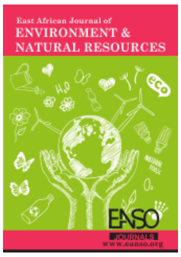

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Original Article

Evaluation of Non-revenue Water Management: A Case Study of Lodwar Water Supply in Lodwar Municipality, Kenya

Keya Mucholwa Wanjala Augustus[1*] *Prof. Ezekiel Nyangeri Nyanchaga, PhD*[1] *& Prof. Eng Bernard. N. Kimani Njoroge, PhD*[1]

[1] University of Nairobi, P.O. Box 30197-00100 Nairobi, Kenya.
[*] Correspondence ORCID ID: https://orcid.org/0009-0004-1669-6134; Email: keyaugustus_90@students.uonbi.ac.ke

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ABSTRACT

This paper scrutinises the availability and effectiveness of non-revenue water management practices at Lodwar Water Supply, which serves an urban populace in Arid, Northern Kenya. The case study is representative of medium-sized water utilities serving populations in water-scarce areas within developing countries. Challenges encountered by water utilities in developing countries are unique, and their resolution requires context-specific approaches. For instance, Lodwar water supply posted an estimated 52% non-revenue water in a recent assessment by Kenya's water services regulatory agency (WaSREB). The utility lost half of its production. This is unacceptable for a water utility serving an arid service area with 43% water coverage. This paper documents the findings of a causal study conducted to identify probable reasons for the water utility performance and develop recommendations to reverse the worsening non-revenue water trend. Four aspects were identified for scrutiny at the water utility; these were: Availability of strategies, methods, and policies for non-revenue water reduction; Employee and Consumer awareness of non-revenue water management; Techniques for enumeration of components of non-revenue water and the nexus between the foregoing and the prevailing poor non-revenue water and overall performance of the water utility. Three hundred eighty-five questionnaires were administered to consumers, randomly sampled across the selected study area. This was followed by a non-quantitative audit of non-revenue water practices by the water utility and focused group discussions with top management and technical staff at the water utility. This study established the absence of deliberate strategies for control of non-revenue water by the water utility as the critical reason for the unacceptably poor non-revenue water and overall performance of Lodwar Water Supply. Recommendations for mitigation of non-revenue water included the establishment of zone-specific, updated consumer database; DMAs with functional inflow meters; acquisition of meter testing and calibration system; institution of active leakage control initiatives and personnel capacity development.

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INTRODUCTION

In recent years, analysis of water supply service performance has attracted huge interest. It has been the focus of many studies, which unfortunately have been centred on developed rather than developing countries (Cetrulo et al., 2020). The contextual difference creates a significant gap in the literature, arising from disregarding features specific to developing countries, most of which are often overlooked and perceived as essential. High levels of water loss threaten the viability of most water supply establishments in developing countries (Faber & Radakrishnan, 2019). Diagnosing causal factors leading to poor NRW performance by a water utility is the first step towards developing optimal NRW reduction strategies (Faber & Radakrishnan, 2019). All water loss control programs begin with water balance estimation (AWWA, 2020). The approach essentially entails tracking flow right from the entry of water into the distribution system and losses as the water is conveyed to the end user. Thus, the role of correct flow measurement is paramount. It is appalling that most water utilities in developing countries have barely invested in system input metering infrastructure, perhaps due to a lack of commercial orientation (Mugabi et al., 2007), raising serious questions about data floated for utility performance rating, locally or globally.

This paper attempts to assess the prevailing NRW management practices for underperforming utilities, using the case study of Lodwar Water Supply, Kenya. The specific objectives of the study were as follows: To assess the availability of non-revenue water mitigation methods, strategies and policies; To establish instituted efforts for ensuring employee and consumer awareness in management non-revenue water by Lodwar water supply; To evaluate the presence of mechanisms for assessment of prevalent contributors to non-revenue water adopted in the study area's distribution system and To establish the impact of non-revenue water on the efficiency, effectiveness and rating of Lodwar water supply scheme.

The study analysed consumer responses sampled across the selected study area regarding strategies for NRW reduction, efforts towards developing employee and consumer awareness of NRW, techniques for enumeration of individual NRW components and impacts of NRW on the utility performance. A non-quantitative audit of NRW mitigation measures was then conducted, borrowing from Kenya's WaSREB guidelines (WASREB, 2018). The following section briefly previews the case study's profile, followed by research methodology, results and discussions, conclusions and recommendations.

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Brief Profile of the Case Study

Lodwar Water Supply Company is a water service provider established as per Kenyan laws, the Water Act 2002 and serves a population of 41,200 out of 93,980 residents. This represents 43.84% water coverage. The acceptable sector benchmark for water coverage is 80% (WASREB, 2021). NRW performance of 52% is alarming, especially because the service area is arid, with a single seasonal river, the Turkwel, thus the need for better management of available water. The water utility is saddled with unsettled power bills, highly demotivated staff, and unsatisfied customers. Should the NRW underperformance proceed unabated, the realisation of better water coverage remains unlikely.

The existing water distribution network relies on eight boreholes sunk along the banks of the Turkwel River. A preliminary network survey established the absence of bulk flowmeters on 7 out of 8 transmission mains. Routine surveys at the only metered borehole during this study revealed recurrent failure of the bulk meter. These observations raise questions about existing non-revenue water data and the water utility's capacity to estimate water balance. District Metered Areas, which are smaller, manageable hydraulic sections that enable focused observation and control of non-revenue Water (Faber & Radakrishnan, 2019), are not defined on this network, making water loss monitoring and analysis a challenge to the water utility. Leakage incidence reporting and resolution are unstructured, leading to lengthy real losses. One extreme case has been observed to last up to 6 weeks.

Despite these deficiencies, there has been continued estimation of NRW and ranking of utility performance, especially locally, based on somewhat misleading data, hence the unending NRW woes. Perhaps there exists an opportunity for this and other water utilities in developing countries to design NRW reduction strategies guided by scrutiny of their prevailing realities (Faber & Radakrishnan, 2019).

Determination for NRW for the isolated area of study and DMA for purposes of this research was made over a billing cycle (June-July 2023) for comparison with the official NRW figures.

Bulk meter reading on 21st June 2022 (@ 1800 hrs) = 429,003 m^3 (a)

Bulk meter reading on 21st July 2022 (@ 1800 hrs) = 494,517 m^3 (b)

Assume storage & pipe water as 180 m^3 (c)

Total Production= (b) – (a) – (c) = 494,517 m^3 - 429,003 m^3 – 180 m^3 = 65,334 m^3

Total consumption for July = Sum (July readings - June readings) = 27,010 m^3

NRW (volume) = 65,334 m^3 – 27,010 m^3 = 38,324 m^3

$$\% \text{ NRW} = \frac{38{,}324}{65{,}334} \times 100\ \%$$

% NRW = 58.66%

58.66% in 2022 is an increase from the 52% reported in 2021, a discouraging trend.

MATERIALS AND METHODS

Methods

Lodwar Water Supply Scheme distributes water to 9,759 connections within Lodwar Municipality. Three hundred eighty-five connections were randomly selected to represent the consumer population in the study area in completing predesigned online questionnaires developed on the Online Data Kit (ODK) tool. The sample size was determined through the sample size formula, equation (i) (Kaslik, 2019).

$$\text{Sample size, n} = \text{N} \times \frac{\frac{Z^2 \times p \times (1-p)}{e^2}}{[N-1+\ (Z^\wedge 2\ \times p \times (1-p))/e^\wedge 2\ ]}$$

Equation 1

Where N = Population size; Z = critical value of the normal distribution at the required confidence level; p = Sample proportion; e = margin of error. For the study area; N = 41,200 (Population served, equals 9,579 connections); z =1.96 for 95% confidence level; p = assume 0.5; e = 5%. The

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appropriate sample size is, therefore, ≥ 370 connections. This research involved 385 random connections.

Questions were designed under 5 categories: All informants' personal data; Method, Strategy, and Policy for NRW management; Employee and Consumer Awareness of NRW; Assessment methods for main NRW components and Impacts of NRW on the performance of the utility. These are outlined as follows;

All Informants' Personal Data

The respondents' identification or connection number; the status of the customer meter, i.e. whether functional or not; position in the household; level of education and role at the water utility (for employees) were probed.

Method, Strategy and Policy for NRW Management

This is represented elsewhere in this paper as MSP. MSP1 inquired on periodic water balance estimation, MSP2; pressure monitoring, MSP3; Availability of network as-built-drawings, MSP4; Active Leakage Control (ALC) Plan, MSP5; Manual or GIS mapping of the distribution network, and MSP6; zones for NRW monitoring (DMAs).

Employee and Consumer Awareness of NRW

This is presented in this paper as ECA. ECA1 inquired on the technical capacity to monitor water usage, ECA2; training plan for staff on NRW, ECA3; records of training and NRW skills development, ECA4; NRW training in the last two years and ECA5; conduct of regular consumer water efficiency campaigns.

Assessment methods for main NRW Components

This is presented in this paper as AM. AM1 inquired on prioritisation of system input metering, AM2; frequency of leak/bursts detection patrols, AM3 availability of meter tests, cleaning, and calibration on a meter bench or otherwise, AM4; records of customer meter ages and ECA5; surveys to establish illegal connections.

Impacts of NRW on the Performance of the Utility

This is represented elsewhere in this paper as IP. IP1 inquired about the interruption of water supply, IP2; profits in the last 3 - 5 years, IP3; expansion in coverage during the previous three years, IP4; sustainability of current water tariffs and IP5; the urgency of O+M services.

Data Analysis

Questionnaire findings were subjected to statistical analysis on IBM SPSS Statistics 28.0.1.0. Deductions were drawn based on four research hypotheses outlined as follows;

Research hypothesis 1 (MSP): Lodwar Water Supply has established assessment methods, strategies, and policies for minimising non-revenue water

Research hypothesis 2 (ECA): There are mechanisms in place to ensure employee and consumer awareness concerning non-revenue Water at Lodwar water supply

Research hypothesis 3 (AM): Lodwar water supply has in place mechanisms to establish prevalent non-revenue water components

Research hypothesis 4 (IP): NRW levels have NOT adversely impacted the performance of Lodwar Water Supply

Responses were coded on a five-point Likert scale: (1 = Strongly Agree; 2 = Agree; 3 = Neutral; 4 = Disagree and 5 = Strongly Disagree). Summary statistics were obtained for each set of questionnaires.

Hypothesis testing then followed, guided by the nature of the questions. One sample t-test was applied to compare the group mean to a pre-established value.

For each hypothesis, the null hypothesis was defined, i.e.

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H_0: $\mu = \mu_0$ (population mean is equal to some hypothesised value μ_0);

The alternative hypothesis was then stated (single-tailed) i.e

H_1 (left-tailed): $\mu < \mu_0$ (population mean is less than some hypothesized value μ_0)

H_1 (right-tailed): $\mu > \mu_0$ (population mean is greater than some hypothesised value μ_0).

The test statistic was determined and keyed in. The p-value was applied in the rejection or non-rejection of the null hypothesis as appropriate (Kaslik, 2019).

A correlation of three key NRW aspects, strategy, awareness & assessment methods, to utility performance was made through a chi-square test (Kaslik, 2019).

Network audit and utility maturity assessment

The tool for assessment of the water utility allowed for audit through consideration of 6 elements: Water balance, Leak repair records, KPIs, Active Leakage Control, Customer metering and Stakeholder engagement (WASREB, 2018). The tool gives 5 categories: **A**: Best Practice; **B**: Good; **C**: Satisfactory; **D**: Low Compliance; **E**: Non-existent.

RESULTS

Demographics of the Respondents

55.2 % of the participants were female, while 44.8 % were male. All participants included in the study were over 18 years of age, with 17.7 % being 45-54 years, 44.8 % being 35 to 44 years, 33.6 % between 18 to 34 years, and 3.9 % between 55 to 65 years. 63 % of the respondents were heads of households, while 37 % were adult representatives of household heads. 54.4 % of respondents had attained a tertiary/university level of education, 35.7% had secondary school education, and only 9.9 % of the participants had not completed primary school education. 96.6% of the respondents confirmed that their meters were functional. Four respondents worked in senior-level management at the water utility and were conversant with the technical operations at the utility.

Non-revenue Water Assessment Strategies and Management Policies

Summary statistics for existing strategies to mitigate non-revenue water are given in *Table 1*. The proposition that the utility prepares a regular or annual water balance was vehemently opposed (mean = 2.07, mode = 7). Similarly, participants agreed that the utility does not measure pressure across the system (mean =1.88, mode 2), making it difficult to detect and control theft, leakage, and pipe bursts. The majority of respondents agreed with the proposition that the network is not captured on up-to-date as-built drawings (mean =1.75, mode = 2) and disagreed with the statement that the utility has an active leakage control plan (mean = 1.6, mode = 1) nor has mapped its network manually or GIS (mean = 1.62, mode = 1). The majority of respondents confirmed the absence of district-metered areas (mean = 1.76, mode = 2). Overall, the mean rating for the non-revenue water strategies and management policies adopted by Lodwar Water Supply is below 2; the mode is 2 (disagree), implying that the water utility does not have efficient strategies and policies for non-revenue water management.

Table 1: Summary statistics for existing strategies to mitigate non-revenue water

	Mean	**Median**	**Mode**
The utility prepares an annual/regular water balance	2.07	2	2
The utility measures pressure across the system	1.88	2	2
The network is captured on up-to-date as-built drawings	1.75	2	2
The utility has in place an active leakage control plan (ALC)	1.6	2	1
The utility has mapped its network manually or through GIS	1.62	2	1
There are established DMA (s) for NRW monitoring	1.76	2	2

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Assessment Methods for Prevalent Contributors of NRW

Table 2 gives findings on measures by the utility to isolate and quantify NRW components. Most respondents confirmed that System input metering is not a priority to the utility (mean = 1.91, mode = 2). Most respondents confirmed that the utility does not run weekly leak detection patrols (mean = 1.59, mode = 2) nor run regular meter tests (mean = 1.61, mode = 2). The utility does not keep records of customer meter ages (mean = 1.6, mode = 1) and does not conduct surveys to establish illegal connections. (Mean = 1.49, mode = 1).

Table 2: Findings on how the utility can isolate non-revenue water components.

	Mean	Median	Mode
System input metering is a priority for the utility	1.91	2	2
The utility runs weekly leak/burst detection patrols	1.59	2	2
The utility runs regular meter tests, cleaning, and calibration on a meter bench or otherwise	1.61	2	2
The utility keeps records of customer meter ages	1.6	2	1
There are regular surveys to establish illegal connections	1.49	1	1

Employee and Consumer Awareness about NRW

Measures to ensure employee and consumer awareness about NRW were evaluated and are represented in *Table 3*. The majority of respondents said the utility lacks proper technical capacity to monitor water usage (mean = 1.91, mode = 2) and agreed that the utility does not provide regular training to its employees (mean = 1.93, mode = 2), hence minimal effort by LoWaSCo in ensuring that technical staff are aware of NRW management. While most participants were neutral regarding training and NRW skills development at LoWaSCo (mode = 3), the mean was 2.24, below 3, suggesting that LoWaSCo does not provide adequate training and room for new skills development. *Table 3* gives a summary of these findings.

Table 3: Measures of employee and consumer awareness of non-revenue water

	Mean	Median	Mode
The utility has the technical capacity to monitor water usage	1.91	2	2
There's in place a regular training plan for staff on NRW	1.93	2	2
There exists a record of training and NRW skills development	2.24	3	3
Staff have received NRW training in the last two years	2.46	3	1
The utility undertakes regular consumer water efficiency campaigns	1.41	1	1

Impact of NRW on Performance of Lodwar Water Supply.

The effects of NRW on the overall performance of the water utility are represented in *Table 4*. Most respondents confirmed enduring long spells of interrupted water supply (mean = 4.35, mode = 5). Most respondents confirmed that over the past three years, the utility appears not to have made significant profit from its operations (mean = 1.98, mode= 10) with limited expansion in coverage (mean = 3.64, mode = 5). The current water tariffs are unsustainable due to the high level of NRW (mean = 4.34, mode - 5).

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Table 4: Effects of non-revenue Water on the overall performance of the water utility

	Mean	Median	Mode
Customers endure long spells of interrupted water supply	4.35	5	5
The water utility has registered significant profits in the last 3 - 5 years	1.98	2	1
The current water utility tariffs are unsustainable, given high NRW levels	4.34	5	5
The utility has not recorded more than a 10% expansion in coverage over the last three years.	3.64	4	5
O + M services and leak repairs are often delayed	4.34	5	5

Testing of Research Hypothesis 1: Methods, Strategies and Policies for Reducing NRW

Research hypothesis: Lodwar Water Supply has established assessment methods, strategies, and policies for minimising non-revenue water.

Null hypothesis: Lodwar Water Supply has NOT established assessment methods, strategies, and policies for minimising non-revenue water.

α – value = 0.05 (95% confidence interval); $H_o \leq 3.5$; $H_a > 3.5$; One sided p – value < 0.001 less than 0.05; hence we CAN NOT REJECT the null hypothesis

Lodwar Water Supply has NOT established Methods, strategies or policies for minimising NRW, as illustrated in *Table 5* below.

Table 5: Research Hypothesis 1; Methods, Strategies & Policies (MSP) for minimising NRW

	t	df	Significance		Mean Difference	95% CI of the Difference	
			One-Sided p	Two-Sided p		L	U
MSP1	-34.381	385	<.001	<.001	-1.430	-1.51	-1.35
MSP2	-43.435	385	<.001	<.001	-1.619	-1.69	-1.55
MSP3	-51.282	384	<.001	<.001	-1.755	-1.82	-1.69
MSP4	-57.816	385	<.001	<.001	-1.902	-1.97	-1.84
MSP5	-56.696	384	<.001	<.001	-1.882	-1.95	-1.82
MSP6	-41.104	385	<.001	<.001	-1.741	-1.82	-1.66

One-Sample Test; Test Value = 3.5

Testing of Research Hypothesis 2: Employee Awareness of NRW at Lodwar Water Supply

Research hypothesis: There are mechanisms to ensure employee awareness concerning non-revenue Water at Lodwar water supply.

Null hypothesis: There are NO mechanisms in place to ensure employee awareness concerning non-revenue Water at Lodwar water supply

α – value = 0.05 (95% confidence interval); $H_o \leq 3.5$; $H_a > 3.5$; One sided p – value < 0.001 less than 0.05 hence we CAN NOT REJECT the null hypothesis

Therefore, there are NO mechanisms in place to ensure employee awareness with respect to non-revenue Water at Lodwar water supply. The results of the single-tailed test are given in *Table 6*.

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Table 6: Research Hypothesis 2; Employee and Consumer Awareness (ECA) of NRW at Lodwar water supply

	t	df	Significance		Mean Difference	95% CI of the Difference	
			One-Sided p	Two-Sided p		L	U
ECA1	-36.967	381	<.001	<.001	-1.592	-1.68	-1.51
ECA2	-38.505	380	<.001	<.001	-1.566	-1.65	-1.49
ECA3	-28.889	381	<.001	<.001	-1.264	-1.35	-1.18
ECA4	-24.153	381	<.001	<.001	-1.042	-1.13	-.96
ECA5	-73.073	381	<.001	<.001	-2.086	-2.14	-2.03

One-Sample Test; Test Value = 3.5

Testing of Research Hypothesis 3: Assessment methods for prevalent non-revenue water components.

Research hypothesis: Lodwar water supply has in place mechanisms to establish prevalent non-revenue water components

Null hypothesis: Lodwar water supply DOES NOT have in place mechanisms to establish prevalent non-revenue water components

α – value = 0.05 (95% confidence interval); $H_o \leq 3.5$; $H_a > 3.5$; One sided p – value < 0.001 less than 0.05; hence we CAN NOT REJECT the null hypothesis

Therefore, there are NO assessment methods for determining specific NRW components at the Lodwar water supply. The results of the single-tailed test are given in *Table 7*.

Table 7: Research Hypothesis 3; Assessment Methods (AM) for prevalent NRW components

	t	df	Significance		Mean Difference	95% CI of the Difference	
			One-Sided p	Two-Sided p		L	U
AM1	-4.259	383	<.001	<.001	-.326	-.48	-.18
AM2	-59.965	383	<.001	<.001	-1.906	-1.97	-1.84
AM3	-60.973	383	<.001	<.001	-1.891	-1.95	-1.83
AM4	-54.172	382	<.001	<.001	-1.899	-1.97	-1.83
AM5	-58.795	383	<.001	<.001	-2.010	-2.08	-1.94

One-Sample Test; Test Value = 3.5

Testing of Research Hypothesis 4: Impacts of NRW on the performance of Lodwar Water Supply.

Research hypothesis: NRW levels have NOT adversely impacted the performance of Lodwar Water Supply. Null hypothesis: NRW levels have adversely affected the performance of Lodwar Water Supply

α – value = 0.05 (95% confidence interval); Ho ≤ 3.5; Ha > 3.5; p-value < 0.001 less than 0.05; hence we CAN NOT REJECT the null hypothesis.

Therefore, Non-revenue water levels have adversely impacted the performance of Lodwar Water Supply. Results are in *Table 8*.

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Table 8: Research Hypothesis 3: Impacts of NRW on the performance (UP) of Lodwar Water Supply

	t	df	Significance		Mean Difference	95% CI of the Difference	
			One-Sided p	Two-Sided p		L	U
UP1	15.628	384	<.001	<.001	.848	.74	.95
UP2	11.093	384	<.001	<.001	.521	.43	.61
UP3	16.697	384	<.001	<.001	.835	.74	.93
UP4	2.259	384	.012	.024	.142	.02	.26
UP5	18.362	384	<.001	<.001	.835	.75	.92
One-Sample Test; Test Value = 3.5							

Chi-Square Test for Impact of Non-revenue Water on Utility Performance

The chi-square test was applied to establish the relationship between the absence of assessment methods for prevalent non-revenue water contributors and the overall performance of the water utility. According to the results in *Table 9*, there is an association between the prevalent non-revenue water contributors and the overall poor performance of the water utility. A correlation was sought between failure to monitor pressure and frequency of water supply interruption. The chi-square test of association results indicates a significant association between the two X^2 (10, 386) = 30.906 $p < 0.01$, which suggests that non-revenue water significantly impacts the performance of Lodwar water supply.

Table 9: Chi-square cross-tabulation

		The utility measures pressure across the system			Total
		disagree	Neutral	Strongly disagree	
Customers endure long spells of interrupted water supply.		0	0	1	1
	Agree	49	28	15	92
	Disagree	18	4	9	31
	Neutral	4	4	1	9
	Strongly agree	100	42	99	241
	Strongly disagree	3	5	4	12
Total		**174**	**83**	**129**	**386**

	Value	df	Asymptotic Significance (2-sided)
Pearson Chi-Square	30.906[a]	10	.001
Likelihood Ratio	32.146	10	.000
N of Valid Cases	386		

Utility audit of Lodwar Water Supply

12 of the 18 best practice items enlisted on the utility audit tools, *Table 10* to *Table 15*, were found non-existent at the water utility. There was minimal effort to establish a simple central volume of records. Overall, the audit reveals low compliance by the water utility in managing NRW, as summarised in the following tables.

Water Balance Estimation, Mapping and Pressure Management

No records exist at the utility concerning the mapping of the network. This limits the ability of the water utility to audit the network. The utility does not measure pressure across its network and, hence, cannot minimise bursts. There were no production meters in the network, hindering water balance estimation for the network. These findings are summarised in *Table 10*.

Metering

The utility relies on a simple set of records. Meter reading is on a monthly basis; records are held by respective readers. Checking unauthorised meter adjustments and illegal abstractions is done by meter readers as a "by-the-way" with limited action. The class and ages of the meters are

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unknown. These findings are summarised in *Table 11*.

Leakage Management

Ad hoc surveys are done for leak detection. The water utility has not established hydraulic zones (DMAs) for non-revenue water management. The leak incident resolution duration is unknown, possibly due to the lack of a dedicated incident register. These findings are given in Table *12*.

Records for Leak Repairs

No central records exist for repairs of leaks. The utility, therefore, lacks a basis for continual improvement with respect to addressing bursts and leaks. This is highlighted in *Table 13*.

Utility KPIs

The water utility has not clearly outlined key performance indicators to aid in organisational performance tracking. See *Table 14*.

Extra Relevant Measures

The water utility does not conduct public water efficiency sensitisation campaigns to ensure NRW awareness. There is also just an inconsistent measure of staff training in the last five years. This indicates the absence of deliberate effort to enhance employee capacity in tackling non-revenue water. These findings are highlighted in Table *15*.

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Table 10: Mapping, water balance and pressure management

	Detail	Score (Description)				
		E: Non-existent	**D: Low Compliance**	**C: Satisfactory**	**B: Good**	**A: Best Practice**
(I)	**Mapping, Water Balance, and Pressure management**					
E	Mapping	Records absent	Paper Records available for > 70% of n/w	Up-to-date paper/GIS records of n/w	Over 80% of n/ w on GIS but unverified	100% n/w on GIS, verified & up to date procedure
E	Pressure Management	Measurement not done	Measurement done at least once in the previous 5 years	Measurement done at least once in the previous 2 years	Measurement is done at the main inflow	Continuous Measurements done across the system
E	SI Metering	Production meters absent	Between 30-80% of flow measured by functional meters	>80% flow measured by uncalibrated working meters	>80% flow measured by working meters ½ calibrated within last 5 years & at 5%	100% flow measured by meters calibrated within the last 5 years & at 5%
E	Estimation of Water Balance	Not done (No record)	At least a year's record but bearing uncertainty	> 2 years. Records with split physical/apparent losses records	Yearly records with SI metering 2	Yearly records With SI metering 1

Table 11: Metering

	Detail	Score (Description)				
		E: Non-existent	**D: Low Compliance**	**C: Satisfactory**	**B: Good**	**A: Best Practice**
(II)	**Metering Aspects**					
C	Records/ Database of customers	None exists	Details available but on paper	The simple central volume of records	Zone-specific central volume of records	GIS-linked, computerised volume of records
D	(%) coverage; Proportion of metered connections	No records OR < ½ of connections	50% - 80%	Up to 80%	Up to 90%	All consumers
D	Reading of meters	Done on an impromptu basis	Reading p.m; Records held by readers; limited checking	Reading p.m. by rotated staff with a proper checking system	Reading p.m. by rotated staff with a proper checking system & partial image capture	Reading p.m, with image capture as a reading verification tool

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D/E	Unauthorised meter adjustments, Bypasses & illegal abstractions	Patrols/surveys not done	Meter readers do check as a "by-the-way" with limited action	Checking done by meter readers as a "by-the-way" disconnecting of illegal connections	Anomalies lead to survey Checking done by meter readers as a "by-the-way"; disconnections	Routine patrols by dedicated staff; Anomalies investigation; disconnections
E	Class of meters	Uncertain/ Unknown	Class B > 30%	Class C/D 80%	Class D– 70%, Class C-30%	100% Class D
E	Age of meters; Tests; Replacement	Uncertain/ Unknown	< 8 years old – 50% Others-Unknown	< 8 years old – 60% Others Unknown	< 8 years old – 80% A few meter bench tests	< 8 years old – 100% Routine meter bench tests

Table 12: Leakage Management

	Detail	Score (Description)				
		E: Non-existent	**D: Low Compliance**	**C: Satisfactory**	**B: Good**	**A: Best Practice**
(III)	**Control of leakage**					
D	ALC	No initiative	Impromptu surveys	Routine surveys for leak identification with average incident resolution time < 5 d	Routine daily/ weekly for Btwn 25% -70% of the network	Over 70% of n/ w were monitored daily for leakages with an average incident resolution time of < 3d
D/E	Duration for leak incident resolution (Distribution pipelines)	Uncertain/Unknown	< a week on average	½ of cases re- solved within 1 day; av. 5 days	½ of cases re- solved within 6 hrs; av. 3 days	90% of cases resolved within 6 hrs; av. 2 days
D/E	Duration for leak incident resolution (consumer end connections)	Uncertain/Unknown	< a week on average	½ of cases re- solved within 1 day; av. 5 days	½ of cases resolved within 6 hrs; av. 3 days	90% of cases resolved within 6 hrs; av. 2 days
E	DMAs	Do not exist	> ½ of SI volume quantified & analysed p.m	> 70% of SI volume quantified & analysed weekly > 1 patrol	There are monitored DMAs for >65% of the n/ w with weekly night lines review	There are monitored DMAs for >80% of the n/ w with weekly night lines review

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Table 13: Records for repair of leaks

	Detail	Score (Description)				
		E: Non-existent	D: Low Compliance	C: Satisfactory	B: Good	A: Best Practice
(V.)	Records for the repair of leaks					
E	Records availability & quality	Central records do not exist	Available for < 2 years; Data un-certain	Available for 2/ more years; repair times uncertain	Split records available for reported & detected cases; clear repair times	Split records available on GIS for reported & detected cases; clear repair times

Table 14: Utility Key Performance Indicators

	Detail	Score (Description)				
		E: Non-existent	D: Low Compliance	C: Satisfactory	B: Good	A: Best Practice
(IV.)	KPIs					
D/E	KPIs	Do not exist	Some targets exist; however, they have not recorded	The performance captured p.a for KPIs	The performance is captured quarterly, but limited review	The performance captured p.m for KPIs targets with annual review

Table 15: Extra Relevant Measures

	Detail	Score (Description)				
		E: Non-existent	D: Low Compliance	C: Satisfactory	B: Good	A: Best Practice
VI.	Extra Relevant Measures					
D/E	Awareness of stakeholders on Non-revenue Water	No public water efficiency sensitisation campaigns	Impromptu campaign within last 3 years	Monthly bills provoke the need for efficient use of water	At least a campaign within the last 2 years	Regular public water efficiency sensitisation campaigns
D	Creation & development of capacity for Non-revenue Water management	No proof/mention of training	Mention of training within the last 5 years	½ of the technical staff benefited from NRW training in the last 2 years	There is in place a training plan & yearly record of training	There is in place a training plan & yearly record of training & skill evaluation

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DISCUSSION

This study investigated NRW management practices by Lodwar Water Supply. No clear strategies and policies to manage non-revenue water management exist at the water utility. This was evidenced by the failure to prepare regular water balance, inability to monitor pressure across the system, absence of updated as-built network drawings, lack of an active leakage control plan, failure to map the network, and failure to establish DMAs. Without the willingness to adopt long-term network-specific strategies, non-revenue water will always rise for this water utility (Faber & Radakrishnan, 2019).

Capacity development and consumer awareness of NRW were established to be lacking at the utility. There was no record of non-revenue water skills development events in the past two years, hence the lack of employee technical capacity to monitor water usage, wastage, and losses. No evidence exists for public consumer water efficiency campaigns by the water utility. These are probable reasons for physical losses experienced by the utility. Staff training and consumer efficiency campaigns have a direct spillover effect on the production costs of water companies (Faber & Radakrishnan, 2019).

Water balance estimation and interpretation accounts for massive non-revenue water reduction (AWWA, 2020). This study established the absence of system input metering structures, which hinders water balance estimation. Consumers admitted to the presence of illegal connections. However, no surveys are conducted to establish such. Meter testing, calibration, and cleaning are not undertaken; hence, metering inaccuracies are potentially prevalent. No leak detection patrols are conducted, leading to prolonged water leakage incidences.

The overall effect of the absence of non-revenue water reduction strategies, absence of employee and consumer awareness initiatives, and lack of assessment methods for non-revenue water components is low utility performance highlighted by a number of indicators as follows: Customers endure long spells of interrupted supply possibly due to unremedied leaks and low pressure in the system. Operations and Maintenance services are often delayed or completely unavailable. Expansion of coverage is also limited.

An audit of the water utility validates the above findings. No measures have been installed to map the network; no system input metering equipment is available, hence the inability to measure water balance, as illustrated in Table 11. It was established that the utility does not run targeted patrols to identify illegal abstraction of water from the distribution network. This leaves the network at the mercy of a handful of well-intentioned consumers who, unfortunately, hardly benefit from water conservation sensitisation.

Without DMAs, the water utility can't initiate locally viable solutions to manage NRW. As illustrated in Table 12, the audit confirmed that Lodwar Water Supply has no records of ages nor meter testing history for consumer meters. It points to the possibility of metering inaccuracies from the customer side.

Table 3 illustrates that the water utility has conducted no public sensitisation for water use efficiency. An uninformed public is highly likely not to report bursts or illegal connections within their locality. The audit also established that a very insignificant staff population mentions capacity development training received in the last five years.

Finally, the audit established that the utility has no defined performance indicators to guide in the transition away from the prevailing non-performance. The utility is not doing much to mitigate non-revenue water, and it is no surprise that the Lodwar water supply is saddled with unsettled power bills, an unmotivated workforce, and dissatisfied customers.

In summary, the absence of initiatives to mitigate non-revenue water places Lodwar Water Supply at risk of continued, unabated losses. These losses threaten both the efficiency and existence of the utility. Conversely, reducing losses slows down

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the need for infrastructural expansion, improves utility performance, and guarantees service delivery (Faber & Radakrishnan, 2019).

The water utility is presented with a massive opportunity to appreciate non-revenue Water as a potent threat to its viability and then embark on a recovery journey through the institution of the recommendations identified above for quick wins. The outcomes of the above actions would then inform longer-term strategies.

Lastly, the Significance of bulk flow meters as the most critical installations for the enumeration of NRW is demonstrated by its limitation to this study's quest to enumerate non-revenue water for the utility. It should be Lodwar Water Supply's initial action point, as it should be with other water utilities in developing nations.

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

Lodwar Water Supply lacks elaborate strategies to address its imminently escalating non-revenue water challenge. Non-revenue Water thus adversely impacts the overall performance of Lodwar Water Supply. Missing measures for non-revenue water mitigation by Lodwar Water Supply are as follows;

Absence of a regularly updated, zone-specific customer database; Absence of system input metering equipment; Absence of pressure management mechanisms; Failure to compute water balance; Absence of an Active Leakage Control plan; Absence of meter testing, cleaning and calibration facilities; Absence of DMAs for NRW monitoring; Lack of capacity development for technical staff on NRW; Absence of consumer water efficiency campaigns; Failure to adopt automation in leak detection, pressure control, illegal connections detection and end-user metering.

Recommendations

The findings of this study point to consistent noncompliance with best practices by the water utility in addressing non-revenue water, arising from the utility's lack of understanding of her operational challenges and realities. A number of practical recommendations are listed as follows;

- Establish an up-to-date, zone-specific database; eliminate from the records ghost entries, dormant and disconnected consumers. This will ensure each consumer detail is captured and, hence, billed. Water theft will be minimised since disconnected customers will not consume water illegally, and dormant connections do not draw water from the network until they have been reactivated in the database.
- Establish non-revenue water monitoring zones (DMAs), each with a functional production bulk inflow meter. This will enable the determination of system input volumes per zone, hence the estimation of water balance for the network, which is key for non-revenue water analysis.
- Prioritise acquiring meter testing and calibration equipment for production and consumer meters. This will inform timely meter repairs and replacement of faulty meters, which tend to under-register water consumption.
- Initiate active leakage plan actions; Routine leak detection patrols; automated valve closure for storage tanks; Toll-free leak incidence reporting phone number; dedicated Incidence register book for bursts and leaks; Pressure monitoring and control. These will ensure instant resolution of pipe bursts and shorter turnaround time for leak and burst incidences, reduce physical losses at storage, and eradicate bursts.
- Arrange for training and capacity development for technical staff through partnerships with external expertise and conduct public water efficiency campaigns for consumers. Locally, KeWI, WASPA, and WASREB, among other stakeholders, run regular seminars and conferences from which the water utility would benefit. This will equip

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employees with the requisite skills for detecting and controlling NRW. Sensitising consumers to efficiently utilise water and report leakages, illegal connections, and water theft will help alleviate losses.

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