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Water Distribution Systems Efficiency Assessment Indicators – Concepts and Application

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Abstract: ***The measure of performance of any water utility is based on the efficiency of the water distribution systems in place. Lately, performance indicators and benchmarking methodologies are the most important approaches used in assessing water distribution systems efficiency. This paper reviews water distribution systems assessment indictors and assesses their application to developing countries. The main indicators in use world over are either financial or operational. It was discovered that many utilities in developing countries do not adequately use these assessment indicators in their water loss management strategies. In a case study of the City of Harare, Zimbabwe, it was established that the city has 53% Non Revenue Water Management systems efficiency after applying non revenue water assessment indicators.***

Keywords: Performance indicators, benchmarking, water distribution systems efficiency, water loss management, non revenue water

1. Introduction

Water supply in many developing countries throughout the world is subject to varying problems [32]. Arid and semi-arid areas are particularly facing severe water scarcity due to rapid growing demand for water resources [32]. Some of the challenges contributing towards inefficient and poor water supply in developing countries have to do with urbanisation. Urbanisation has resulted in increased pressure on water resources thereby causing supply-demand mismatches. Other challenges faced by developing countries include political interventions, financial constraints, poor management structures as well as aged infrastructure among other things. As a result, urban water utilities are characterised by intermittent supplies and illegal connections [43]. Although challenges affecting developing countries are more or less the same, Africa with the lowest water supply and sanitation coverage than any other region in the world, is worst affected [32]. More than 30% of Africans residing in urban areas currently lack access to adequate water services and facilities [16]. New sources of water are increasingly expensive to exploit, limiting the potential for expansion of new water supplies [58]. 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 [46].

Many urban water systems in developing countries are characterised by heavy losses both financially and of water itself [16]. Furthermore, the water losses are resulting in poor service delivery. Water losses are seriously affecting performance of water utilities in developing countries. As a result many of the water utilities operate at technical efficiency levels well below a best-practice frontier that is determined by the relatively efficient ones from the same group [64]. Thus, there is considerable difference between the amount of water put into the distribution system and the amount of water billed to consumers [9, 26]. High levels of non revenue water (NRW) reflect huge volumes of water being lost through leaks, not being invoiced to customers, or both. Such a situation seriously affects the financial viability of water utilities through lost revenues and increased operational costs [26]. A high NRW level is normally a surrogate for a poorly run water utility that lacks the governance[64], the autonomy, the accountability, and the technical and managerial skills necessary to provide reliable service to their population [9, 26]. Transparency enhances citizen awareness of local performance and provides political leaders with important information for developing water sector policy [34]. The total cost to water utilities caused by NRW worldwide can be conservatively estimated at $141 billion per year, with a third of it occurring in the developing world [26]. Water availability challenges are worsened by high volumes of water losses and in the process, many water utilities fail to satisfy customer demands [26]. The failure to satisfy customer demands is one reason why customers are unwilling to pay for water delivery services particularly in urban settings. Thus, there is need for a paradigm shift to utilize water resources as efficiently as possible [8] .Water loss in the distribution system worldwide ranges from 15 to 60% of the total water supply [9]. In developed countries the water losses are in the range of 15% whilst in the developing countries averages approximately 50 % [26]. These countries also face challenges in accounting for water losses due to poor infrastructure, equipment failure and illegal use, [26]. Water utilities lose water in two forms: apparent or commercial losses, and real or physical losses. Physical losses include leaks from reticulation systems (especially service connections), leaks from transmission or distribution mains and overflow and leaks from storage and balance tanks.

Performance Assessment Systems (PAS) and benchmarking are powerful management tools for evaluating and improving performance as has been demonstrated through their systematic use in many industries for decades [4]. However, their application to the water industry for water loss management particularly in developing countries is still limited [38]. By conducting water audits, a water utility can monitor its water loss performance over time or compare itself with other water utilities (i.e. benchmarking) [55]. Benchmarking uses a collection of performance indicators to numerically evaluate different aspects of the distribution system. Performance indicators need to be consistent, repeatable, and presented in meaningful standardized units [19]. Benchmarking can be done at any increment of time: daily, monthly, yearly or every few years. By benchmarking, a system can: Evaluate its performance; Identify areas where improvement is necessary; Compare itself to other water systems; Evaluate financial options; Gauge itself competitively; and Provide data for reports to the public, regulators, and ultimate water users [19]. Performance indicators may include: (i) breaks per mile of distribution main per year, (ii) gallons of water lost per service connection, (iii) gallons lost per mile of distribution main, (iv) gallons lost per customer, (v) real losses in gallons per year, and (vi) dollars of apparent losses per year [28]. The AWWA/IWA Water Audit Methodology has a standard array of performance indicators that the public water system (PWS) can track annually when compiling the water audit[29].

Performance assessment plays a very important role in evaluating performances of water utilities with respect to their peers. This is evidenced by a study of 21 utilities [64], about 12.9 per cent of the water utilities operate efficiently as compared to their peers. This finding supports the commonly held view that Africa's water sector operates at unacceptable levels of technical inefficiency [64]. The best way of ensuring that utilities enhance their water distribution efficiency is by adopting proactive performance assessment systems [26, 44]. These water utilities often operate under a weak governance and financial framework, with utility managers having to face multiple political and economic constraints [26, 64]. There is need for water utilities to adopt performance assessment systems in order to enhance service delivery and match international standards. They have to provide some form of service to customers on a daily basis with mostly deteriorated infrastructure [26]. Zimbabwe's access to water-utility services is nominally among the highest in African low-income countries [65]. Access to piped water is more than three times the rate found in other low-income countries, and Zimbabwe's reliance on surface water, at only 7 percent of the population, is correspondingly one of the lowest in Sub-Saharan Africa, below the average for middle-income countries and only one-fifth of comparable low-income countries [65].

The objective of this paper is to review performance assessment systems used by many water utilities with a view of enhancing their application in developing countries like Zimbabwe. The paper focuses more on Non-Revenue Water (NRW) as an indicator of water supply system's efficiency. The paper first reviews NRW global trends, then an exposition of benchmarking, followed by systems performance indicators and performance assessment systems. Finally, the paper applies NRW performance indicators through a case study of the City of Harare, Zimbabwe.

2. Non Revenue Water Global Trends

Non revenue water, though it is a generalisation, is a good indicator of the efficiency of performance of water utilities [20]. Figure 1 shows performance of water utilities in the IBNET database (a database with more than 2000 water utilities), where less than 10% of the utilities have 3% NRW, between 10% and 20% utilities have NRW of 7%, between 20% and 30% utilities have NRW of 24%, between 30% and 40% utilities have NRW of 28%, between 40% and 50% utilities have NRW of 19% while greater than 50% of the utilities have NRW of 16%. From Fig.1 it can be easily inferred that the utilities in developing countries (30-40%) have the highest levels of NRW. This is also confirmed by [63] as shown in Table 2. Each year more than 32 billion M^3 of treated water is lost through leakage from distribution networks while 16 billion M^3 of treated water per year is delivered to customers but not invoiced because of theft, poor metering, or corruption [21].

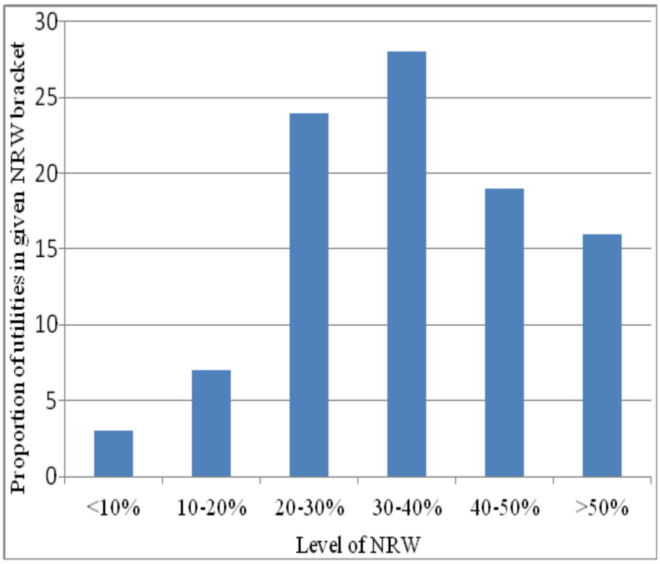

Figure 1: Performance of water utilities in terms of NRW

A conservative estimate of the total annual cost to water utilities worldwide is 14 billion United States Dollars [52]. In some low-income countries this loss represents 50-60% of total water supplied, with a global average estimated at 35%. By saving half of this amount an additional 100 million people would be supplied with water without further capital investment [60].

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Table 1: Sectoral estimates of worldwide NRW volumes

	Supplied Population (Millions 2002)	System Input (L/cap./d)	Level of NRW (% of system input)	Ratio		Volume (billion of m^3/yr)		
				Physical Losses	Commercial Losses	Physical Losses	Commercial Losses	Total NRW
Developed countries	744.8	300	15	80	20	9.8	2.4	12.2
Eurasia(GS	178	500	30	70	30	6.8	2.9	9.7
Developin	837.2[1]	250[2]	35	60	40	16.1	10.6	26.7
Total						32.7	15.9	48.6

Source: Mutikanga [37]

2.1 Impacts of Non Revenue Water on performance of water utilities

Water scarcity is envisioned world over due to increasing urbanisation, population overgrowth and climate change. These global change pressures are more pronounced on poorly managed urban water distribution systems [8, 44]. In the Middle East and North Africa Region (MENA), countries such as Tunisia and Algeria are experiencing absolute water scarcity with less than 500 m^3 /person/year of freshwater [38]. In East Africa, Kenya falls below the freshwater water poverty line, defined by experts as 1,000 m^3/person/year [52]. By the year 2025, Tanzania and Uganda will be approaching the critical levels [66]. High levels of utility NRW often lead to low levels of efficiency, leading to increased cost of water collection, treatment and distribution [20]. Furthermore, water sales decrease and capital expenditure programs become the last option to meet the ever-increasing demand [21]. For developing countries with serious capital constrains, the dilemma is unbearable, and often leads to deprivation of other sectors of the economy [9, 20]. High physical water losses often lead to discontinuous water supply, either because of limited raw water availability or because of water rationing. In addition to substandard service, erratic water supply contributes a significant health risk [33]. Furthermore, erratic water supply will leave customers unsatisfied, resulting in low willingness to pay for service received [56]. In the case of erratic water supply (typical of poor urban utilities), which is frequently caused by excessive leakage, the urban poor often suffer most, as they cannot afford proper storage facilities and pumps and often have to buy water from vendors during non-supply hours [56]. In addition, leakages often increase flow rates in pipe networks, causing unnecessary pressure losses that affect customers and often lead to supply interruptions during peak demand hours [24]. Therefore, water utilities could increase service coverage by reducing physical losses from the distribution network to the satisfaction of their customers. To avert the NRW situations, water utilities may evaluate their overall performance with respect to other utilities operating in the same environment through benchmarking.

[1] Based on total population having access to safe water supply of 1.9 million people with 44% of these receiving water through household connections; [2] show wide discrepancy from 100L/Cap./day to 400L/Cap./day

3. Benchmarking

Benchmarking can be described as a "best practice" process approach for comparing systems efficiency with respect with others regarding quality and work processes [33]. Normally, the main applications of benchmarking are; (i) internal improvement of productivity and efficiency by learning from "best practice", and (ii) to control the systems efficiency in terms of quality development with respect to other sectors [30, 51]. Benchmarking is a powerful management tool used for comparing one's business processes and performance metrics with the industry's best and/or best practices [51]. Benchmarking is usually used by water utility managers, policy makers, regulators and financial institutions for different purposes with the target of improving water services and optimizing operations [33]. However, benchmarking will not solve all water supply challenges faced by water utilities.

Although benchmarking has been used widely in other sectors, it has recently become very popular in the water industry as indicated by numerous publications [11, 38, 61]. The International Benchmarking Network for Water and Sanitation (IBNET) program has grown into the largest publicly available water sector performance mechanism that collects, analyzes, and provides access to information of more than 2,500 water and wastewater service providers from more than 110 countries around the world [61]. In the Netherlands, the Dutch water companies are self-regulated through voluntary benchmarking under the Association of the Dutch Drinking Water Companies (VEWIN) [14]. There are various benchmarking methods widely used in the water industry. The methods are usually categorized as metric or process benchmarking [27].

3.1 Overview of benchmarking methods

Process benchmarking is a normative tool for comparing the effectiveness of one's processes and procedures for executing different functions to those of selected peer groups [27]. Comparisons often reveal performance gaps and help underperforming undertakings to adapt and internalize those more efficient and effective processes and procedures as appropriate. The methods used for process benchmarking are usually partial methods that deal with parts of the business such as PIs and can either be quantitative or qualitative [14, 39]. Its effectiveness depends on the level of information provided by different PIs. It is the most widely used in the water sector (e.g. IWA/AWWA PIs, IBNET, OFWAT, VEWIN etc.) due to its simplicity [8, 11]. Its disadvantage is that it does not provide any overall efficiency measure. However, the future paradigm of performance measurement is a multi-factor, informative and relative one [57].

In parametric benchmarking, well established empirical procedures are used by analysts to measure performance and identify performance gaps. It is more meaningful when carried out over time, tracking year-to-year changes in performance. The quantitative total methods that cover the whole business are the most preferred for metric benchmarking [44]. They are categorized as either parametric or non-parametric methods. The parametric methods such as stochastic frontier analysis (SFA) use econometric approaches. The non-parametric approaches such as Data Envelopment Analysis (DEA) use linear programming techniques to determine a company's efficiency frontier, which is assumed to be deterministic. The DEA and SFA methods are two main approaches used to construct production frontiers [12]. DEA is the most widely used non-parametric method in practice [18, 61] and is increasingly being applied for measuring efficiency of water utility companies [41, 44]. The method is simple to use, requires relatively small data sets and does not require specification of a functional form for production frontier. On the other hand SFA methods require several choices, mainly on the functional form and distribution assumptions, which both parties may find difficult to understand and communicate. Further details on these methodologies and their applications can be found in several textbooks [1, 54, 61].

3.2 The Operational Performance Indicators

The Operational Performance Indicator serves as a useful tool for performance tracking and target-setting of efforts to control real losses [19]. The AWWA/IWA audit methodology relies on four performance indicators to help characterize real losses from distribution systems. These performance indicators are the Current Annual Volume of Real Losses (CARL), Operational Performance Indicator for Real Losses, the Unavoidable Annual Real Losses (UARL), and the Infrastructure Leak Index (ILI) [19]. The Operational Performance Indicator for Real Losses is the annual volume of real losses from the water audit divided by the number of customer service connections. The indicator exists with the units of gallons per service connection per day for water utilities with a customer service connection density greater than 32 per mile [19]. If the customer service connection density is less than 32 per mile, then the form of the indicator is gallons per mile of pipeline per day. The Unavoidable Annual Real Losses (UARL) is a reference value that represents the theoretical low level of leakage that would exist in a distribution system if all of the best leakage management techniques were successfully employed [24]. By defining and then calculating the reference volume of the UARL in the system, an indication of the Potentially Recoverable Real Losses can be calculated as the difference between the CARL and the UARL. However, AWWA/IWA research across a large number of systems, together with actual operating data from many countries has resulted in the development of a relationship between various system parameters and the UARL with statistically good accuracy [28, 29, 31]. A system's UARL is a function of the length of the distribution system, the number of service connections, the length of the service lines, and the average system operating pressure [63].

3.3 Benchmarking success stories

The most remarkable example for Water Loss Management (WLM) that combines PIs, target setting and benchmarking techniques is perhaps the one of England and Wales where the water industry is highly regulated. In the last two decades, leakage has been reduced from 5,112 ML/d in 1994/95 to now 3,281 ML/d (2009/10) or 9.7 m^3/km/d or 133.1 L/property/d [39]. This is a reduction of more than 35%. Assuming an average consumption of 150 L/c/d, the water saved (1,831 ML/d) is enough to serve more than 12 million people or the whole area served by Severn Trent, the second biggest water company in England and Wales. [10] attributes this success to industry reforms in 1989, comparative competition, incentive regulation and development of more robust asset management tools and methodologies. Other water loss benchmarking studies on WLM using partial methods have been reported in various countries that include Canada [22, 35] South Africa [30] New Zealand [36], Australia [29], in Austria [27], in Asia [3], in Africa [67], in Latin America [61] and internationally [30,36]. In a more recent benchmarking study on 18 water utilities in India, the analysis based on the Data Envelopment Analysis (DEA) methodology reveals inefficiency in the Water Distribution Systems (WDSs) and considerable potential for NRW reduction by 12.6% among other parameters [51]. In Palestine, the efficiency of the WDSs was evaluated by applying DEA to 33 municipalities and the findings indicated that water losses were the main cause of inefficiency and network rehabilitation was required starting with the most DEA inefficient municipalities in order to minimize water losses [5]. In a benchmarking study carried out in the USA, over 100 water utilities were analyzed using linear regression models and findings confirm that water utilities that use proactive strategies for WLM had better system efficiency [40]. DEA and Corrected Ordinary Least Squares have been used in comparative efficiency evaluations and regulation of water distribution companies in England and Wales [13, 54]. The major drawback in performance benchmarking is that the whole process loses credibility unless data used to define the PIs is reliable and accurate, generated in a transparent and auditable process. The next section reviews the generally applied water loss management systems performance indicators.

4. Systems performance indicators

The assessment of an undertaking's performance using Performance Indicators (PIs) can measure the quality of service and the utility's effectiveness and efficiency [17]. Furthermore, performance indictors make transparent the comparison between the objectives, provide benchmarking between similar undertakings and encourage them to provide an improved service [4]. The most widely used indicators for water loss management were developed by IWA [4, 28] and adopted by the American Water Works Association (AWWA), [7]. Some useful indicators selected from the IWA/AWWA menu of PIs [4] for water loss management included the following: (a) Real losses (m^3 /connection/day,). The breakdown of water loss into real and apparent loss components in the absence of reliable and accurate data is however subjective and debatable [31]. The usefulness of these indicators in developing countries will heavily depend on acquisition of accurate data which is likely to be a challenging task amidst inadequate resources [4, 17] (b) Mains break (number/km/year), a proxy measure for pipeline asset condition, and (c) Apparent losses (m^3 /connection/day). For benchmarking purposes, performance indicators can be classified as Operational, Asset serviceability, Meter management, Legal use management, Human Resources Management, and Economic and Financial [27]. Ultimately, non revenue water, a proxy of water losses, is a noble starting point in assessing water distribution systems efficiency [14]. It is worth noting that systems performance indicators are part of performance assessment systems adopted by water utilities.

4.1 Performance Assessment Systems

Literature on performance assessment systems of water utilities was reviewed through a desk study where several literature sources were analysed. It was discovered that several performance assessment approaches are being utilised in many parts of the world. Performance Assessment Systems (PAS) are systems used by water utilities to assess their performance through identification of performance drivers and by measuring success in reaching their set objectives [8, 12] Different institutions use PAS to measure performance of water utilities. These include regulators (e.g. OFWAT in the UK), financial institutions (e.g. the World Bank), policy makers and utility management [37]. Performance assessment systems play a very pivotal role in ensuring that a water service provider understands the drivers and level of performance of the system being operated. Many public utilities in developing countries find themselves locked in the vicious cycle from which they cannot escape due to poor performance [8]. Poor performance creates a vicious spiral as the problems regenerate [8]. Utility performance could be described as a low level equilibrium where low prices lead to low quality, limited service expansion, operational inefficiency and corruption, thereby further eroding public support, [8, 44].

Policy analysis should be concerned both with prescriptions aimed at maximizing the efficiency of specific institutions in terms of operators' efficiency, regulators' competence and endowments [53]. The next section reviews NRW as a water distribution systems performance indictor.

4.2 Non Revenue water as a performance indicator

The most widely used PI for assessing water losses and target setting is percentage Non Revenue Water (NRW) [9, 26, 29]. In particular, NRW has been used widely as a measure of performance of a water supply system's efficiency. That means citizen satisfaction with urban services is closely associated with the actual performance of the services with respect to the initial expectations about the services [2]. Performance- based service contracting for NRW reduction should not be viewed as a new magic formula for solving the many woes of public water utilities in developing countries, which come from more fundamental institutional problems [26]. However, a successful performance-based service contract for NRW reduction can create a positive dynamic for change within the utility and the sector as a whole [26]. Although percentage NRW is recommended as a basic financial indicator, its main disadvantage is that it is affected by consumption patterns, independent of the utility's WLM [29].

Table 2: Indicators widely used for Water Loss Management

Level	*Water Resources*	*Operational*	*Financial*
Basic	Inefficiency of use of water resources: Real losses as a percentage of system input volume	Water losses: (volume/service/conn/year)	NRW:NRW as a percentage of system input volume
Intermediary		Real Losses: volume/service conn/day (when system is pressurised)	NRW: value of NRW as a percentage of the annual cost of running the water system
		Apparent Losses: volume/service. conn/year	
Detailed		Infrastructure leakage index (ILI)	

Source: AWWA [7]

4.2.1 NRW percentage by volume as an Operational Performance Indicator (PI)

Because consumption (including water exported) normally makes up a very substantial part of system input volume 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 [30,33]. Calculation of percentage by volume is traditional and usually a simple 'first step'. However, the best simple traditional real losses PIs are 'per service connection' or 'per km of mains' (depending upon connection density); and they should be accompanied by an estimate of average pressure, and preferably with a calculation of Infrastructure Leakage Index (ILI) [28]. Thus, this is not totally illogical for a crude financial PI, as it represents the percentage of system input volume which is generating revenue. However, NRW percentage by volume takes no account of the different valuations of components of NRW, or the cost of operating the system [28]. 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 m^3) to each of these NRW components, and dividing by the operating cost of running the system [28]. However, the numerous problems that occur if percentages by volume are used as Operational PIs for NRW and its components have been well documented internationally [4, 17, 29]. In its totality, the absence of an Operational and Target Setting PI for NRW needs to be remedied; while percentage of Water Supplied might be used initially for some minor components of NRW, it is not suitable for NRW as a whole, so the choice should logically be the PI that is selected for the largest component of NRW (normally Real Losses)[12,31,63], and will therefore usually be either volume/service connection/day or volume/km of mains/day, depending upon density of connections [33]. Another vital operational performance indicator to be reviewed is the Infrastructure Leakage Index.

4.2.2 Infrastructure Leakage Index

The concept of expressing NRW in terms of percentage of input volume does not account for operating pressures [63].

Furthermore, NRW is influenced by difference in connection density and distance of customer to street boundary. As a result [28] realised the need for a performance indicator which would allow for international comparisons between systems with very different characteristics. This led to the adoption of Infrastructure Leakage Index, a key component of a water balance and a System Loss Management Plan. The Infrastructure Leak Index (ILI) is a ratio indicator recommended by the IWA to perform benchmarking of utility leakage status [33]. The ILI was developed to address the lack of an objective benchmarking indicator [33, 63]. It is a ratio of current annual real loss (CARL) to Unavoidable Annual Real Loss (UARL). The Economic Level of Real Losses usually lies somewhere between the CARL and the UARL. Thus, IWA recommended ILI a Level 3 indicator, (indicators that provide the greatest amount of specific detail but still relevant to top management). ILI best describes the efficiency of the real loss management of water utilities. It's a measure of how well a distribution network is managed for control of real losses at the current operating pressure [30, 63]. The ILI value in the range of 1-2 corresponds to performance category A, meaning that the water utility has good performance with respect to real losses [63]. 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 virtual rarity in actual practice. 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 to 2.5[63]. If the water audit quantifies real losses as excessive, a targeted level of leakage reduction should be established by the water utility, or may be established by regulatory authorities. The Operational Performance Indicator for Real Losses (gallons per connection per day or gallons per mile per day, depending upon system size) is best to use for target-setting and performance tracking. In setting a targeted level of leakage reduction, the water utility should carefully assess the economic justification of the leakage management effort [19, 31]. Another important indicator to be reviewed is the Apparent Loss Index.

4.2.3 Apparent Loss Index

Proper water meter management effectively reduces apparent water losses, thereby making much economic sense [23]. The apparent loss index (ALI), an analogy of ILI, has been proposed [43, 55]. The ALI is defined as the ratio of the current annual apparent losses (CAAL) to unavoidable annual apparent losses (UAAL). Table 3 shows ALI performance bands for both developed and developing countries. In the absence of a reliable UAAL, a base value of 5% of water sales is recommended as a reference value [44]. However, the benchmark reference value of 5% of water sales is rather high for most water utilities in developing countries as shown in Table 4 [27]. In the developed countries, the benchmark seems low for cities with universal customer metering and too high for partially metered systems [27]. AL for systems with customer storage tanks should not be compared directly with systems on direct mains pressure supply due to the ball-valve effect that amplifies AL in systems with storage tanks [29]. Thus, there is clear need for more appropriate PIs and indices to cover diversities in water distribution systems in developing countries and for performance comparisons across utilities [63].

Table 3: ALI performance bands

Region	*Technical Performance Group*	*ALI*	*Remarks*
Developed countries	A	1-2	Acceptable performance. Further reduction may be uneconomical unless if the cost of water is very high
	B	2-3	There is room for improvement
	C	3-4	High revenue losses, Acceptable where cost of water is very low
	D	>4	Very inefficient with poor meter management practices and in adequate policies for revenue protection. Urgent action required to minimise revenue losses
Developing countries	A	1-2	Acceptable performance. Further reduction may be uneconomical unless if the cost of water is very high
	B	2-4	There is room for improvement
	C	4-6	High revenue losses, Acceptable where cost of water is very low
	D	>6	Very inefficient with poor meter management practices and in adequate policies for revenue protection. Urgent action required to minimise revenue losses

Source: Mutikanga [37]

Table 4: Variation of AL of water sales for different countries

City and/ country	*%AL*	*Data source*
Kampala, Uganda	37	[37]
Lusaka, Zambia	33	[49]
Manila, Philippines	16	[15]
Jakarta, Indonesia	36	[48]
Philadelphia, USA	9.6	[6]
England and Wales	2.8	[39]

Source: Mutikanga [37]

4.2. 4 Traditional performance indicators for real losses

The four traditional performance indicators are (i) Water Losses and Real Losses as a % of system input volume (ii) Water Losses and Real Losses per property per day (iii) Water Losses and Real Losses per km of mains per day and (iv) Water Losses and Real Losses per service connection per day. Leakage component analyses in water distribution systems across the world have shown that the greatest proportion of annual real losses occur on services connections, including the connecting point to the main. This applies to all systems with a connection density of more than around 20 connections per km main. The IWA Task Force recommended [55] that the basic traditional PI with the greatest range of applicability for real losses, to be referred to as the 'Technical Indicator Real Losses' (TIRL). TIRL equals Real Loss Volume/Service Connection/Day. TIRL is the best of these traditional indicators - but should always be calculated when the system is pressurized, to allow comparisons between systems with different levels of supply [55]. However, this indicator still does not take operating pressure into account, which is a major disadvantage. Thus, the best option would be Unavoidable Annual Real Losses (UARL), a methodology which takes account of the local factors of density of connections, location of customer meters on service connections, and average operating pressure [17]. The application of a performance assessment approach was undertaken at one local authority in Sub-Saharan Africa, the City of Harare.

4.3 Financial Indicators

There are many different financial indicators available, and it has been necessary to restrict the listing to those which are likely to be measurable in the context of government bodies whose accounting systems are not geared up to management accounting [62]. In urban water and sewerage systems, the efficiency of revenue collection is one of the most important indicators; many organizations simply do not collect the user charges from those to whom they send bills. Improving this indicator is one of the highest priorities for increasing revenue [62]. Thus, NRW performance assessment indicators play a very important role in enhancing service delivery efficiency of water utilities and these indicators are easily applied in developing countries.

5. Case study of the City of Harare

5.1 Background Information

A case study of Harare, Zimbabwe was documented in this paper. The Greater Harare Region has a population of about 2.1 million people. The average water losses are in the range of 60%. The case study sought to assess the level of management of NRW. The assessment was done following the self assessment methodology proposed by the International Water Association [7].

5.2 Harare Water NRW Performance Assessment

Self Assessment Matrix on Non-Revenue Water management for the best practice developed by Africa Development Bank [3] was adopted to assess levels of interventions for each NRW management strategy employed in Harare Water. According to Harare Water utility assessment matrix which was done for the Urgent Water Supply and Sanitation Rehabilitation Program for Harare in 2011, it was reported that, the level of NRW management in Harare is 3 out of 5 scores developed for the excellence in NRW management as shown in Table 5. This self-assessment methodology was adapted from the International Water Association (IWA) to assess the efficiency of water utility [60].

Table 5: NRW management assessment matrix for Harare Water

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

The NRW implementation level is divided into 5 levels. For each level, there is a range of scenarios that describes the implementation level in a given area ("1" is poor and "5" is excellent). The Self Assessment Matrix on Non-Revenue Water management for the best practice developed by Africa Development Bank [3] was adopted to assess levels of interventions for each NRW management strategy employed by Harare Water. The proposed assessment parameters for utility's NRW management are shown in Table 6. Table 6 presents the enabling factors for each of the strategies currently implemented and proposed respectively.

Table 6: Enabling factors and challenges for each implemented strategy

Strategies		Strengths (enabling factors)	Weaknesses (barriers to implementation)	Opportunities (for increasing the levels of interventions)	Threats (to the strategy)
CURRENTLY IMPLEMENTED	Pipe Replacement	Mains data for the areas that require pipe replacement is known	Construction difficulties in built up areas and water cut off during replacement	Employment of zone based customers in pipe replacement to increase participation	Financial Resources
	Pressure Release Valve (PRV) servicing	Data on PRV available	Corroded PRV	Use of PRV which can control pressure during off-peaks period	Resources
	Leaks and Burst repairs	Data on networks available	Manual maps in use	GIS asset management system	Resources
	Meter Replacement	All connections metered. Need replacement	Leaking and corroded service pipes and water cut off during repairs	Proper metering will increase revenue	Resources (funding, manpower) Vandalism (destroying)
	Task Force for active leak Detection	Pipe routes are known and accessible	Current slow pace of repairs – turnaround time	Increasing support for demand management	Funding
	DMAs and Pressure Management	Zones are well defined	Failure of valves, meters, pressure control valves	Increased water supply control -	Resources
	Improve metering (Bulk Meters in Supply and Distribution mains)	Data known, areas accessible	Water cut off during repairs	Employment of zone based customers in pipe replacement to increase participation	Resources
	Reduction of Night Pressure	Data on PRV available	Use of Fixed PRV which are not flexible	Flexible PRV to control pressure during off-peaks period	Resources

According to Harare Water Utility assessment matrix which was done for the Urgent Water Supply and Sanitation Rehabilitation Program for Harare in 2011, it was reported that the level of NRW management in Harare is 3 out of 5 scores developed for the excellence in NRW management as shown in Table 5. This self-assessment methodology was adapted from the International Water Association's (IWA) to assess the efficiency of water utility [60]. However, this study showed that NRW management situation in Harare Water, considering strategies used and according to the ranking that was done referring to individual strategies, was 2.67 out of 5 representing 53.4% implementation of NRW strategies.

From the case study it was concluded that the implementation of NRW management strategies is just intermediate to minimize losses to the acceptable values as suggested by [59] and [23]. The improvement in the efficiency of the sector should go a long way in financing the need to improve access and/or quality of water production and distribution. Continuing the public or private financing of the sector without significant efficiency improvement is a major waste of scarce resources. Efficiency savings exceeds revenue from user fees which implies that average tariff levels continue to be too high as compared to what they would be if firms were operated efficiently [64]. The main challenges are however not in the water sector. Governance issues and the weakness of institutions have been and continue to contribute to a large share in the excess of costs [64].

6. Conclusions and Recommendations

NRW percentage by volume, Infrastructure Leakage Index and benchmarking methodologies thus play a pivotal role in assessing the efficiency of performance of water utilities worldwide. Whereas, performance assessment systems and benchmarking are useful tools for evaluating and improving WDS efficiency, their application in the water industry of developing countries is still limited. The systems and tools developed for the water industry may not be directly applicable to WDSs of the developing countries. As a result water utilities in developing countries should be more proactive in their operation and adopt international standards in their operations in order to match their developed countries counterparts.

The prospects for WLM lie in increasing capacity building of water utility employees, research, performance based contracting, emerging new equipment and technology for leak detection, and increasing dissemination of emerging "state-of-the-art" tools and methodologies for water loss reduction and performance improvement of utility water services. Operational performance efficiency is very vital for perpetuation of a sound service delivery. Many water utilities fail to identify and apply indicators appropriate and relevant to their operations. Thus, developing countries utilities should be capacitated to be able to apply assessment indicators in order to elevate their systems efficiency to international standards. This is mainly because their systems suffer from inadequate water supply, poor billing, and poor operation and maintenance records, resulting in exceptionally high NRW, and poor service delivery coupled with unrealistic water pricing. Water utilities and regulators of the operations of water utilities should make it a top priority that utilities operate within the right frameworks of efficiency assessment indicators. Thus, performance assessment systems including self assessment methodologies are applicable to the Zimbabwean situation.

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