

Research Paper

Investigating unaccounted for water and its components in Zomba City water supply system, Malawi

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ABSTRACT

This study assessed Unaccounted for Water (UFW) in Zomba City, Malawi in 2009 and quantified its real and apparent loss components. The study was carried out in the period January–May 2009 and focussed on three selected water supply zones (Airwing, Malonje and Sadzi) especially for determination of the components of non-revenue water (NRW). Field measurements of flow and utility records formed the basis of the study. It was established that the NRW for Zomba for the period 1999–2008 ranged from 20 to 36%. During the study period, the average UFW in the specific study areas was 13% of which 81% were real losses (Airwing); 62% with 58% real losses (Malonje); and 51% with 60% real losses (Sadzi). It was concluded that UFW for 2009 Zomba was above 23%, achieved by good performing water utilities in developing countries. Real losses were higher than apparent losses in all three specific study areas and this was driven by pressure. The study recommends real loss reduction through pipe replacement and improved pressure management, and apparent loss reduction through improved metering. Reduction of water losses is imperative in the wake of climate change and the need to attain Sustainable Development Goals.

Key words | apparent losses, minimum night flow, real losses, non-revenue water, water utility

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INTRODUCTION

Non-revenue water (NRW) often constitutes a major problem in water supply systems, resulting in considerable loss in revenues and necessitating excessive production (SIDA 2000). Unaccounted for Water (UFW) forms a significant portion of NRW. According to Schwartz (2006), high levels of NRW indicate inefficiency on the side of a water utility. Many water utilities in low-income countries, in an effort to improve their performance, often begin with heavy infrastructural investment projects (Mugisha 2007). Schwartz (2006) suggests that operation and maintenance of water supply infrastructure in developing countries is poor, and is usually not given adequate attention compared to new construction and system extension. SIDA (2000) suggests that Water Demand Management (WDM) with improvements to the existing water supply systems should be pursued before construction of new and costly systems is undertaken.

With the increasing international trend towards sustainability (Gumbo & van der Zaag 2002), economic efficiency and protection of the environment (Savenije & van der Zaag 2002), the problem of losses from water supply systems is of major interest world-wide (Lambert & Hirner 2000). Both technical and financial aspects are receiving increasing attention, especially during water shortages or periods of rapid development in urban areas. The rapidly growing and urbanised global population and the impacts of climate change which together put greater demand on scarce water resources, dictates the need for management of UFW. Goal 6 of the Sustainable Development Goals targets to ensure access to water and sanitation for all by 2030. There is evidence that climate change and climate variability will have a negative impact on water security as communities will become increasingly water insecure due to water scarcity (Lesolle 2012), thereby

creating risks to the achievement of Goal 6. The reduction of non-revenue water will contribute towards mitigating the impacts of climate change on water security leading to increased opportunities for achieving the SDG Goal 6.

Most of the utilities in Southern Africa have UFW higher than 20% found in best performing Southern African Urban Utilities (Gumbo 2004). In most of these water supply systems, reliable estimates of water loss components are not available (Farley 2001). A crude figure of UFW which is reported by many water utilities does not give the water utility adequate information to prioritize and schedule properly the operation, maintenance and management of the system (Kingdom *et al.* 2006). According to Liemberger (2002), when the magnitude of all components is known it is possible to develop real and apparent loss reduction strategies and set realistic targets. According to Lambert & Hirner (2000), apparent losses occur as a result of errors in water flow measurement, errors in water accounting and unauthorized usage or theft. They are related to management losses resulting in a shortfall of revenue for water supplied (Farley 2001). On the other hand, real losses are categorized as water losses from reported and unreported bursts, background losses, reservoir leakage and overflow, and leakage from valves and pumps (Tabesh & Asadiani Yekta 2005). Farley (2001) argued that since real losses comprise physical water losses from the water supply system, real losses lead to reduced supply to customers. Breaking down of UFW may assist the water utility to improve knowledge and documentation of the distribution system including problem and risky areas. Considering the crisis of water supply in large cities owing to increases in population, quantifying the UFW in terms of both physical and non-physical losses of water in the network to improve the system efficiency represents an important issue that managers need to consider (Motiee *et al.* 2007). Kingdom *et al.* (2006) highlight that no proper NRW reduction strategy can be planned without the quantification of physical and apparent (commercial) losses. Thornton (2002) and McKenzie & Seago (2005) indicate that water loss reduction programs lead to reduced water losses, financial improvement, increased knowledge of the distribution system, more efficient use of existing supplies, capacity to safeguard public health, improved public relations, reduced legal liability, and reduced disruption of supplies to customers. Thus it is

critical to partition UFW into its component for improved UFW management.

The Southern Region Water Board (SRWB) supplies water to the City of Zomba and other districts of the southern region of Malawi. The water utility targets to reduce the high UFW, which is currently around 36%, down to 20% by 2020. According to the utility most of the network is old, experiences frequent bursts and is in need of repairs and upgrading. The water shortages in some of the areas in the city are believed to be worsened by excessive water loss or unaccounted for water in the distribution system. Thomson & Koehler (2016) highlight that in order to address the requirements of SDG 6.1, water must be available when needed. Thus water shortages which are worsened by high UFW makes it difficult for most utilities in developing countries, including SRWB, to attain this goal.

It is against this background that a study was carried out in the Zomba City water supply area to quantify UFW and determine the two main components of UFW (real and apparent losses). The study also sought to investigate the main factors affecting these components in order to enhance the proper planning of operation, maintenance and management of the water supply system.

MATERIALS AND METHODS

Study area

This study was carried out in Zomba City in Malawi. Zomba is located in the southern region of Malawi (Figure 1). Zomba District receives an annual rainfall of between 600 and 1,500 mm (GoM 2009). Zomba is the district headquarters, and it is the second largest town in the southern region after Blantyre and the fourth largest in the country. From the 2008 Population and Housing Census, Zomba City had a population of 87,366 with an annual growth rate of 2.9% (NSO 2008).

The Southern Region Water Board (SRWB) is mandated by the Water Works Act of 1995 to supply potable water to the southern region of Malawi including Zomba City. The Zomba City water supply system originally consisted of an intake on the Mulunguzi River, a conventional treatment plant with a capacity of 6,000 m³/day, 17 storage tanks with capacities ranging from 25 to 455 m³ and 90 km of

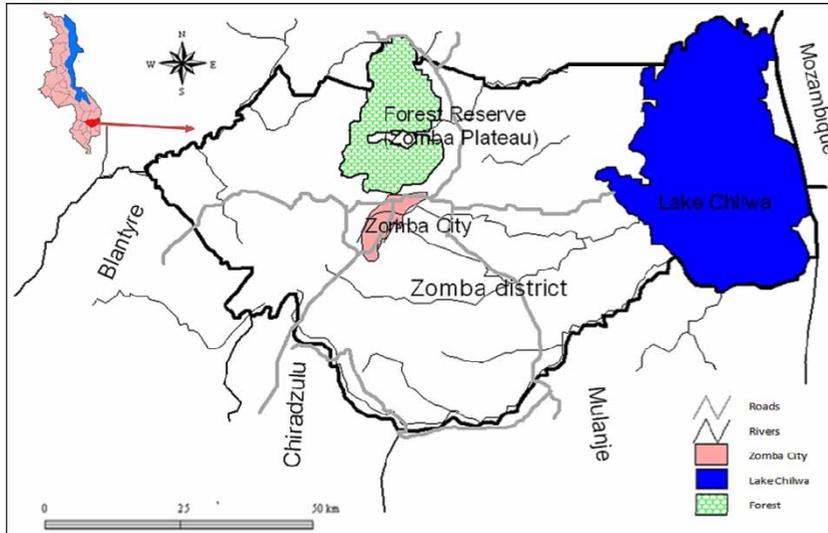


Figure 1 | Map of Zomba District in Malawi.

distribution pipelines with pipe diameters ranging from 25 to 200 mm made of various types of materials. During the period 1994–2001, the water supply system was expanded through the construction and commissioning of a 3.4 Mm³ Mulunguzi Dam, an additional 12,200 m³/d capacity treatment plant, storage tanks with a total storage capacity of 9,750 m³; and a total of 41.3 km of pipeline of PVC, GI and ductile iron with diameters ranging from 80 to 350 mm (SRWB 2009). There are plans to further expand the system to cope with the growing population.

The water production for Zomba City is currently around 400,000 m³ monthly. The city water supply system has service coverage of 89% by population based on the results from a household survey within the city conducted by SRWB (2008). It serves an average of 6,000 connections (SRWB 2008). Almost 58% of the water supply network was constructed in the early 1950s and hence have surpassed their service design period (SRWB 2009). The city water supply system has a high water loss in the range of 30–40% (SRWB 2009). The high unaccounted for water is mostly due to pipe bursts which are as a result of old pipelines that can no longer withstand high pressures in the water supply network. The high pressures are due to the nature of the terrain of the area. The high UFW is also as a result of old meters that usually under-register consumptions (SRWB 2008). During the study period, SRWB estimated that 43% of the meters (out of a total of about

9260) were 10 or more years old and these were targeted for replacement. As a way of controlling real losses, SRWB has increased efforts to deal with bursts and leakages. In an effort to reduce apparent losses, the SRWB started the replacement of faulty meters in March 2009. However, according to key staff of the water board, no significant impact has been realized in terms of reducing UFW. This could have been due to the fact that there has not been significant progress as the meter replacement had just started. However the progress of meter replacement was not established. The specific study areas were Airwing, Malonje and Sadzi (Figure 2).

Malonje has reported problems of pipe bursts and water shortages (SRWB 2009) and 40% of the population in this area relies on boreholes, suggesting inadequacy of water supply from the SRWB system. In Sadzi, the reported problems include tank overflows, leakages and stuck meters. From a socio-economic survey carried out by Stewart Scott International Consulting Engineers, it was found that Malonje and Sadzi had coverage of a piped water supply of 65% (SRWB 2009). The airwing zone covers an Army institution and some properties surrounding the institution. Further expansion of service to other properties is possible when available water is increased through improved system management including leakage control. Table 1 presents details of the specific study areas. The three areas generally receive water supply over 24 hours from the

Trends of unaccounted for water for Zomba City

Water treatment and consumption figures from January 1999 to December 2008 were collected from utility records for the entire Zomba City, and water balances carried out to assess UFW and its components as recommended by Lambert (2003) and Thornton (2005). The water production values were obtained from treatment plant records which are recorded daily while the water consumption figures were obtained from the billing section based on customer meter readings. The study team assessed the procedures for determination of flows and meter reading and found them satisfactory. The production readings are recorded daily and the clear water meter at the treatment plant was working during the entire study period. The study team also established that customer meter reading was routine and bills were largely determined from meter readings. According to Motiee *et al.* (2007) the water balance in a water network system can be defined as:

$$Q_p = Q_c + Q_L \quad (1)$$

where Q_p = produced or supplied volume per time; Q_c = consumption volume per time; Q_L = total water losses volume per time (Non-Revenue Water).

Determination of UFW for specific study areas

Water balances were also carried out in the three selected study areas. This was achieved by measuring the volume of water entering into the zones by data loggers and that consumed within the zones from billed consumption. UFW for the three specific areas was determined using Equation (1). UFW was determined as the differences between the monthly zone supply (based on bulk meter readings at the tank outlet) and monthly consumption billed for the areas (obtained from the utility billing section). Interviews with key staff for Zomba Water Supply Scheme were carried out to investigate or confirm characteristics of the water supply scheme such as age of network, trends of water loss, water bursts, tank overflows; and information on errors on estimation and data acquisition. The staff interviewed included the Zomba scheme manager,

distribution engineer, plumber, meter reading supervisor and billing officer.

Partitioning of UFW into real and apparent losses

The UFW was partitioned or divided to determine the real and apparent loss fractions. The overall aim of partitioning was to determine which component of UFW was significant thus enabling proper targeting and prioritization of UFW reduction strategies. The first step in partitioning of the UFW was to determine real losses. In order to determine real losses, the Minimum Night Flow was determined from flow measurements. Flow loggers were installed on the tank outflow pipelines for each of the three areas (Airwing, Malonje and Sadzi) to measure the flows into each zone. The lowest flows occurring between 12 a.m. and 4 a.m. are taken as Minimum Night Flow (MNF) according to Thornton *et al.* (2008). However, the exact timing of the MNF will vary from zone to zone depending on the characteristics of the zone. During the MNF period, authorized consumption is normally at a minimum and therefore real losses are at their maximum. A flow logger was installed at the inlet to each of the zones as suggested by Farley (2001). In this study the inlet to each water zone was taken as the outlet pipe of the tank serving the zone. The point of flow measurement was the bulk meter on the tank outlet pipe. To investigate the influence of pressure on absolute water loss, pressure loggers were installed at critical points in the distribution system for each zone.

MNFs obtained from the outflow pattern were analyzed to determine Excess Night Flow as recommended by McKenzie (1999). The measured night use by large customers and the estimated night use by households (these two make the expected night use) are subtracted from the measured MNF to give the loss in the distribution system (Farley 2001). According to Thornton (2005), the estimation of the leakage component (real losses) at minimum night flow is carried out by subtracting an assessed amount of legitimate night-time consumption for each of the customers connected to the mains in the zone being studied. McKenzie (1999) further suggested that the result obtained from subtracting the assessed night use and exceptional night use from the minimum night-time flow is known as the Net

Night-time Flow (NNF) or the Excess Night Flow (ENF) and this predominantly consists of real or physical losses from the distribution system.

Tables 2 and 3 present assumed leakage parameters and the infrastructure variables for the three study areas. These were used to obtain excess night flow from the minimum night flows measured.

Experience from various parts of the world, including Southern Africa, has shown that the population active during each hour during the night (POPACT) is approximately 6% of the total (Mckenzie 1999). The corresponding water use of the active population (POPUSE) is in the order of 10 L/head-h and is based on a standard 10 L toilet cistern and may vary from one country

Table 2 | Leakage parameters, based on Mckenzie (1999)

Description	Value			
	Default ^a	Airwing	Malonje	Sadzi
% of population active during night	6	6	6	6
Quantity of water used in a cistern (l)	10	10	10	10
Non-domestic use m ³ /hr	–	6 ^b	0	0

^aDefault value accepted after experience from various parts of the world (Mckenzie 1999).

^bIn Airwing exceptional use of 6 m³/hr was assumed to represent the non-domestic night use in the army barrack served from one bulk meter. This is above the normal expected water use based on 6% population active. High water usage is common in institutions where service is through a bulk meter and where water bills are covered by the institution and often not even paid for. The 6 m³/hr is estimated from observations on the bulk meter readings around the times MNF is expected during the field work. The flow readings during this time were exceptionally high compared to what would be expected for night use of the population in the barrack at 6% population active. We actually observed that households left irrigation hoses running at night and a number of plumbing fittings were leaking. The army barrack also has a great many activities at night including restaurants for staff as it run 24 hours. Irrigation of the landscape for the army compound is also usually 24 hours.

Table 3 | Infrastructure parameters (based on distribution system data)

Description	Value		
	Airwing	Malonje	Sadzi
Length of mains (km)	1.2	2.4	12.1
Number of connections	101 ^a	179	965
Number of households	120	220	1,300
Estimated population	800	800	6,500

^aThere were 52 connections in Airwing, one of which is the Airwing (Army) institution bulk meter. An equivalent of 50 connections has been used for the Airwing institution.

or region to another (Mckenzie 1999). POPACT is expressed as a percentage of the total population (POP). The normal household night use or Expected Night Use (ENU) is therefore easily estimated from the product of the active population and the average use per hour (i.e. POPACT * POP * POPUSE). The ENF is calculated by subtracting ENU from measured MNF (Fanner, 2004). Expected Night Use is based on the fraction of the population that is active (Table 2).

$$ENF = \text{Measured MNF} - ENU \quad (2)$$

ENF was used to compute Real Losses (RL) using Equation (3) as recommended by Mckenzie (1999). Only ENF for days that did not have major bursts were used in the computation of RL. Equation (3) converts the daily real loss into monthly real loss assuming an average month of 30 days:

$$RL (m^3/month) = ENF (m^3/hr) \times (hour/day \text{ factor}) \times 30 \text{ day/month} \quad (3)$$

According to Fanner (2004), to convert the volume of real losses during the MNF period into a daily volume of real losses it is necessary to take into account diurnal variations in system pressure by applying an hour/day factor which is normally less than 24, but this factor depends on the degree of pressure management. In this study an hour/day factor of 22 was used as there was no significant difference between the losses during the hour of MNF and the remainder of the day as recommended by Lambert (2002). Apparent losses (AL) were calculated as the difference between UFW and RL (Equation (4)):

$$AL (m^3/month) = \text{Average UFW} - RL \quad (4)$$

Meter inaccuracies

A meter testing bench was used to verify the accuracy of customer meters (Sánchez 2007). The testing bench was installed in line with the customer meter in the field test. Most of the residential under-registration occurs at low

flows (IWA 2008). Meters were tested at standard rates of 150, 300, 500, 800 and 1,000 L/hr. The results of the meter testing were used to investigate whether there was a significant portion of the meters that were malfunctioning. A detailed estimation of the contribution of the meter inaccuracies to unaccount for water was not carried out as the sample size of the meters was small. A total of 9, 15 and 22 meters selected at random were tested in Airwing, Malonje and Sadzi respectively.

RESULTS AND DISCUSSION

Trends of UFW in Zomba

Figure 3 presents the trend of water production, consumption and UFW from 1999 to 2008. The average UFW for the 10-year period translates to 27.5% ($293 \text{ m}^3/\text{conn}/\text{yr}$ (m^3 per connection per year)) with the lowest occurring in 2007 at 19.6% ($165 \text{ m}^3/\text{conn}/\text{yr}$) and the highest occurring in 2001 at 36.2% ($459 \text{ m}^3/\text{conn}/\text{yr}$). Based on discussions with key utility staff, the highest UFW occurred in 2001, possibly as a result of accelerated burst of old pipes after upgrading of the water supply system which resulted in increased flows at higher pressures than before the upgrade. The upgrading was carried out in the period 1994–2001. Nkhoma *et al.* (2005) established the UFW for Lilongwe City in Malawi as 38%. Gumbo (2004) established the UFW for the City of Bulawayo in Zimbabwe as 20%.

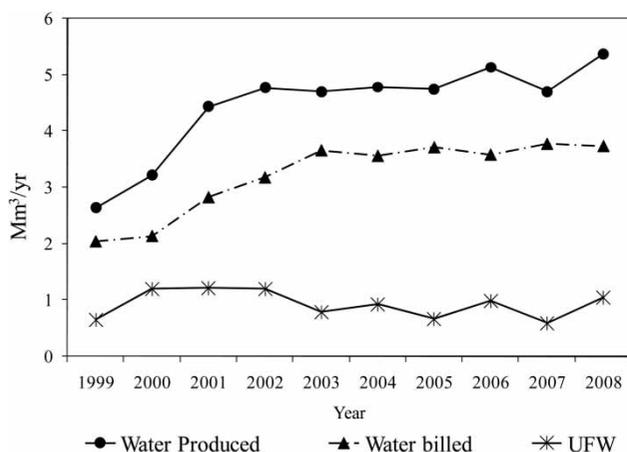


Figure 3 | Total water produced, billed and UFW for Zomba City from 1999 to 2008.

Marunga *et al.* (2006) found out that UFW for Mutare (Zimbabwe) was 57% in 2005. In Kampala (Uganda) the UFW was 35% in 2005 (Mugisha 2007). Kalulu & Hoko (2010) found that the level of unaccounted for water for Blantyre Water Board ranged from 36 to 47%. It can therefore be concluded that the average UFW for Zomba was within the range reported in literature of 20 to 57% but higher than the 23% target for developing countries suggested by Tynan & Kingdom (2002).

Unaccounted for water for the specific study areas

The UFW for the three specific study areas are presented in Table 4. The UFW is presented as a percentage of total water supplied and also as absolute volume of water loss per connection and volume/pipe length to account for local conditions, including size of the system as suggested by Fantozzi *et al.* (2006). Airwing had the lowest distribution losses of 13% while Malonje had the highest distribution losses (62%) among the specific study areas. The low distribution losses in Airwing could be due to the fact that the Airwing Army Barrack, which has an equivalent of 50 connections, is served by a bulk meter and as such the losses in the internal distribution system in the barrack are not reflected. Losses in Malonje and Sadzi were higher than the levels established from studies within the region including Malawi. Nkhoma *et al.* (2005) established losses of 44% for Area 49 (with 844 connections) in Lilongwe City, in Malawi. In another study in Malawi, Harawa *et al.* (2016) found losses ranging from 20 to 44% in three selected areas in Lilongwe. Marunga *et al.* (2006) established that the distribution losses for Chikanga 1 Stage 2 (735 connections) in the City of Mutare in Zimbabwe were 32%. This is also lower than the distribution loss established for Malonje and Sadzi in this study. However the distribution losses reported in the literature above are higher than that of Airwing. Thus Airwing had a lower level of non-revenue water compared to those found in the region including the limit suggested by Tynan & Kingdom (2002) of 23% for well performing utilities in developing countries. Malonje and Sadzi had UFW values higher than ranges reported in literature and the limit of 23% proposed by Tynan & Kingdom (2002), suggesting unacceptable UFW in these areas.

Table 4 | Average UFW^a for the three specific study areas for the period January to March 2009^b

Area	Average supply (m ³ /month)	Average consumption (m ³ /month)	Conns (number)	Length of dist syst (km)	UFW			
					m ³ /month	%	m ³ /conn/yr	m ³ /km/yr
Airwing	9,277	8,043	101 ^c	1.2	1,234	13	147	11,942
Malonje	8,892	3,388	179	2.4	5,504	62	369	27,751
Sadzi	24,153	11,923	965	12.1	12,230	51	152	12,125

Conns, connections; Dist Syst, distribution system.

^aThe NRW for the specific areas is actually the distribution losses in these distribution areas as there is no transmission loss component.

^bThis was the period this research was carried out.

^cEquivalent individual connections.

Partitioning of UFW

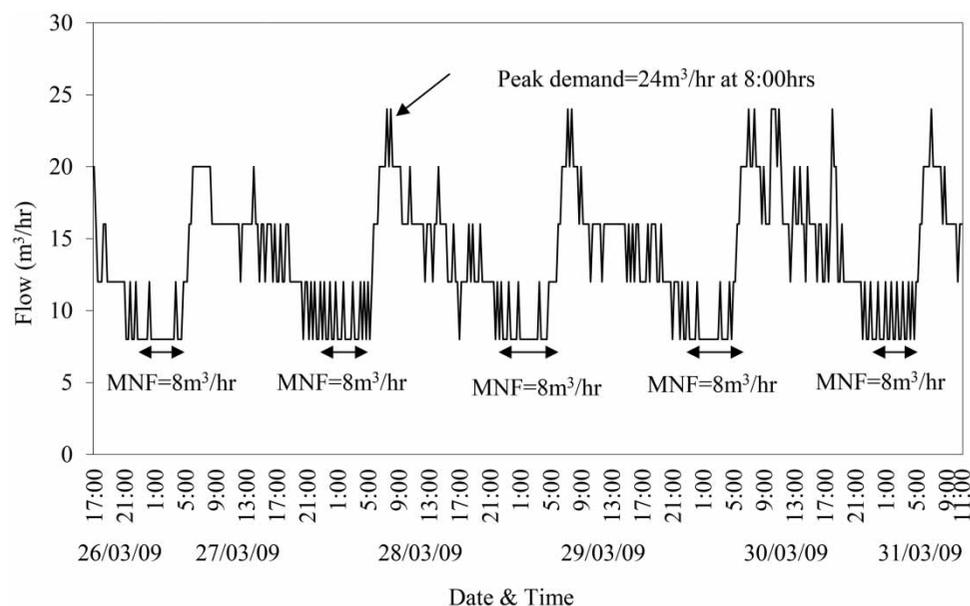
The flow pattern for each area is presented in Figures 4–6 while the pressure variation in each zone is presented in Table 5.

From Figures 4–6, the minimum flow occurring between 12:00 am and 4:00 am was taken as the MNF for each day. From Figure 5, pipe bursts appeared to have been a major problem in Malonje and accounting for some of the sudden increases in measured tank outflow including during the minimum flow period. This could have been due to high pressures in the system (40–114 m). MNF was not computed for days that were affected

by bursts for Malonje, thus these days were not used to calculate the average real loss. Table 6 presents the MNFs for the three specific study areas based on Figures 4–6. Real losses were then obtained from Equation (3) and are also presented in Table 6.

The average real losses for each area were determined from the daily real loss values in Table 6 and are presented in Table 7. Apparent losses were estimated as the difference between average UFW and real losses according to Equation (4) and are also presented in Table 7.

Table 7 shows that the average real losses ranged from 58 to 81% for the three specific study areas. In all three areas, real losses contributed the greater part of UFW. The

**Figure 4** | Airwing tank outflow pattern for the period 26 March 2009–31 March 2009.

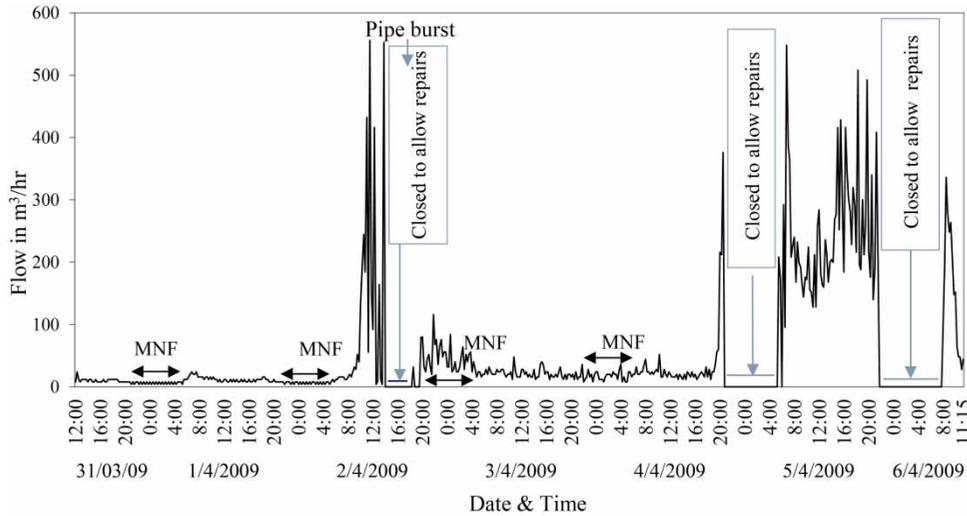


Figure 5 | Malonje tank outflow pattern for the period 31 March 2009–6 April 2009.

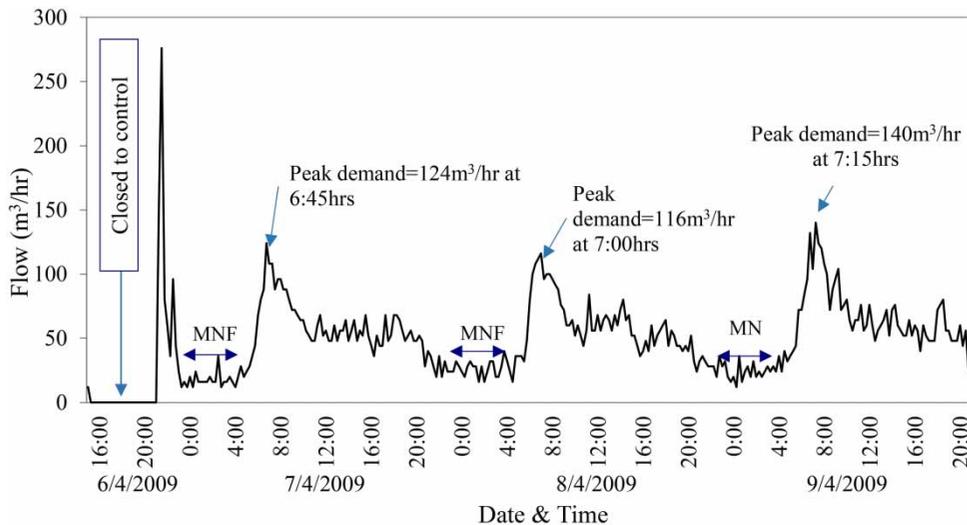


Figure 6 | Sadzi tank outflow pattern for the period 6 April 2009–10 April 2009.

highest real loss percentage was found in Arwing (81%). This could be due to the fact that the major water user, i.e. the barrack which accounted for about 50% of the housing units, is metered by a functional bulk meter. As such it is likely that the contribution of apparent losses to water loss due to non-functional individual meters and billing errors was low resulting in a high real loss percent. Airwing also has the oldest network constructed in the 1950s while the other two areas were constructed around 2001.

When real losses (i.e. UFW^* Real loss fraction) are computed as a fraction of the total zonal system input volume, real losses contributed to 10% for Airwing, 36% for Malonje and 31% for Sadzi. It can be seen that Malonje, which had the highest system pressure (40–114 m, Table 5), had the highest real loss contribution followed by Sadzi which had the second highest pressure range (32–72 m) while Airwing which had the least pressure had the lowest real loss contribution. Trifunovic

Table 5 | Pressure range in the study areas

Area	Pressure (m)
Airwing	7–40
Malonje	40–114
Sadzi	32–74

(2006) suggests that pressures greater than 60–70 m should be avoided in the distribution system as this will lead to increased leakage. Malonje and Sadzi had pressures exceeding 60 m in some parts of the network and had much higher real loss contribution compared to Airwing which had pressure far less than 60 m. *Ndunguru & Hoko (2016)* found real losses ranging from 73.6 to 85.1% in four selected suburbs of Harare, Zimbabwe which had generally old networks. The same study found that apparent losses were far lower than real losses. This agrees with findings of this study. *Harawa et al. (2016)* found real losses of 81 and 86% for Area 15 and Area 18 respectively in Lilongwe, Malawi.

Apparent losses ranged from 19 to 42% in specific study areas in this study. The low apparent losses for Airwing (19%) could have been affected by the presence of one bulk meter to supply the barrack as discussed above. Generally, the high apparent losses in Malonje and Sadzi were mainly driven by meter inaccuracies. The high levels in these two areas suggest that apparent losses in the distribution system can be much higher than the 20% commonly assumed for water utilities in South Africa (*Seago et al. 2004*). A meter accuracy test carried out during this study showed that about 53% of the meters sampled had errors outside the allowable limits of –5% at low flow rates (150 and 300 L/hr) and –2% at high flow rates (500, 800 and 1,000 L/hr). Meter errors are believed to contribute a major component of apparent losses in Zomba (*SRWB 2008*).

In this study real losses contributed the larger component of UFW in all three areas and it appears real losses were being driven by pressure coupled with old age of pipes, especially for Airwing. Apparent losses were higher than figures reported as common in literature,

Table 6 | MNF and real losses for study areas for the period 27 March 2009–April 2009

Area	Date	MNF ^a (m ³ /hr) (1)	Normal night use (m ³ /hr) (2)	Excess night use (m ³ /hr) (3) = (1) – (2)	Real loss (m ³ /day) (4) = (3)*22 ^b	Real loss (m ³ /month) (5) = (4)*30
Airwing	27/03/09	8	6.48	1.52	33.44	1,003.20
Airwing	28/03/09	8	6.48	1.52	33.44	1,003.20
Airwing	29/03/09	8	6.48	1.52	33.44	1,003.20
Airwing	30/03/09	8	6.48	1.52	33.44	1,003.20
Airwing	31/03/09	8	6.48	1.52	33.44	1,003.20
Malonje	1/4/2009	4	0.48	3.52	77.44	2,323.20
Malonje	2/4/2009	4	0.48	3.52	77.44	2,323.20
Malonje	3/4/2009 ^c	–	0.48	–	–	–
Malonje	4/4/2009	8	0.48	7.52	165.44	4,963.20
Malonje	5/4/2009	–	0.48	–	–	–
Malonje	6/4/2009	–	0.48	–	–	–
Sadzi	7/4/2009	12	3.9	8.10	178.20	5,346.00
Sadzi	8/4/2009	16	3.9	12.10	266.20	7,986.00
Sadzi	9/4/2009	16	3.9	12.10	266.20	7,986.00
Sadzi	10/4/2009	16	3.9	12.10	266.20	7,986.00

Note: ENF based on Equation (2) and RL based on Equation (3).

^aThe minimum flow occurring between 12:00 and 04:00 am (*Farley 2001*).

^bDepending on local conditions of pressure variation and management, a factor of 22 was recommended for Zomba City Water Supply (*SRWB 2009*).

^cEither the tank was closed to facilitate repairs, hence there was no record for MNF or MNF was high because of major pipe burst at night. Refer also to *Figure 6*.

Table 7 | Partitioning of UFW for specific study areas

Zone	UFW m ³ /month	Real losses		Apparent losses	
		m ³ /month	% of UFW	m ³ /month	% of UFW
Airwing	1,234	1,005	81	231	19
Malonje	5,504	3,203	58	2,301	42
Sadzi	12,230	7,326	60	4,904	40

UFW is from Table 4, Real losses are based on average values computed from Table 5.

especially for Malonje and Sadzi. Apparent losses were possibly being driven by meter errors and billing and data handling errors.

CONCLUSIONS AND RECOMMENDATIONS

The following conclusions were drawn from this study:

1. The average unaccounted for water in Zomba was found to be high (27.5%) compared to the World Bank recommended limit of 23% for well performing utilities. The drivers for this high UFW could have been the old age of distribution system and high system pressures in most parts of the city.
2. UFW in the specific study areas varied a great deal and ranged from a minimum of 13% (in Airwing) to a maximum of 62% (in Malonje).
3. Real losses generally contributed the larger part of the UFW in the three specific study areas and this ranged from 58 to 81%. Real losses were among other factors driven by high pressures generally. Apparent losses were higher than commonly assumed levels of 20% in two of the study areas and these were affected by meter inaccuracies.

Recommendations

Given that water supply coverage and access in the study area is below 100%, reduction of water losses is imperative in the wake of climate change and the need to attain Sustainable Development Goals. In order to reduce water losses the utility should consider carrying out the following:

1. Active pressure management including installation of pressure-reducing valves at strategic points should be considered, especially in Malonje.

2. Pipe replacement should be considered in Malonje. A pipe rehabilitation and replacement program for the entire city should be developed targeting areas with an old pipe network.
3. Routine meter error assessment, documentation, repair and replacement are recommended to reduce apparent losses due to meter errors. Priority should be given to the assessment and replacement of bulk meters in the distribution system, as in the one for Airwing.

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