Performance Based Water Loss Management for Gweru, Zimbabwe

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Abstract Different water utilities use different performance indicators to assess their performance. Although these indicators are peculiar to particular situations, it is paramount that each indicator is applied consistently among utilities as this is good for benchmarking purposes. Besides being well documented, performance indicators have not been well reviewed from the perspective of developing countries. Furthermore, there is limited understanding of the application of performance indicators among developing countries. Therefore this paper reviewed performance indicators for physical water loss management. The African Development Bank self-assessment matrix was applied to the City of Gweru, Zimbabwe. Furthermore, the infrastructure leakage index was used to assess the performance of the water utility. The self-assessment approach showed a 62% level of implementation of NRW strategies by the city. This means that the city was poorly managing its non-revenue water. The city had an infrastructure leakage index of 9.7. This index is in Category C of the International Water Association physical loss matrix meaning that the city was managing its non-revenue water poorly. Therefore the city must be proactive in the management of its physical water losses as well as maintain its infrastructure consistently.

Keywords: *infrastructure leakage index, non-revenue water, performance indicators, water loss management*

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1. Introduction

Many developing countries throughout the world are facing a variety of water supply challenges [1]. Arid and semi-arid areas are particularly facing severe water scarcity due to rapidly growing demand for water resources [2]. Resultantly, urban water supply suffers a myriad of challenges that include intermittency and unauthorised connections [3].

Despite the challenges affecting developing countries, Africa has the least water supply and sanitation coverage than any other region in the world [2]. More than a third of Africans living in urban set-ups are currently lacking access to adequate water services and facilities [1]. New strategies for water development and management are urgently needed to avert severe national, regional and local water scarcities that will depress agricultural and industrial productivity [4].

There is considerable difference between the volumes of water transmitted and the volume of water billed to consumers [5,6], hence non-revenue water. Non-revenue water (NRW) is a measure of a utility's efficiency in terms of both operational performance and financial performance [6]. The utilities in developing countries (30-40%) have the highest levels of NRW [7,8]. NRW has severe impacts on the efficiency of water utilities thereby affecting water customers [9]. Although it is a generalisation, non-revenue water is a good indicator of the efficiency of performance of water utilities [10].

Each year more than 32 billion cubic metres of treated water is lost through leakage from water supply systems, of which 16 billion cubic metres of treated water annually is conveyed to customers but not invoiced because of theft, poor metering, or corruption [9]. A conservative estimate of the total annual cost of non-revenue water to water utilities worldwide is 14 billion United States Dollars [11]. In some low-income countries the loss constitutes 50-60% of total water supplied, against a global average of 35% [11]. According to USAID and WBI [12], one hundred million more people could be supplied with enough water if half the amount of water lost was saved.

Water losses are seriously affecting performance of water utilities in developing countries [13]. Water utilities in the state of Selangor, Malaysia (1997) and Bankok, Thailand (2000) are examples where water losses affected performance [14]. Water availability challenges are exacerbated by escalating volumes of water losses and whose consequences force water utilities to fail their customers [6]. Performance Indicators (PIs) help water utilities evaluate their water losses, benchmark and measure performance set against standards and optimise investment decisions [6].

Underperformance causes water utilities to operate at low technical efficiency levels below best-practice determined by the relatively efficient ones [15]. Reflecting on the status quo, there is need for a paradigm shift to utilize water resources as efficiently as possible [5].

Managers, policymakers, regulatory agencies and financing institutions use NRW PIs to rank a utility's performance against industry standards and other water utilities.

The objective of this paper is to review the applicability of NRW and Infrastructure Leakage Index as key performance indicators used widely in developing countries. In so doing the paper fills the knowledge gap due to the divergent views of many schools of thought. The paper further explores the self-assessment methodology for assessing the level of management of NRW [16] by the City of Gweru, Zimbabwe.

2. Performance Indicators in Water Loss Management: Performance Assessment Systems

Performance measurement plays key roles in assessing performances of water utilities. Therefore it is important for water utilities to adopt performance assessment systems for enhanced service delivery. Poor service delivery by water utilities is often due to poor governance and financial frameworks [6,15]. Thus, this notion confirms the commonly held view that Africa's water supply systems run at unacceptably low levels of technical efficiency [15]. Water utilities have to provide some service to customers daily against the backdrop of deteriorated infrastructure [6]. By assessing a utility's performance using PIs one can determine the quality of service and the utility's efficiency. Furthermore, PIs allow for the comparison of objectives, provides benchmarks among similar institutions and encourages the provision of improved services [17].

Most indicators for water loss management were developed by the International Water Association (IWA) [18,19] and adopted by the American Water Works Association (AWWA), African Development Bank and Asian Development Bank. Important indicators by IWA for water loss management include the following [18]: Litres per service connection per day (l/c/d); Litres per service connection per day per metre of pressure (l/c/d/m pressure); and Litres per kilometre of pipeline per day (l/km/d). A good NRW PI must be rational and easily applied [9]. It should be easily computed using readily available utility data [9].

Utilities should include standard PIs to measure performance in order to facilitate comparisons with other utilities. Tools such as decision trees are available for managers to select appropriate PIs for their utility needs and operating context [20]. On the other hand Performance Assessment Systems (PASs) are systems used by water utilities to evaluate own performance by identifying

performance drivers and by measuring success in achieving their set targets [5,21].

Each institution may use a different PAS to measure performance. Poor performance results in a vicious spiral as the problems regenerate with time [5]. The performance of a water utility can be described as a low level equilibrium in which low prices result in low quality, limited service expansion, operational inefficiency and corruption, whereby stakeholder support is compromised [5,22]. Thus, policy should be concerned with prescriptions aimed at maximizing the efficiency of specific institutions in terms of the operators' efficiency, regulators' competence and endowments.

The most widely used water loss management indicators are shown in Table 1. AWWA [23] classified the levels as basic, intermediary and detailed.

The "Basic" level is the first level of indicators that provides a general management overview of the efficiency and effectiveness of a water supply institution. The "Detailed" level represents indicators providing the greatest and specific detail but are still relevant to the top management.

Several performance indicators are recognised by many water management institutions world-over. However, the traditional PIs for real losses were chosen on the backdrop of the simplicity of calculation, country norms, data availability for the calculation, or even on the basis of producing the best performance impression [24].

Performance indicators provided in the Manual of Best Practice of IWA [17] which are used to compare the performance of water losses management are: water losses and real losses as a percentage of system input volume (SIV), water losses per house connection, water losses per km of mains per day (density of connections less than 20 per km of mains) and the Infrastructure Leakage Index (ILI).

Following, are the generally applied water loss management systems PIs.

2.1. NRW as an Indicator

2.1.1. Expressing NRW as a Percentage

Percentage NRW is the most widely used PI for evaluating water losses [6,25,26]. It has been widely used to measure performance and system efficiency. That means citizen satisfaction with urban service delivery is closely related to the actual performance of the services with respect to the initial expectations about the services [18].

Table 1. IWA Recommended Performance Indicators

Function	Level	Performance Indicator	remarks
Financial: NRW by volume	Basic	Volume of NRW as % of system input volume	Can be calculated from simple water balance
Financial: NRW by cost	Detailed	Value of NRW as % of annual cost of running system	Allows different unit cost for NRW components
Inefficiency of use of water resources	Basic	Real loss as % of system input volume	Unsuitable for assessing efficiency of management of distribution system
Operational: Real losses	Basic	M^3/service line/day, when system is pressurised	Best traditional basic performance indicator
Operational: Real Losses	Detailed	Infrastructure leakage index	Ratio of CARL to UARL

(Adapted from [27]).

Non-revenue water has traditionally been expressed as a percentage of input volume [18]. Although this is preferable to setting no targets at all, percentage of input volume is a misleading PI because it favours utilities with high consumption, low pressure, and intermittent supply [24]. Despite percentage NRW being recommended as an elementary financial indicator, its main disadvantage is that it is affected by consumption patterns independent of the utility's water loss management [26]. In addition, it does not differentiate between physical losses and commercial losses. The other disadvantage is that the indicator still does not take operating pressure into account [8].

Although the IWA no longer recommends using the percentage of system input as an indicator of real losses, it is still used as one of the key PIs in the United Kingdom [24]. Nonetheless, NRW as a percentage of input is sometimes useful for its "shock value"; a high result spurs for a utility to resume studies of the network's operational performance [9]. Furthermore, it is also useful as a measure of the utility's year-on-year financial performance, as long as the measurement principles are consistent [7]. Therefore, NRW should be represented as the value and not the quantity of water lost.

2.1.2. NRW Percentage by Volume

Since consumption normally makes up a very significant part of SIV or water supplied for most systems and sub-systems, this severely compromises the use of percentages by volume as a suitable PI for NRW and its components [28,29]. Computation of percentage by volume is traditional and usually a simple initial step. However, the best simple traditional real losses PIs are "per service connection" or "per km of mains" and they should be accompanied by an estimate of average pressure [19]. Furthermore, NRW percentage by volume does not account for different valuations of components of NRW or the cost of running the system [19].

A better financial PI for NRW is percentage by cost, which calculates the cost of each of the three principal components of NRW (Unbilled Authorised Consumption, Apparent Losses and Real Losses) by attributing different monetary valuations (per cubic metre) to each of these NRW components, and dividing by the operating cost of running the system [19]. However, challenges due to the use of percentages by volume as operational PIs for NRW and its components are extensively published [18,26]. Besides percentage NRW, infrastructure leakage index is

an operational PI to be reviewed.

2.2. Infrastructure Leakage Index

Infrastructure Leakage Index (ILI) determines the overall infrastructure management performance to be assessed independent of the influence of current operating pressure [24]. The ILI was developed to address the lack of an objective benchmarking indicator [8,29]. The ILI and other recommended NRW and physical loss PIs based on the IWA's PIs for water supply services are shown in Table 2.

The ILI is a new PI for real losses; a ratio of current annual real losses to system-specific unavoidable annual real losses [8,30].

$$ILI = CARL / UARL \qquad (1)$$

where CARL is the Current Annual Real Loss and UARL is Unavoidable Annual Real Loss.

The ILI is an excellent indicator of physical losses, which takes into account how well a network is managed [31]. It is more applicable in networks where NRW is relatively low, for example below 20%, as the ILI can help to identify areas that can be improved on [32].

UARL can be used reliably to predict the lowest technical annual real losses for any combination of mains length, number of connections, customer meter location at current operating pressures, assuming that the system is in good condition and there are no financial or economic constraints [8]. Using existing knowledge and experience, UARL can be computed for any system in excess of five thousand service connections, density of connections greater than 20 per km mains, and operating pressure between 25 – 100 metres [8,24].

Since 1999, the UARL formula has proved to be robust in predicting the lowest threshold of real losses in best performing utilities [28]. An ILI index of 1.0 indicates that current annual real losses (CARL) are equal to unavoidable annual real losses (UARL) and the water utility is operating at the technically low level of leakage possible, a very uncommon possibility [29]. Limited data from water utilities who were the early adopters of the AWWA/IWA water audit methodology indicates that ILI values typically fall in the range of 1.5 - 2.5 [8,17].

The physical loss target matrix showing the expected level of ILI and physical losses in litres/capita/day from utilities in countries at differing levels of network pressure is shown in Table 2.

Table 2. Physical Loss Target Matrix

| Technical Performance category		ILI	Physical Losses[litres/connection/day] (When the system is pressured) at an average of				
			10m	20m	30m	40m	50m
Developed countries	A	1-2		<50	<75	<100	<125
	B	2-4		50-100	75-150	100-200	125-250
	C	4-8		100-200	150-300	200-400	250-500
	D	>8		>200	>300	>400	>500
Developing countries	A	1-2	<50	<100	<150	<200	<250
	B	2-4	50-100	100-200	150-300	200-400	250-500
	C	4-8	100-200	200-400	300-600	400-800	500-1000
	D	>8	>200	>400	>600	>800	>1000

(Adapted from [12]).

The ILI indicators are provided as crude guidelines and should not be taken to be restrictive limits [33,34]. However, for the greater parts of Africa and Asia, very high ILI values are a norm and the limits given in Table 2 are subdued [34]. The main purpose of the ILI indicator is to help identify areas where leakage/losses are abnormally high to ensure that action is taken in the most appropriate areas [8].

To guide further network development and improvement, utility managers could use a matrix with the following categories [12]. For Category A, the ILI value ranges 1-2, representing good performance with respect to real losses [8]. Further loss reduction may be uneconomic and careful analysis is needed to identify cost-effective improvements. Category B indicates that there is potential for improvement. The category entails good pressure management, better active leakage control and better maintenance. Category C denotes poor performance. This class is only tolerable when water is plentiful and cheap, and there is need to intensify NRW reduction effort. Category D connotes bad performance and the utility is using resources inefficiently and NRW reduction programmes are imperative.

3. Study Area

The case study of Irvine middle density suburb of Gweru, Zimbabwe was considered. Irvine was chosen because it is a standalone district metered area and had the least water supply interruptions. Gweru city has a total population of about 157,000 [35]. Gweru City Council is responsible for water supply in the city. Irvine has about 390 residential stands, all connected to municipal water supply system. Poor water supply infrastructure management is the major water related challenge the city faces [36].
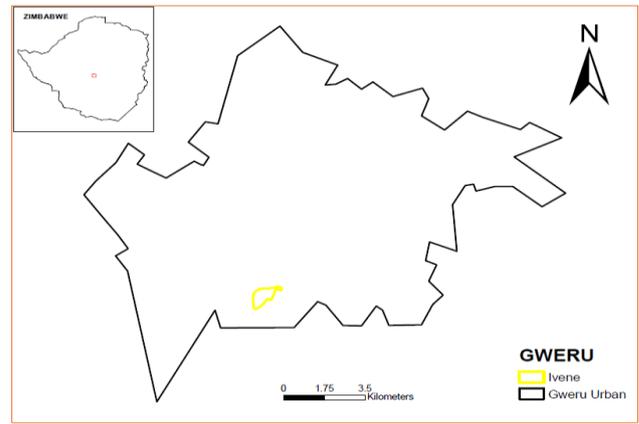
Map 1. Map of Gweru Showing Location of Irvine

4. Materials and Methods

4.1. NRW Performance Assessment

The level of management of NRW in Irvine, Gweru was done following the self-assessment methodology proposed by the International Water Association [16]. The self-assessment matrix of non-revenue water management for the best practice was developed by Africa Development Bank [37] and adapted from IWA [12]. The proposed assessment parameters for a utility's NRW management are shown in Table 3. Table 3 presents the enabling factors for each of the strategies currently implemented and proposed respectively.

For the matric shown in Table 3, each level has a range of scenarios ("1" is poor and "5" is excellent) which describes the implementation level in a given area. The City of Gweru water managers and the author used the matric to assess the city-wide level of management of NRW.

Table 3. NRW Management Assessment Matrix

Management Level				
1 (Poor)	2	3	4	5 (Excellent)
No monitoring of NRW indicators. No NRW management strategy.	% NRW Monitored. Water balance is available. No NRW Management strategy.	% NRW monitored. Water balance available. Some actions are undertaken to reduce commercial or physical losses but without NRW management strategy	Some actions are undertaken to reduce commercial or physical losses but without NRW management strategy.	IWA Water balance available and regularly updated. Physical and commercial Losses' performance indicators monitored. Regular NRW reduction activities as per a comprehensive NRW management strategy. Sufficient budget for NRW management.

4.2. Real Loss Computations Using Night Flow Analysis Method

The Night Flow analysis method computes flow in a network when the water demand is at its lowest [30]. The minimum night flow approach was used to determine water leakage in the water distribution system. Flow loggers were installed and flow data recorded from the 9th of May 2016 to 13th May 2016.

Equations (2) through Equation (4) were used in computing real losses [38].

$$\text{Expected Minimum Night Flow} = \text{Background losses} + \text{Normal night use.} \quad (2)$$

$$\text{Excess Night Flow (ENF)} = \text{Measured MNF} - \text{Expected Minimum Night Flow.} \quad (3)$$

$$\begin{aligned}&\text{Leakage } \left(\text{m}^3 / \text{month}\right)\\ &= \text{ENF } \left(\text{m}^3 / \text{hr}\right) \times \left(\text{hour} / \text{day factor}\right) \times 30 \text{ days} / \text{month.}\end{aligned} \quad (4)$$

Thus, equation (4) represents the real losses in a water supply system.

5. Results and Discussion

5.1. Self-assessment for NRW Management

A result of 3.1 out of 5 was obtained from the strategies used by Gweru city following the ranking of individual strategies. This represents 62% implementation of NRW strategies. Thus the outlined methodology can be effectively used to assess the level of non-revenue water management of a water utility. Such an indicator would prompt the water utility to embrace other water loss management approaches such as active monitoring and leakage management.

5.2. ILI Computation

Minimum night flows

The results for the minimum night flow for the period 9th -13th May 2016 are shown in Table 4.

Table 4. Five-day MNF Values (9th May 2016-13th May 2016)

Day	MNF (m^3/hr)
1	12.0
2	12.0
3	11.0
4	13.0
5	13.0
Average	12.2

Total NRW = Annual SIV − Annual Billed Consumption

$$NRW = 250421 - 109813 = 140608 \text{ m}^3 / \text{year}$$

Real loss = ENF x hour / day factor x365 days / year

$$= 9.13 \text{x} 24 \text{x} 365 \ = 79979 \text{ m}^3 / \text{year}$$

Apparent losses = NRW − Real Losses

$$AL = 140608 - 79979 = 60629 \text{m}^3 / \text{year}$$

$$UARL = \left[(18 \text{x} Lm) + (0.8 \text{x} Ns) + (25 \text{x} Lp) \right] \text{x} P$$

where Lm is length of mains (km); Nc is number of service connections; Lp is total length of private pipe, property boundary to customer meter (km); and P is average pressure (m).

Thus,

$$UARL = \left[(18 \text{x} 7.9979) + (0.8 \text{x} 384) + (25 \text{x} 0) \right] \text{x} 50$$
$$= 22558 \text{ litres} / \text{day}$$
$$= 8234 \text{ m}^3 / \text{year}$$

Thus

$$ILI = CARL / UARL$$
$$= \ 79979 / 8234$$
$$= 9.7.$$

Thus, the ILI for Irvine falls in the range 8-16, category C of the Technical Performance Category for developing countries [39] meaning that there is poor real loss management in the City of Gweru.

6. Conclusions

Therefore performance based water loss management plays a pivotal role in the assessment of the efficiency of water utilities. However, the comparison of performances between utilities should not be based entirely on percentage of SIV. IWA Manual of Best Practice with litres/connection/day gives a more accurate picture hence a better indicator.

The implementation of NRW management strategies by City of Gweru is just intermediate, to minimize losses to the acceptable values, and as such the city should up-scale their NRW management initiatives. The City of Gweru's ILI is too high and more effort should be channelled towards NRW reduction. Thus the two indicators, NRW and ILI, confirm the need for the city to manage water losses and maintain their infrastructure proactively.

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