National Journal of Advanced Research
Online ISSN: 2455-216X; Impact Factor: RJIF 5.12
www.allnationaljournal.com
Volume 3; Issue 1; January 2017; Page No. 29-34

Non-revenue water loss in Norton, Zimbabwe: Levels, Sources and mitigatory measures

***Tanyaradzwa Chigonda, Evans Chazireni**

Department of Physics, Geography and Environmental Science. Great Zimbabwe University. Masvingo, Zimbabwe

Abstract
Understanding elements of non-revenue water loss has become more crucial in an era where urban water demand, particularly in developing countries, is rapidly increasing. Non-revenue water is the difference between the amount of treated water put into the distribution system and the amount of water billed to consumers. The study sought to establish the levels and sources of non-revenue water loss in Norton between 2010 and 2014. The study revealed an unacceptably high average annual non-revenue water loss of 40% in Norton during the period under review. Various sources of non-revenue water loss including pipe bursts, metering inaccuracies, authorized unmetered use and unauthorized unmetered use were identified. The study recommends that Norton Town Council should install computerized leak detection for quick response to pipe bursts in the reticulation network. Norton Town Council should also ensure that all water consumption in the town is accurately billed through properly functioning water meters.

Keywords: water loss, non-revenue water, unaccounted-for water, non-billed water, water reticulation network, computerized leak detection

1. Introduction
Due to ever-increasing urban populations and expanding service areas, many water utilities in the world, particularly in developing countries, are struggling to meet growing demand for clean drinking water [1]. One of the major challenges facing public water supply entities, as they strive to meet increasing demand, is the high level of water loss in transport and distribution networks. Such lost water yields no revenue, makes it difficult to meet consumer demand, in addition to making it harder for water utilities to keep water tariffs at reasonable and affordable levels [1]. In addition, water losses in the distribution system require more water to be treated, which in turn requires the use of additional energy and chemicals, resulting in wasted resources [2]. With growing concerns about shrinking budgets, public water supply systems must implement water loss control programmes as water lost in the distribution system means lost revenue [2].

The water losses in the distribution network, usually dubbed non-revenue water, unaccounted-for water, non-billed water, or vanishing water, may reach levels of over 60% in old and dilapidated reticulation systems [3, 4]. Non-revenue water is the difference between the amount of water put into the distribution system by a public water supply and the amount of water billed to consumers [1]. It includes leakages in the reticulation network, unauthorized use, metering inaccuracies, and authorized unmetered use [1, 3, 5, 6].

Theoretically, no water loss should be acceptable, but experience shows that it is not possible to operate even the most efficient system without a certain amount of water loss occurring [7]. Some of the losses could be considered legitimate, including water used by the utility for operational purposes such as filter backwashing; water used for firefighting, street washing, and sewer flushing; and water provided for free to certain consumer groups [1, 8, 9]. As such, efforts to address the problem of non-revenue water loss aim at reducing this water loss to normal or acceptable levels, as total elimination of non-revenue water is impossible [7]. With some slight variations from country to country, the optimum or maximum acceptable level of non-revenue water loss in a well-managed urban water utility has been set within the range of 15% to 20% [2, 10]. Non-revenue water loss exceeding 20% of the water put into the supply network can represent a substantial financial loss to any water treatment and supply undertaking [2, 10]. In addition to economic considerations, leaking systems may present substantial threats to public health through the infiltration of contaminated groundwater into the distribution network, especially during low pressure flows [2, 4, 6, 11].

There is mounting evidence indicating that non-revenue water loss in most of Zimbabwe's towns and cities is occurring at unacceptable levels, thereby threatening the economic viability of water supply undertakings in these areas, in addition to hampering efforts to provide adequate water to various consumers [12]. For example, non-revenue water loss in Mutare was estimated at 52% of the treated water produced in 2001 [13], while for Harare it was estimated to be 37% in 1997 resulting in Harare City Council losing US$10 million worth of treated water [14]. For the City of Kwekwe, non-revenue water loss was estimated at 30% in 1992 [15].

While no studies to estimate non-revenue water loss have been carried out in Norton, evidence on the ground particularly that of a high frequency of bursting water pipes, points to a high likelihood of the occurrence of unacceptable levels of non-revenue water loss. The need for extra attention to non-revenue water loss in Norton is also due to the fact that the town has no water treatment facility of its own, but buys all its treated water from the City of Harare.

In addition, Norton, with a population of about 65,000 people, requires 10 megalitres of water per day but receives between six and seven megalitres daily from Harare's Morton Jaffray Water Treatment Plant, as Harare is also struggling to meet its own rapidly growing water demand [16]. The above scenario

shows that Norton cannot afford to lose treated water through unacceptable non-revenue water loss levels.

Studies on non-revenue water loss in some cities in Zimbabwe have resulted in the reduction of water losses to acceptable levels. For example, the City of Kwekwe introduced a water loss management programme using electronic leak detection, which resulted in a reduction of water loss from 30% in 1992 to 14% in 1996 [15]. It is therefore hoped that this study might also help in ensuring acceptable non-revenue water losses in Norton. The aim of this research is to establish the levels of non-revenue water loss in Norton during the period from January 2010 to December 2014. The study also aims to identify the sources of the established non-revenue water losses. The paper then concludes with a combination of measures in order to reduce non-revenue water loss to acceptable levels.

2. Study area

Norton is one of Harare's satellite towns alongside Chitungwiza, Ruwa and Epworth (Figure 1). It is situated 40 km to the west of Harare, Zimbabwe's capital, in Mashonaland West Province. Norton's population was estimated at 65 000 in the 2012 national population census [17].

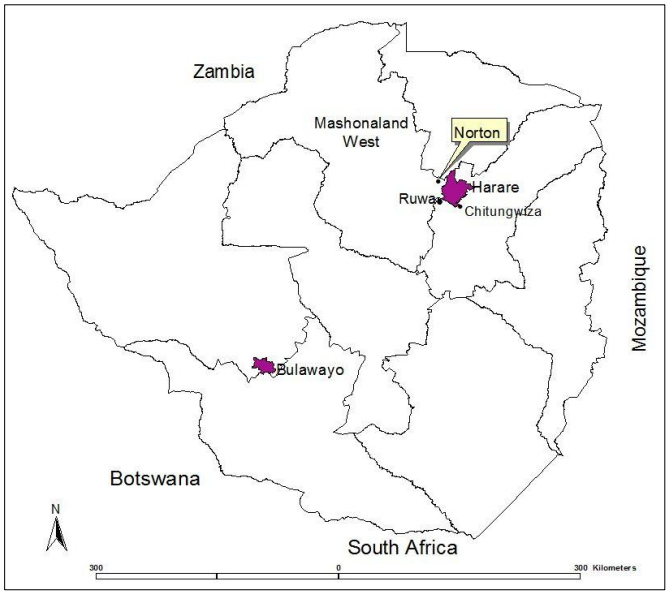

Fig 1: Location of Norton

Unlike some of the other satellite towns of Harare such as Ruwa and Chitungwiza which at least have their own limited water treatment infrastructure (in addition to buying water from Harare), Norton relies on buying treated water from Harare City Council for its entire water supply [18]. This has resulted in perennial water supply problems for Norton as Harare is struggling to meet its own huge and rapidly growing water demand. This has forced Norton Town Council to introduce some water rationing measures. Many residents, especially those in new suburbs, have resorted to various copping strategies including the digging of wells at their homes [16]. The water reticulation network within the town has been developed over 50 years and therefore comprises of both old and new sections and components.

3. Materials and methods

The study was conducted between June 2015 and August 2016. Monthly water purchases by Norton Town Council from Harare City Council, and monthly water sales to consumers in the town between January 2010 and December 2014 were compiled using records kept in the Treasury Department. The difference between purchased water quantities and billed water quantities for each month then became the non-revenue water loss for that month. The monthly non-billed water quantities were then aggregated into annual non-revenue water or annual water losses in the whole reticulation network. Efforts to establish non-revenue water losses for specific sectors or sections of the town were frustrated by the unavailability of such records.

A personal interview was held with a representative from Norton Town Council's Engineering Department so as to establish the condition of the town's water reticulation network, in addition to identifying various sources of non-revenue water loss. A short questionnaire was also self-administered to 50 households, 25 in the high-density suburbs and another 25 in the low-density suburbs, so as to solicit their views on the causes of non-revenue water loss in Norton, and measures that can be adopted to solve the problem. Simple random sampling was employed in selecting households into the sample.

4. Results and discussion

4.1 Levels of non-revenue water loss in Norton

Table 1 presents the annual levels of non-revenue water loss for the whole water reticulation network in Norton in the five-year period from January 2010 to December 2014.

Table 1: Non-Revenue Water Loss Levels For Norton, 2010-2014

	2010	2011	2012	2013	2014	Average	Total
Purchased water (m^3/yr).	2036762	2410590	1907328	2540108	2216056	2222169	11110844
Billed water.	1323895	1510040	1163470	1320856	1307473	1325147	6625736
Non-billed water.	712867	900559	743858	1219252	908583	897024	4485119
Non-billed water (%).	35	37	39	48	41	40	
Monetary Value of non-billed water (US$).	342176	432268	357052	585241	436120	430572	2152857

***Source*:** Norton Town Council

The highest percentage of non-revenue water loss, 48%, representing 1,219,252 m^3 of treated water, was recorded in 2013, while the lowest was 35%, representing 712,867 m^3 for the year 2010. The average non-revenue water loss for the whole five-year period was 40%, representing 897,024 m^3 of water. The cumulative non-revenue water loss for the whole five-year period was 4,485,119 m^3. In other words, of the 11,110,844 m^3 of treated water bought by Norton Town Council from Harare City Council between 2010 and 2014, only 6,625,736 m^3 were billed to various consumers while the remaining 4,485,119 m^3 could not be accounted for, that is, were either used legally or illegally without being paid for or

were lost through leakages in the reticulation network.

Norton buys its water from Harare at US$0.38c per cubic meter and then adds a 25% surcharge to consumers, which means that consumers eventually pay US$0.48c per cubic meter. This enabled the calculation of the monetary value of non-revenue water loss for Norton (Table 1). In 2013 alone Norton lost US$585,241 worth of treated water. On average, Norton was losing US$430,572 every year between 2010 and 2014 in the form of non-revenue water, while the cumulative monetary value of non-revenue water loss for the five year period was US$2,152,857. However, since Norton uses the increasing block tariff method for charging water, the actual monetary value of non-revenue water loss in Norton is therefore much higher.

The results show that non-revenue water loss levels in Norton are unacceptably high as they far surpass the acceptable range of between 15% and 20% [2, 10]. Taking the lower limit of the acceptable range of non-revenue water loss, the lowest non-revenue water loss (35%) recorded in 2010 was higher by 20 percentage points; the highest non-revenue water loss (48%) recorded in 2013 was higher by 33 percentage points; while the average non-revenue water loss for the five-year period (40%) was higher by 25 percentage points. All this water being lost could be used to improve water services to existing customers or to extend services to the population not served or not regularly served such as the newly established suburbs of Maridale, Marshlands, Knowe and Trafalgar. The results have also shown that huge revenue losses are resulting from the non-revenue water losses thereby rendering the water supply service in Norton cost ineffective. What is also worrying about the non-revenue water losses, as Table 1 indicates, is that they have been steadily increasing over the years.

4.2 Sources of non-revenue water loss in Norton

After establishing the non-revenue water loss levels for Norton, the study then sought to establish the sources or causes of the established non-revenue water losses. The study identified pipe bursts as one of the major causes of non-revenue water loss in Norton in the period under review. Table 2 shows the frequency of water pipe bursts between 2010 and 2014.

Table 2: Burst water pipes in Norton, 2010–2014

	2010	2011	2012	2013	2014	Average	Total
Number of burst water pipes.	103	111	97	133	128	114.4	572
Average pipe bursts per month.	8.6	9.3	8.1	11.1	10.7	9.5	

***Source*:** Norton Town Council

Norton had 572 recorded water pipe bursts between 2010 and 2014. The highest annual number of bursts recorded was 133 for the year 2013 with a monthly average of 11.1 bursts while the lowest number of bursts occurred in 2012 totaling 97 with a monthly average of 8.1 bursts. The annual average number of recorded pipe bursts for the whole five-year period was 114.4 bursts. The pipe bursts show an increasing trend with a slight decline registered in 2012. The years 2013 and 2014, which had the highest numbers of reported pipe bursts respectively, also coincidentally had the highest percentages of non-revenue water loss, which proves pipe bursts to be a major source of non-revenue water loss in Norton.

The occurrence of the pipe bursts appears to be correlated with high-pressure zones. Eighty eight percent of the pipe bursts occurred in areas experiencing relatively high static water pressure such as the suburbs of Ngoni, Flamingo, Twin Lakes, Nharira, and the industrial areas. Such pipe bursts due to high water pressure also seem to be correlated with pipe size as 70% of the pipes that burst in the period under review were less than 300 mm in diameter while those 300 mm in diameter or wider were less affected by high water pressure.

The water reticulation network for the older sections of the suburbs of Ngoni and Katanga, the oldest suburbs in Norton, were laid over 50 years ago using galvanized iron pipes. Such pipes are no longer recommended today due to the problem of rusting. The ageing and rusting pipes in these suburbs have also contributed to non-revenue water loss in Norton. Forty eight percent of all the pipe bursts in the period under review were caused by the rusting galvanized iron pipes in Ngoni and Katanga. The ageing pipes also mean that pipe bursts can even occur under conditions of relatively low water pressure. Such pipe bursts at low water flows are a very possible source of tap water contamination as contaminated groundwater can infiltrate into the reticulation network [2]. It is important to note that these suburbs also experience frequent sewage outbursts.

The contribution of burst water pipes to non-revenue water loss in Norton has further been exacerbated by the way in which Norton Town Council has reportedly reacted to them. Sixty seven percent of questionnaire respondents confirmed that slow reaction in fixing burst pipes by Council has resulted in the loss of a lot of treated water. Sometimes burst pipes such as the 600 mm pipe are too big and heavy and can only be handled with the aid of a forklift and excavator, which may sometimes not be available. At times, especially during the rainy season, water accumulates in areas that need pipe repairs and lack of dewatering pumps has often slowed the pipe repairing process. In 2013 it took two weeks to repair burst 300 mm and 225 mm pipes due to lack of joining couplings which finally had to be borrowed from Chinhoyi Municipality. In addition, due to shortage of funds, replacement pipes are sometimes of substandard quality such that they will soon succumb to high water pressure, resulting in pipe bursts frequently occurring in the same areas.

All questionnaire respondents indicated that they had witnessed some pipe bursts either within their suburbs or in other parts of the town, thereby further highlighting pipe bursts as a major source of non-revenue water loss in Norton. However, only 15% of the questionnaire respondents said that they had ever reported the pipe bursts to Norton Town Council. The remaining 85% who had never made an effort to report observed burst water pipes had varied reasons explored below.

All of the questionnaire respondents who indicated that they had never reported observed pipe bursts to Council said that Council often responds slowly to burst water pipes and

therefore it was pointless for them to report the pipe bursts. The slow response to burst water pipes was also confirmed by those respondents who had at one time reported the pipe bursts to Council, with 74% of them indicating that their reports on pipe bursts had not been responded to as quickly as they would have expected.

Another 58% of those who had not reported observed burst pipes said that they did not know where to report the pipe bursts. Besides the Council offices, which are far removed from most residents, the respondents said that there is nowhere else they can report the pipe bursts. Twenty three percent said that they do not report observed pipe bursts in retaliation for allegedly high water charges by Council. Some of the respondents, especially those from suburbs such as Maridale, Johannesburg, Knowe, and Marshlands that do not have regular water supply, said that there is no incentive for them to report burst pipes in other areas as such pipe bursts only occur in areas with regular water supply. Another 42% said that burst water pipes were not their concern but Council's and therefore they did not care about reporting them. Nineteen percent indicated that, while it would be a good and beneficial thing to report observed pipe bursts, a generally poor working relationship between them and Norton Town Council discourages them from reporting the pipe bursts. Another 61% said that as long as the pipe bursts occurred behind their water meters, they do not make an effort to report them, as this does not affect them directly. Some of these respondents openly admitted that they actually benefit from such pipe bursts as they offer an opportunity to use free water. Some went on to say that the benefits from such pipe bursts behind the water meter are enhanced when the burst occurs within one's yard. The water is then used for watering the lawn and the garden, water uses that are sparingly executed using metered water.

Several points that are seminal in fully appreciating the contribution of burst pipes to non-revenue water loss in Norton can be deduced from the above responses by Norton residents. First, the alleged slow response to burst water pipes by Norton Town Council, whatever the reason, has in turn also made some residents not to care about burst water pipes in the town. In other words, Norton Town Council has unfortunately sent a wrong signal to residents, albeit unintentionally, that water conservation is not important. The unfortunate result of this is that whatever other move by Council aimed at conserving water will not be taken seriously by some residents. Secondly, the responses have also exposed an apparent lack of consciousness among some of the residents on the need to conserve water. This also questions Norton Town Council's efforts towards creating awareness on water conservation among the residents. The reportedly unpleasant working relationship between Council and some residents has also translated into increased non-revenue water loss as the residents are now reluctant to report pipe bursts.

In addition to pipe bursts, overflows from storage tanks in the distribution network were also identified as another source of non-revenue water loss. Seventy one percent of questionnaire respondents indicated that they had, at least once, seen an overflowing storage tank in Norton's water reticulation network between 2010 and 2014.

While high water pressure in some parts of Norton has contributed to non-revenue water loss by inducing some pipe bursts, low water pressure in other areas has also contributed to non-revenue water loss. Most water meters do not effectively detect water flows of less than 2 litres per hour [19]. With suburbs such as Maridale, Marshlands, Johannesburg, and Knowe, among others, experiencing very low water flows frequently, cumulatively large qualities of water are passing thorough the water meters without being recorded, thereby contributing to non-revenue water loss. This represents non-revenue water loss from authorized metered use.

Besides pipe bursts, storage tank overflows and low water flows, metering inaccuracies have also contributed to non-revenue water loss in Norton. Water meter accuracy is reduced over time due to dirt deposits on the internal gears of the meters [2, 8, 20, 21]. The Engineering Department of Norton Town Council estimated that about 40% of all the meters for various consumers are no longer accurately functioning due to ageing and dirt deposits. With the passage of time most meters will eventually fail to function properly due to ageing internal gears and therefore require constant maintenance [2, 8, 21]. Again, Council estimated that about 20% of the water meters to various consumers were no longer functioning and billing is based on estimates which may under-represent actual water consumption. There were some reports that sometimes residents temper with water meters so that the meters under-record the amount of water used. Such a practice was reportedly more common in the high-density suburbs where, due to higher margins of poverty, the water bill may take a sizeable amount of often meager family incomes.

Another source of metering inaccuracy emanates from fatigue on the part of meter readers as they cover large areas of the town on foot. For example, a single meter reader may be tasked to cover about 200 housing units per day. The fatigue which is likely to result from such a tiresome exercise, may result in the misreading of water meters. In the first instance, under-recording will directly lead to non-revenue water loss. Over-recording, on the other hand, will indirectly result in non-revenue water loss through angry consumers not reporting pipe bursts as revealed earlier, or through some consumers tempering with water meters so that their water consumption is under- recorded.

An assessment of the bulk water meters at six wet industries in Norton representing the major water consumers in the town revealed that approximately one quarter of their bulk meters were not functioning and the water bills were based on estimates. It is worth noting that estimating water consumption for huge consumers like industries is a very difficult exercise as large quantities of water are involved.

Another source of non-revenue water loss in Norton was due to authorized unmetered use. Norton Town Council also uses water for various unmetered uses such as firefighting, public building among others. It was also reported that Norton Town Council employees owning houses, or staying in Council houses, do not pay for their domestic water uses as part of their employment benefits. All this adds to non-revenue water loss. It is worth noting that such authorized unmetered water uses are most likely to lead to careless water use. Studies have proven that metered water consumers use considerably less water compared to unmetered consumers as they know that they will pay for the misuse of water [8], and therefore attaching a cost to the use of water acts as an effective economic incentive for water conservation among users.

One other category of the sources of non-revenue water loss in Norton was that which could be referred to as unauthorized

unmetered water use. Such water losses include illegal water connections without water meters especially in the new high-density suburbs of Maridale, Johannesburg, and Marshlands. Another practice by residents leading to unauthorised unmetered water losses involves the stealing of water behind the meter by some of those residents whose water supply would have been turned off due to overdue water bills.

5. Conclusion and recommendations

The study has revealed that non-revenue water loss in Norton, averaging 40% between 2010 and 2014, was above the acceptable non-revenue water loss range of between 15% and 20%. Various sources of non-revenue water loss have also been identified including pipe bursts, tank overflows, extremely low water flows which cannot be effectively detected by water meters, metering inaccuracies, authorized unmetered use and also unauthorised unmetered use. The high non-revenue water losses have also translated into huge financial losses for the water supply service in Norton. Norton was losing an average of US$430,572 worth of treated water every year between 2010 and 2014 due to non-revenue water losses, with the cumulative monetary value of non-revenue water loss reaching US$2,152,857. The huge financial losses by the water supply service through non-revenue water loss also mean that the service is not financially efficient.

The study now ends by suggesting some recommendations aimed at reducing the high non-revenue water loss levels in Norton to acceptable levels, a move that will go a long way towards meeting water demand in Norton. To begin with, there is need for swift response to pipe bursts by Norton Town Council as these have emerged to be a major source of non-revenue water loss. First and foremost, Norton Town Council has to acquire Burst and Background Estimates (BABE), a leak detection software for simulation purposes in order to set the priority order for the rehabilitation of the reticulation network [22]. The BABE concept is useful in modelling the anticipated level of losses from a system with given characteristics, and for deriving some improvement measures [22, 23]. This will see the dilapidated and old-fashioned galvanized iron reticulation network in the older sections of Ngoni and Katanga suburbs being replaced by a modern reticulation network of PVC or asbestos-cement pipes which are resistant to corrosion. The next step would be to install a computerized leak detection mechanism for the whole reticulation network so as to enable timeous response to pipe bursts. With some cities in Zimbabwe such as Kwekwe already having installed leak detection mechanisms on their water reticulation networks, the task will not be too novel for Norton Town Council.

The installation of a leak detection mechanism requires a time lag before it is finally implemented as it needs financial backing. While funds for the leak detection technology are being mobilized, Norton Town Council needs to come up with more instant measures to deal with pipe bursts. One option would be to install main water meters at the entrance of each zone in the town and then compare the zonal meter readings with the total of all the consumer meter readings of that zone. The differences in the readings will then be the non-revenue water losses for the various zones in the town. These can then be dealt with on a priority basis starting with the most worrisome zonal non-revenue water losses. Currently there are no zonal or sectional main meters in Norton and only the total non-revenue water loss for the whole reticulation network can be worked out.

Another option for quick leak detection would be through direct observation by the public who then report the leaks to Council. However, such an option, as already noted, is currently being impeded by the walls of suspicion and lack of confidence that have been erected between Norton Town Council and some of the residents, including the difficulty involved in making a report on pipe bursts by the residents. Norton Town Council, therefore, needs to create good rapport in its various circles of interaction with residents so as to encourage them to report pipe bursts. This includes the need to have a Council representative in each suburb for the specific purpose of receiving pipe burst reports, probably through a toll-free hotline. A good working relationship between Council and residents will have other far-reaching beneficial consequences, including active involvement by the public in rooting out practices by fellow residents leading to unauthorised unmetered water losses.

Early leak detection, either through direct observation and reporting by the public or through the installation of computerized leak detection, on its own, does not automatically translate into reduced non-revenue water loss. It needs a complementary rapid response by Norton Town Council. As long as Norton Town Council will not react quickly to detected burst pipes, the enhanced leak detection will be of no value and residents will eventually stop reporting the burst pipes once again. Council should know that it has a duty to foster public awareness on water conservation and its actions, including how it responses to burst pipes, will be used by the residents to judge its commitment to water conservation. This also means that practices by Council of replacing burst pipes with substandard ones should end.

A robust water meter monitoring inspectorate should be set up within the Engineering Department so as to deal with malfunctioning and non-functional water meters as metering inaccuracies have also been identified as a major source of non-revenue water loss in Norton. The duty of the inspectorate should include the expeditious diagnosis and repair of malfunctional water meters at a cost, of course, to the consumers. It is recommended that water meters should be tested and calibrated every seven to ten years [8], a task Norton Town Council is not fulfilling. The other duty of the inspectorate should be, at whatever cost, to make sure that all water consumption in Norton by every consumer, including Council, is metered and billed. This is because unbilled water use, whether authorized or unauthorized, is a potentially huge source of non-revenue water loss as it promotes wastefulness. Since the Dublin International Conference on Water and the Environment (ICWE), it has become generally accepted among water resource managers that water should be considered an economic good [24]. This means that water should be priced at its economic value. It is this attachment of an economic value to water, which will necessitate and encourage its conservation.

Heavy and deterrent penalties should be executed upon all those who contribute to unauthorised unmetered water losses, including illegal water connections and the tampering with water meters among other illegal practices. This will more effectively discourage other consumers from emulating such practices.

There is also a glaring need for the management of water pressure in two ways so as to reduce non-revenue water loss. Firstly, the high static water pressure being experienced in some suburbs, which has induced some pipe bursts, should be monitored so that it does not reach hazardous levels. Funds permitting, an electronic control system that signals to the pumps when the pressure is approaching alarming levels could be installed so as to prevent the pipes from bursting, or storage tanks from over spilling. In line with the above, Norton Town Council is planning for the constructing of a water treatment plant of its own in the near future [25] so as to eliminate its dependency on Harare's water. Such a move will eventually mean higher water pressure throughout the entire reticulation network for Norton, and hence more pipe bursts, if adequate measures are not taken to regulate water pressure. Secondly, there is need by Norton Town Council to avoid extremely low water flows, as is currently the case in many parts of the town. This is because such extremely low flows have been proven to cause non-revenue water loss, as water meters cannot effectively detect such low flows. An option would be to introduce relay rationing in which various consumers throughout the town will have water at reasonably high pressure in turns instead of trying to service many consumers at the same time at very low water flows.

6. References

1. Frauendorfer R, Liemberger R. The issues and challenges of reducing non-revenue water. Asia Development Bank, Manila. 2010.
2. United States Environmental Protection Agency (EPA). Review draft: control and mitigation of drinking water losses in distribution systems. Washington DC: EPA. 2009.
3. Sharman S. Performance indicators of water loss in distribution systems. Delft, The Netherlands. 2008.
4. World Bank. The challenge of reducing non-revenue water in developing countries. World Bank, Washington DC. 2006.
5. Borrows PF, Bloomfield MJ. Leakage investigation in Hounslow. Journal of the Institute of Water Engineers and Scientists. 1984; 38:424-434.
6. Davies B, Day J. Vanishing waters. University of Cape Town Press, Cape Town. 1998.
7. Chicago Metropolitan Agency for Planning (CMAP). An assessment of water loss among Lake Michigan permittees in Illinois. CMAP, Illinois. 2014.
8. Satterfield Z. Water efficiency and conservation. Water Efficiency and Conservation. 2011; 11(1):1-4.
9. United Utilities. Design guidance for water mains and services on new development sites. United Utilities Water plc. 2012.
10. Sastry GS. Issues of unaccounted for water in the urban water sector. Institute for Social and Economic Change, Bangalore. 2006.
11. World Health Organisation. Global water supply and sanitation assessment report. WHO, Geneva. 2000.
12. Chenje M, Sola L, Paleczny D. The state of Zimbabwe's environment. Government Printers, Harare. 1998.
13. Gumbo B, van Der Zaag P. Water losses and political constraints to demand management: the case of the city of Mutare, Zimbabwe. In Integrated water resources management: Theory, practice, cases. 2nd WARFSA/WaterNet Symposium. Cape Town. 2001, 30-31.
14. The Herald. Harare city council losing US$10 million to water leakages. Zim Papers Publishing, Harare. 1997, 20.
15. Goldblatt M, Ndamba J, van Der Merwe B, Gomes F, Haasbroek B, Artnzen J. Water demand management: towards developing effective strategies for Southern Africa. IUCN, Harare. 2000.
16. Chigonda T. Water supply and sanitation in new residential areas in Zimbabwean towns: the case of Maridale high-density suburb in Norton. Journal of Sustainable Development in Africa. 2010; 12(3):349-360.
17. Central Statistical Office. Zimbabwe national census 2012. Government Printers, Harare. 2012.
18. Chigonda T. Thirst in the midst of the twin lakes: a quest for Understanding Norton's ironical water woes. Journal of Sustainable Development in Africa. 2011; 13(1):295-303.
19. Mukheibir P, Stewart R, Giurco D, O'Halloran K. Understanding non-registration in domestic water meters: implications for meter replacement strategies. Water (Technical Features). 2012, 95-100.
20. Lambert A, Taylor R. Water loss guidelines – water New Zealand. Water New Zealand. 2010.
21. Satterfield Z, Bhardwaj V. Water meters. Water Meters. 2004; 4(2):1-4.
22. Koelbl J, Theuretzbacher-Fritz H, Schrotter S, Fuchs-Hanusch D. Detailed analyses of water loss management processes in support of network asset management. Water Loss Europe, Ferrara, Italy. 2012, 1-9.
23. Farley M. Leakage management and control: a best practice training manual. WHO, Geneva. 2001.
24. International Conference on Water and the Environment (ICWE). The Dublin statement and report of the conference. International Conference on Water and the Environment: development issues for the 21st century. Dublin. 1992, 26-31.
25. The Herald. No funds for Norton water plant. Zim Papers Publishing, Harare. 2009, 24.