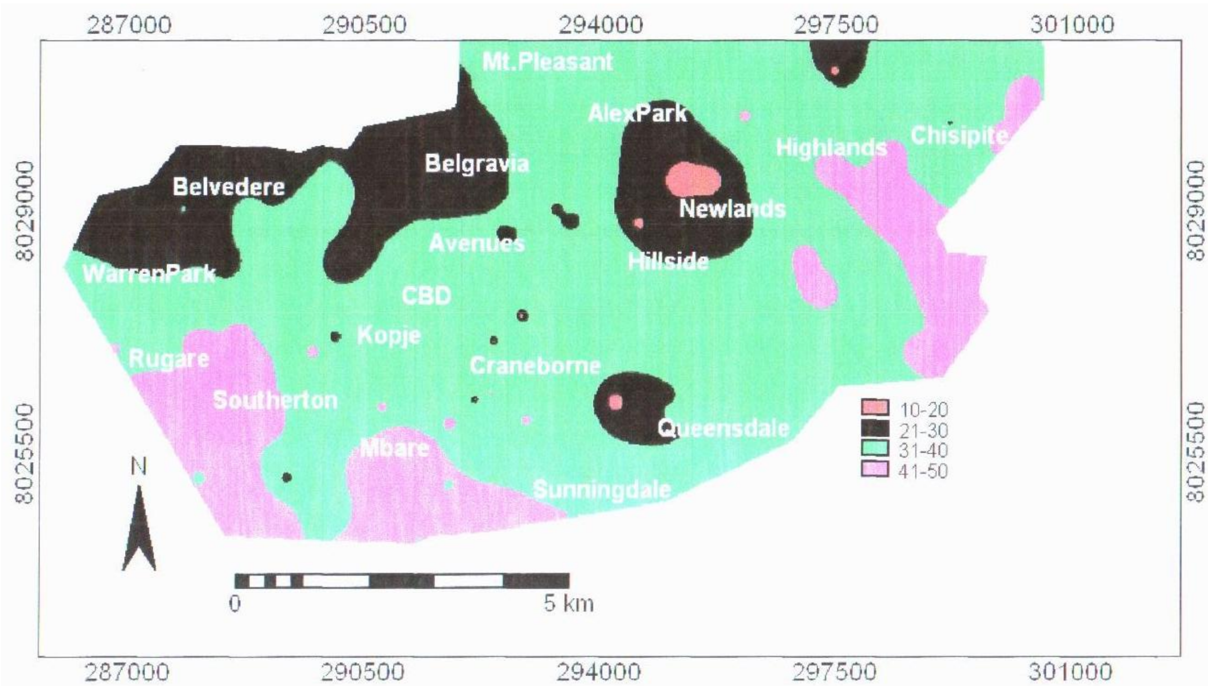
Appendix 3: Digitized Elevation Model



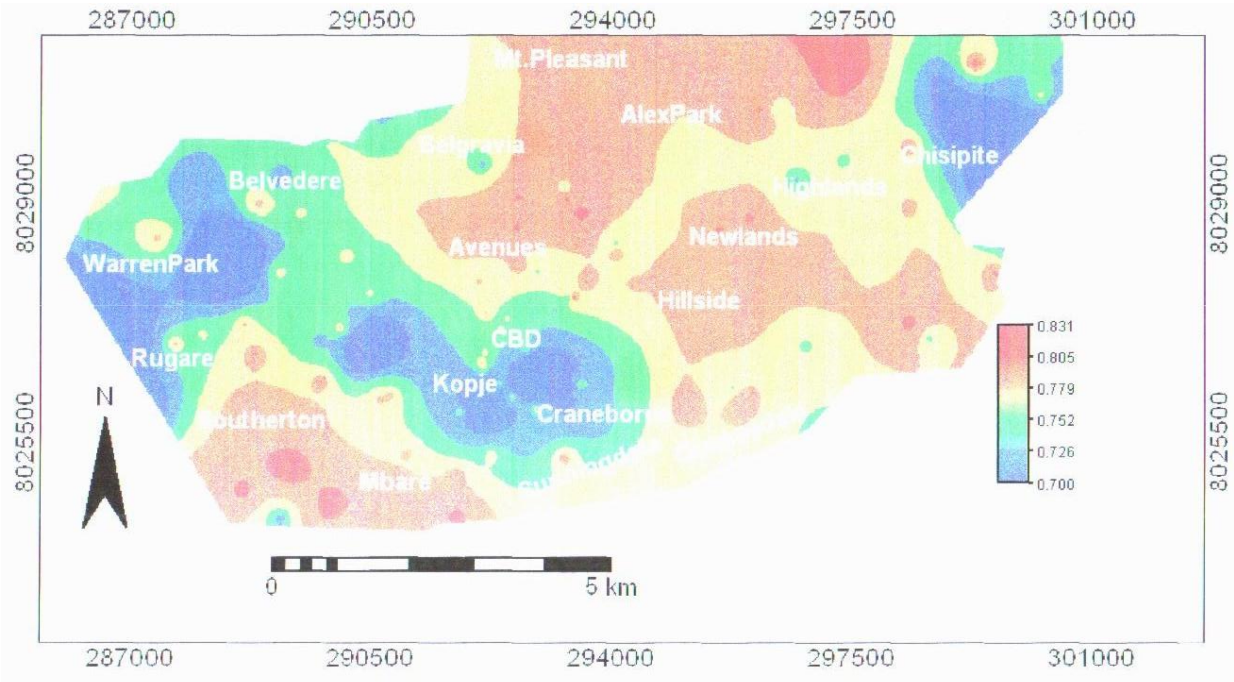
Appendix 4: Slope of study area



Appendix 5: Spatial age variations



Appendix 6: Spatial pressure variations



Appendix 7: Spatial pressure variation