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Effectiveness of Non-Revenue Water Reduction Strategies among Water Service Providers in Homa Bay County, Kenya

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Abstract: *Non-Revenue Water (NRW) remains a major challenge to water conservation, financial sustainability, and service delivery in Kenya. This study evaluated NRW reduction strategies employed by Homa Bay Water and Sanitation Company Limited (HOMAWASCO) across four water supply schemes in Homa Bay County. A mixed-methods descriptive design was adopted, guided by the Theory of Competitive Advantage and Natural Resource Use Theory. Data were collected from staff and customers through questionnaires, focus group discussions, field observations, and operational records, and analyzed using descriptive statistics, weighted means, chi-square tests, and thematic analysis. Findings showed that NRW consistently exceeded 40% across all schemes. Among 27 respondents, 55.56% rated real losses as moderate, 29.63% as high, and 7.41% as very high, with 92.59% rating them moderate to very high. Apparent losses were rated moderate by 55.56%, high by 18.52%, and very high by 11.11%. Major causes included ageing infrastructure, leakages, bursts, meter inaccuracies, billing errors, overflows, and illegal connections. Infrastructure rehabilitation was the most effective strategy. The study recommends integrated technical, commercial, and institutional interventions for sustainable NRW reduction.*

Keywords*: Non-Revenue Water, Water loss reduction, Water service providers, Infrastructure rehabilitation, Homa Bay County, Kenya*

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1. Introduction

Non-Revenue Water (NRW) remains a major challenge to water utilities globally, undermining financial sustainability, operational efficiency, water conservation, and reliable service delivery. NRW refers to water produced and distributed but not generating revenue because of physical losses, including leakages, bursts and overflows, and apparent losses arising from illegal connections, meter inaccuracies, and billing and data management errors. Aging infrastructure, inadequate operation and maintenance, high system pressures, and weak institutional management further contribute to persistent NRW, particularly in developing countries (Tabesh et al., 2018; McKenzie et al., 2012).

Globally, approximately 346 million cubic metres of water are estimated to be lost daily through distribution systems, resulting in substantial financial losses and increased energy and treatment costs. NRW is therefore an important indicator of water utility performance and a key priority in water sector management. Evidence from different countries demonstrates the scale of the challenge. Ahmad et al. (2025) reported an increase in NRW in Malaysia from 4,912 million litres per day in 2018 to 5,389 million litres per day in 2022, attributed mainly to leakage, water theft, inaccurate metering, and aging infrastructure. In Sub-Saharan Africa, NRW commonly ranges between 20% and 70%, compared with approximately 15% in developed countries (Al-Omari, 2013; Farah & Shahrour, 2018).

In Kenya, water service provision is regulated by the Water Services Regulatory Board (WASREB), which monitors utility performance through indicators that include NRW, water coverage, metering, supply hours, revenue collection, water quality, and operational efficiency. The WASREB Impact Report No. 18 (2024/25) reported a national NRW level of 48%, up from 44% in the previous year. This represented approximately 242 million cubic metres of water lost annually, valued at about KShs 15.7 billion, highlighting the magnitude of water and revenue losses within the sector.

At county level, Homa Bay Water and Sanitation Company Limited (HOMAWASCO), the regulated water service provider in Homa Bay County, recorded NRW of 40% in 2024/25, compared with 43% in 2023/24. The reported losses were approximately 548,000 m^3 of water, with an estimated financial loss of KShs 43.2 million. This performance remains substantially above the recommended NRW range of 20–25%, indicating the need for effective and context-specific interventions.

The International Water Association (IWA) water balance framework provides a standardized basis for assessing NRW by distinguishing real losses from apparent losses. Effective management strategies include District Metered Areas (DMAs), pressure management, active leak detection, rapid repair of bursts, meter testing and replacement, improved billing and data systems, customer verification, network mapping, and continuous NRW monitoring (IWA & JICA, 2020). However, their effectiveness depends on infrastructure condition, institutional capacity, technical expertise, and available financial resources.

The persistent NRW levels in HOMAWASCO therefore necessitate systematic assessment of existing reduction strategies and the relative contribution of physical and commercial losses. Evidence from such an assessment can support targeted interventions to improve operational efficiency, financial sustainability, water conservation, and reliable water service delivery in Homa Bay County.

1.1 Research objective

The specific objective for this article is to establish the most effective approaches to Non-Revenue Water reduction strategies across the four selected schemes namely; Homabay, Oyugis, Mbita and Kendu Bay for HOMAWASCO.

1.2 Research Hypothesis

There are no most effective approaches to NRW reduction strategy for the selected schemes.

2. Literature Review

Non-Revenue Water (NRW) is a multidimensional challenge influenced by technical, managerial, institutional, and socioeconomic factors. Orsini et al. (2025), using multilevel analysis in Brazil, found that population size and network length significantly influence NRW levels. The study emphasized network monitoring technologies, pressure control, proactive maintenance, improved metering, fraud detection, and enforcement. Apparent losses were particularly prominent among non-residential consumers, while private utilities generally recorded lower NRW because of stronger accountability and efficiency incentives. Similarly, Gonzalez-Gomez et al. (2011) attributed high NRW in European cities to weak management incentives, corruption, limited political commitment, and low public awareness.

Kenyan studies demonstrate similar challenges. Mukundu (2014) found water theft and intermittent supply to be major NRW contributors in Murang'a County, while bursts, leakages, aging infrastructure, and poor pipe quality were moderate contributors. Mwangi et al. (2017) reported that NRW in Webuye was significantly associated with meter inaccuracies, unmetered consumption, and illegal use. These findings demonstrate the importance of addressing both physical and commercial losses.

NRW also has significant economic and operational consequences. Santos (2024) established a significant negative relationship between unbilled water and profitability among Portuguese water utilities. Maina (2016) similarly found that high NRW adversely affects utilities and consumers through inadequate and costly water supply, recommending prioritization of interventions with rapid financial returns.

Effective NRW management requires strategic planning, continuous monitoring, and adequate institutional capacity. Sisman et al. (2020) emphasized proactive management supported by skilled personnel, sufficient budgets, and logistical capacity, while Hatem-AbuEtayef et al. (2025) highlighted performance indicators, management-by-objectives, results-based management, and scenario planning. Al-Washali et al. (2019) noted that intermittent supply complicates NRW estimation but confirmed that continuous monitoring remains essential.

Organizational capacity is equally important. Nwachuku et al. (2019) linked financial and human resources, organizational policies, structural alignment, and employee commitment to strategic performance. In Kenya, Ernest (2022) found that WSPs commonly use leak and burst repairs, mobile meter reading, NRW reporting, customer awareness, NRW teams, and GIS, while pressure management, active leak detection, District Metered Areas, systematic water balancing, and meter testing remain underutilized.

Despite extensive literature, limited evidence exists on the effectiveness of NRW reduction strategies at county-level utilities operating under persistently high NRW conditions. This study therefore addresses this gap by assessing NRW drivers, management practices, and reduction strategies within HOMAWASCO in Homa Bay County.

3. Methodology

3.1 Study Area

The study was conducted in four HOMAWASCO water supply schemes: Homa Bay Town, Oyugis, Kendu Bay, and Mbita, located in Homa Bay County, western Kenya. HOMAWASCO operates six schemes drawing water from Lake Victoria, rivers, and boreholes. The selected schemes are supplied mainly by Lake Victoria in Homa Bay Town and Mbita, and rivers in Oyugis and Kendu Bay. Collectively, HOMAWASCO's six treatment plants produce approximately 1.37 million m³ of water annually, serving 225,953 people within a service-area population of 320,801. The study area lies within a semi-humid zone at approximately 1,133–1,350 m above sea level and has an undulating landscape characterized by hills, valleys, rivers, wetlands, and lakeshore areas. Annual rainfall ranges from 600 to 1,400 mm, with a bimodal pattern. The main economic activities are fishing, agriculture, trade, and small and medium-scale enterprises. The selected schemes were appropriate for assessing NRW reduction strategies under varied operational and geographical conditions.

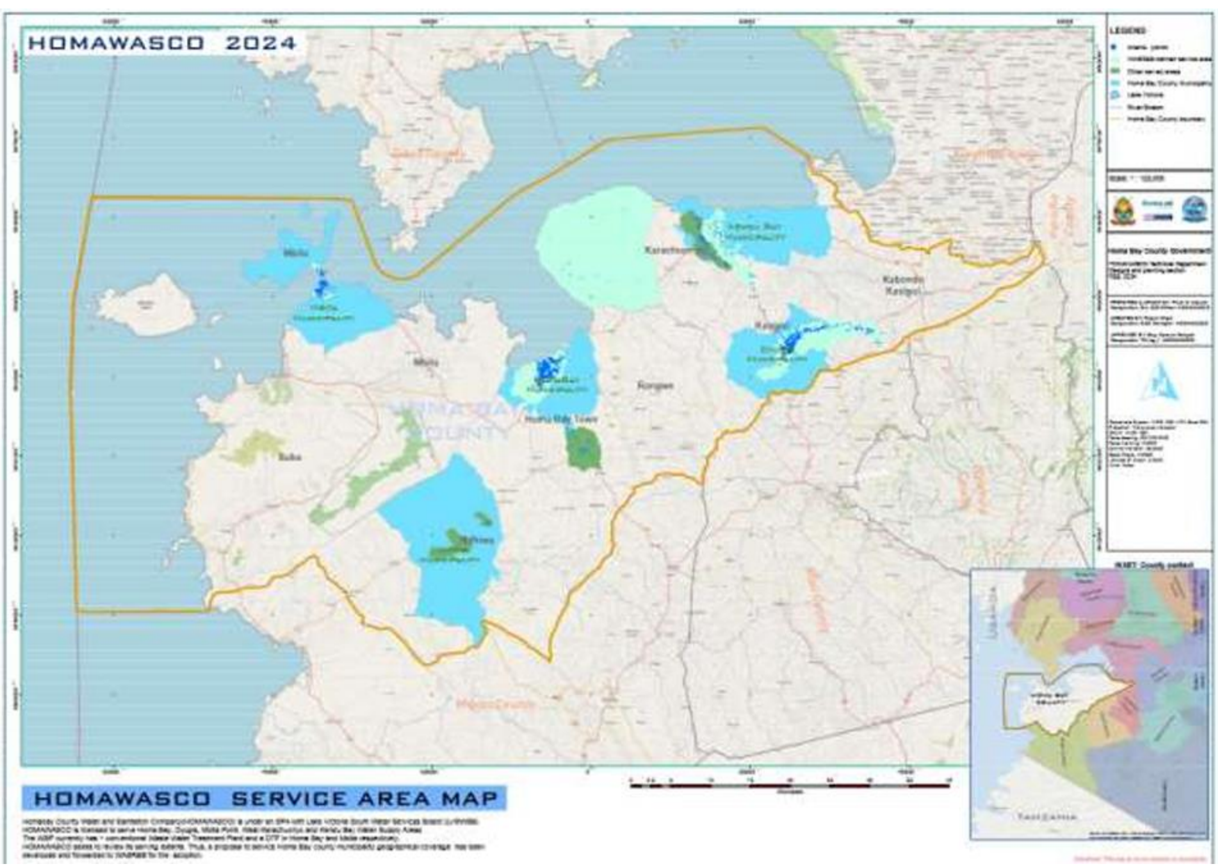

Figure 1: Map showing HOMAWASCO service area.

3.2 Research Design and Sampling

A descriptive cross-sectional survey design was adopted to assess non-revenue water (NRW) and its reduction strategies across four HOMAWASCO schemes: Homa Bay, Mbita, Kendu Bay and Oyugis, together with the headquarters. The study population comprised 103

HOMAWASCO staffs Sample size was determined using Yamane (1967) formula:

Sample size determination formula was applied.

$$n = \frac{N}{1+N(e^2)}$$

………………3.2

where (n) = required sample size, (N) = total population (103 staff), and (e) = level of precision. A precision level of 13% ((e=0.13)) was adopted.

A sample of 36 staffs was therefore selected using proportionate stratified random sampling: headquarters (3), Homa Bay (14), Mbita (6), Kendu Bay (7), and Oyugis (6). In addition, four Focus Group Discussions (FGDs) involving 40 purposively selected customers were conducted across households, water kiosks, institutions and commercial users to obtain customer perspectives on NRW and water-service challenges.

3.3 Data Collection Tools and Procedures

Both primary and secondary data were collected. Primary data were obtained between January and March 2026 using structured questionnaires, FGD guides and field observation checklists. Questionnaires were administered through face-to-face interviews with sampled staff. The instruments captured information on NRW causes, management practices, metering, billing, leakage control and reduction strategies.

Before interviews, participants were informed about the study purpose, voluntary participation and intended use of the findings, and written informed consent was obtained. Interviews were conducted in English, with Kiswahili clarification where necessary. FGDs were conducted using a semi-structured guide and audio-recorded with participants' consent. Field observations were undertaken to document relevant physical and operational conditions.

Secondary NRW data were obtained from HOMAWASCO's Monitoring and Evaluation Officer through company monitoring records maintained in Google Sheets, covering March 2025–March 2026. Additional contextual data were obtained from WASREB Impact Reports.

3.4 Variables and Instruments

The study examined NRW and its physical and apparent loss components, including water supplied, billed consumption, leakage, metering, illegal connections, billing practices and NRW reduction interventions. Instruments comprised a structured questionnaire, FGD guide, observation checklist and secondary-data extraction sheet.

NRW reduction strategies were assessed through identification of NRW components, scheme-specific loss drivers and implemented interventions. Qualitative responses were analysed thematically by coding similar responses into categories and determining the frequency of identified themes.

3.5 Data Analysis

Quantitative data were checked, coded, tabulated and analysed using descriptive and inferential statistics. Frequencies and percentages summarized categorical variables, while weighted means ranked the perceived effectiveness of NRW reduction strategies. A five-point Likert scale was used: Very High = 5, High = 4, Moderate = 3, Low = 2 and Very Low = 1.

The weighted mean was calculated as:

Weighted mean analysis

A five-point Likert scale was used, where Very High = 5, High = 4, Moderate = 3, Low = 2 and Very Low = 1. The weighted mean was calculated as:

The weighted mean was calculated using:

$$\bar{X} = \frac{\sum(fx)}{\sum f}$$

where:

- f= frequency
- x= Likert score

where (f) = frequency and (x) = Likert score.

The Chi-square ((\chi^2)) test at a 5% significance level was used to assess differences in the contribution of real and apparent losses to NRW:

The Chi-square statistic was computed as:

$\chi^2 = \Sigma [(O - E)^2 / E]$

where:

- O = Observed frequency
- E = Expected frequency, calculated as:

E = (Row Total × Column Total) / Grand Total

The degrees of freedom will be calculated as:

df = (r − 1)(c − 1)

where r is the number of rows and c is the number of columns. A p-value < 0.05 will indicate a statistically significant difference in the contribution of real and apparent losses to NRW.

3.6 Ethical Considerations

Ethical safeguards were applied throughout the study. Participants received information on the study purpose, voluntary participation, intended use of findings and their right to withdraw without penalty. Written informed consent was obtained before data collection. Confidentiality and anonymity were maintained by excluding personal identifiers and assigning numerical codes to research instruments. FGD recordings were made only with participants' consent and stored on a password-protected device accessible only to the researcher. Data were used exclusively for research purposes and securely managed. The study adhered to the principles of beneficence, non-maleficence, autonomy and justice, consistent with the National Commission for Science, Technology and Innovation (NACOSTI) Kenya Research Ethics Guidelines (2020).

4. Results and Discussion

4.1 Socio-demographic characteristics of respondents

Table 1: Socio demographic characteristics of respondents

Variable	Category	Frequency (n)	Percent (%)
Age group	18–30 years	10	44.4
	31–45 years	15	55.6
	Above 45 years	2	7.4
Gender	Male	18	66.7
	Female	9	33.3
Education level	Certificate	10	37.0
	Diploma	13	48.1
	Degree	3	11.1
	Master’s	1	3.7
	PhD	0	0.0
Years worked with HOMAWASCO	0–5 years	17	63.0
	5–10 years	8	29.6
	Above 10 years	2	7.4

Source: Field Data, 2026.

Table 1 presents the socio-demographic characteristics of the respondents. Of the 27 valid responses, 55.6% were aged 31–45 years, while 44.4% were aged 18–30 years. Males constituted 66.7% and females 33.3% of respondents. Regarding education, diploma holders were predominant (48.1%), followed by certificate holders (37.0%), degree holders (11.1%) and master's degree holders (3.7%). In terms of institutional experience, 63.0% had worked with HOMAWASCO for 0–5 years, 29.6% for 5–10 years and 7.4% for more than 10 years.

The age and experience profile indicates that the respondents were largely drawn from an active working-age workforce with exposure to HOMAWASCO operations. This is relevant to NRW assessment because effective water-loss management depends on operational knowledge, accurate information systems, technical capacity and institutional practices. The World Bank identifies organizational capacity, information systems, diagnostic capability and staff skills as important components of sustainable NRW management. The demographic characteristics therefore provide an appropriate context for interpreting the respondents' perceptions of NRW drivers and reduction measures.

4.2 NRW reduction strategies and approaches

Table 2: Thematic description of NRW reduction strategies

Theme	Specific Measures Reported	Frequency (f)	Percentage (%)
Infrastructure rehabilitation	Rehabilitation of dilapidated pipelines; prompt repair of bursts; use of quality materials; stockpiling repair materials	4	28.6
Meter management	Consumer metering; meter testing, calibration and replacement	2	14.3
Illegal connection control	Eradication of spaghetti lines; legalization and surcharging of illegal connections; use of police to curb water theft	3	21.4
Pressure management	Pressure reducing valves; pressure monitoring	1	7.1
Institutional strengthening	Deployment of NRW staff and NRW unit; capacity building	2	14.3
Commercial improvements	Smart billing systems	1	7.1
Construction coordination	Proper coordination during road construction	1	7.1
Total		**14**	**100**

Source: Author (2026)

Table 2 shows that infrastructure rehabilitation was the most frequently reported NRW reduction strategy (28.6%), comprising rehabilitation of deteriorated pipelines, prompt repair of bursts, use of quality materials and stockpiling repair materials. Illegal-connection control ranked second (21.4%), including eradication of unauthorized connections, regularization of connections and action against water theft. Meter management and institutional strengthening each accounted for 14.3%, while pressure management, smart billing and construction coordination each accounted for 7.1%.

The prominence of infrastructure rehabilitation is consistent with international evidence that real losses are strongly associated with leakage from distribution infrastructure and that pipe rehabilitation, active leakage control and rapid repair are core NRW interventions. The World Bank recommends integrating real-loss management with asset management and prioritizing pipe rehabilitation based on infrastructure condition and economic considerations. Similarly, the IWA identifies leakage from failed distribution infrastructure as a major component of real losses.

The relatively high ranking of illegal-connection control also reflects the distinction between real and apparent losses. Unauthorized consumption, inaccurate metering and billing/data-handling errors are recognized components of apparent losses. The findings therefore indicate that HOMAWASCO's NRW response is not restricted to physical infrastructure but also incorporates commercial-loss management.

Meter management and institutional strengthening further demonstrate the importance of combining technical and organizational interventions. International NRW practice recommends meter testing and replacement, accurate customer databases, billing controls, NRW units, staff training and regular performance monitoring. Overall, the results support an integrated NRW management approach in which infrastructure rehabilitation is complemented by pressure management, metering, commercial controls, customer engagement and institutional capacity development. This is particularly relevant in Kenya, where WASREB identifies NRW as a key water-service performance indicator and continues to emphasize reduction of water losses as a sector priority.

4.3 Contribution of real and apparent losses to overall NRW

Table 3: Level of contribution of apparent and real losses to the overall NRW

Loss category	Very High (%)	High (%)	Moderate (%)	Low (%)	Very Low (%)
Real losses	2 (7.41)	8 (29.63)	15 (55.56)	2 (7.41)	0 (0.00)
Apparent losses	3 (11.11)	5 (18.52)	15 (55.56)	4 (14.81)	0 (0.00)

Source: Author (2026)

Table 3 shows that respondents perceived both real and apparent losses as important contributors to NRW. Real losses were rated moderate by 55.56%, high by 29.63% and very high by 7.41%, while 7.41% rated them low. Thus, 92.59% of respondents rated real losses from moderate to very high. Apparent losses were rated moderate by 55.56%, high by 18.52% and very high by 11.11%, while 14.81% rated them low. Consequently, 85.19% perceived apparent losses as moderate to very high.

The slightly stronger perception of real losses is consistent with the subsequent finding that ageing infrastructure, pipe and fitting quality, and pipeline pressure were prominent physical-loss factors. The World Bank distinguishes real losses as physical water losses associated with leakage and system conditions, while apparent losses arise mainly from unauthorized consumption, metering inaccuracies and billing/data errors. The results therefore suggest that physical losses constitute a particularly important starting point for NRW interventions at the study schemes, although commercial losses should not be neglected.

Table 4: Real losses to the overall NRW

Contributor	High/Very High (%)	Predominant rating
Quality of pipes and fittings	46.16	High
Pipeline pressure	46.15	High
Age of infrastructure	37.50	Moderate
Other physical factors	34.79	Low
Meter-reading errors	16.00	Moderate
Billing errors	24.00	Low
Corruption	20.83	Low
Other accounting factors	16.67	Very Low
Water theft	38.46	Low

Source: Author (2026)

Table 4 further indicates that quality of pipes and fittings (46.16%) and pipeline pressure (46.15%) had the highest combined high/very-high ratings, followed by age of infrastructure (37.50%). In contrast, billing errors, corruption and other accounting factors recorded lower predominant ratings. Water theft was predominantly rated low, although 38.46% of respondents rated it high or very high, suggesting that unauthorized consumption may be significant in particular locations.

The prominence of pressure and infrastructure condition is supported by NRW literature. Excessive or poorly controlled pressure can increase leakage rates, while deteriorating infrastructure increases the likelihood of bursts and background leakage. The World Bank identifies pressure management, active leakage control, pipe rehabilitation and asset management as important measures for reducing real losses. The findings therefore justify prioritizing preventive maintenance, systematic leak detection, pressure monitoring and targeted pipeline rehabilitation.

Table 5: Apparent losses to the overall NRW

Apparent-loss factor	Weighted mean	Rank
Individual perception	3.00	1
Billing errors	2.95	2
Meter-reading errors	2.40	3
Intermittent water supply	2.30	4
Corruption	2.15	5
Other factors	2.15	5
Institutional corruption	2.05	7
High water tariff	1.55	8

Source: Author (2026)

The weighted mean analysis provides further evidence on the relative importance of the identified factors. For real losses, age of infrastructure ranked first (M = 3.50), followed by other physical factors (M = 3.22), quality of pipes and fittings (M = 3.19), and pipeline pressure (M = 3.15). Since all scores were above the neutral value of 3.0, respondents generally regarded these factors as contributors to physical NRW.

For apparent losses, individual perception ranked first (M = 3.00), followed by billing errors (M = 2.95), meter-reading errors (M = 2.40), intermittent water supply (M = 2.30), corruption (M = 2.15), other factors (M = 2.15), institutional corruption (M = 2.05), and high water tariff (M = 1.55). The relatively higher scores for customer behaviour and billing suggest that commercial-loss management should complement physical-loss interventions. Metering is particularly important because accurate measurement provides the basis for identifying losses and ensuring that consumption is appropriately billed.

The overall pattern is consistent with international NRW guidance, which recommends addressing both technical and commercial losses rather than focusing exclusively on leakage.

4.5 Chi-square test of commercial factors

A Chi-square goodness-of-fit test was used to determine whether the observed distribution of responses across the four commercial-factor categories differed significantly from an equal distribution.

The hypotheses were:

H_0: Respondents rated the commercial factors equally.

H_1: Respondents did not rate the commercial factors equally.

The Chi-square statistic was calculated as:

Since these are frequency data, the Chi-square goodness-of-fit/independence approach is adopted.

$$\chi^2 = \sum \frac{(O_i - E_i)^2}{E_i}$$

$$\chi^2(3) = 5.04, p = 0.169$$

Where:

- (O) = observed frequency; and
- (E) = expected frequency.

Contribution	Observed	Expected
A =1.96	18	25
B =0.36	22	25
C = 0.16	27	25
D = 2.56	33	25
Total contribution =5.04 below 5% cut off		

At the 5% significance level, the critical Chi-square value for 3 degrees of freedom is approximately 7.815. Since 5.04 < 7.815, the null hypothesis is not rejected ((p\approx0.169)). Thus, although the observed responses varied across the commercial factors, the differences were not statistically significant at the 5% level.

Overall, the findings demonstrate that NRW at the HOMAWASCO schemes is associated with both real and apparent losses, with physical infrastructure factors perceived as somewhat more influential. Ageing infrastructure emerged as the leading real-loss factor, while customer behaviour and billing errors were the leading apparent-loss factors. The findings support a comprehensive NRW strategy combining pipeline rehabilitation, preventive maintenance, pressure management, leakage detection, accurate metering, billing improvement, control of unauthorized consumption and institutional capacity strengthening. Such an integrated approach is consistent with international NRW practice and the Kenyan regulatory emphasis on improving water-utility efficiency and reducing NRW.

5. Conclusion and Recommendation

5.1 Conclusion

The study established that both real (technical) losses and apparent (commercial) losses contribute substantially to the overall Non-Revenue Water (NRW) experienced in the four selected water supply schemes. However, respondents generally perceived both categories of losses to contribute at a moderate level.

Regarding real losses, 55.56% of the respondents rated their contribution as moderate, while 29.63% considered them to contribute highly and 7.41% very highly. Overall, 92.59% of respondents indicated that real losses contribute from moderate to very high levels. These findings demonstrate that physical losses arising from leakages, pipe bursts, reservoir overflows and ageing infrastructure remain a significant source of NRW. The concentration of high ratings in Homa Bay Scheme further suggests that infrastructure deterioration and maintenance challenges are more pronounced in some service areas than others.

Similarly, apparent (commercial) losses were also perceived to contribute moderately to NRW. The majority of respondents (55.56%) rated their contribution as moderate, while 18.52% rated them high and 11.11% very high. Altogether, 85.19% of respondents agreed that commercial losses contribute from moderate to very high levels. These losses were mainly associated with inaccurate meter readings, billing errors, illegal connections, unauthorized consumption and weaknesses in customer management systems.

A comparison between the two categories indicates that although both significantly influence NRW, real losses were perceived to contribute slightly more than apparent losses, as reflected by the higher proportion of respondents assigning high or very high ratings (37.04% compared to 29.63%). This suggests that physical infrastructure challenges remain the dominant source of NRW within the study area, although commercial inefficiencies also represent an important component requiring management attention.

Overall, the findings indicate that effective NRW reduction strategies should simultaneously address both physical and commercial losses through infrastructure rehabilitation, proactive leakage management, improved metering systems, accurate billing, strengthened customer monitoring and enhanced enforcement against illegal water use.

The study concludes that effective reduction of Non-Revenue Water requires an integrated approach that combines technical, commercial, and institutional interventions. Among the strategies identified, infrastructure rehabilitation emerged as the most effective, accounting for 28.6% of all measures reported. This underscores the importance of rehabilitating aging pipelines, promptly repairing leaks and bursts, and using quality materials to minimize physical water losses, which remain the largest contributor to NRW in the study area.

The findings further indicate that controlling illegal connections (21.4%) is a critical strategy for reducing commercial losses by curbing water theft, regularizing unauthorized consumers, and improving revenue collection. Meter management and institutional strengthening (14.3% each) were also identified as essential measures, highlighting the need for accurate customer metering, regular meter calibration and replacement, dedicated NRW units, and continuous staff capacity building to enhance operational efficiency and accountability.

Although pressure management, smart billing systems, and coordination during road construction (7.1% each) were mentioned less frequently, they remain important complementary interventions that support leakage reduction, infrastructure protection, and improved commercial performance. Their relatively lower frequency suggests that these strategies are either less implemented or receive less emphasis despite their proven effectiveness.

Overall, the study concludes that no single intervention can sustainably reduce NRW. Instead, water service providers should adopt a comprehensive NRW management strategy that integrates infrastructure rehabilitation, active leakage control, pressure management, meter management, commercial loss reduction, institutional strengthening, and modern billing technologies. Such a balanced approach is consistent with the International Water Association (IWA) Water Loss Management framework and is essential for improving operational efficiency, financial sustainability, service reliability, and long-term water security in Water Service Providers such as HOMAWASCO.

5.2 Recommendations

1. Prioritize infrastructure rehabilitation, preventive maintenance, and active leakage management. HOMAWASCO should prioritize the rehabilitation and replacement of ageing pipelines, defective fittings and other vulnerable infrastructure, particularly in areas experiencing frequent bursts and leakages. Systematic leak detection and timely repair should be strengthened, alongside regular network pressure monitoring and pressure management, to minimize physical water losses and recurrence of pipe failures.
2. Strengthen commercial loss management and modernize billing and data systems. Regular meter testing, calibration and replacement of defective meters should be institutionalized, while meter-reading and billing procedures should be strengthened to minimize errors. HOMAWASCO should progressively adopt digital metering, automated meter-reading and integrated billing systems where feasible. Regular customer audits, network inspections and enforcement against illegal connections and unauthorized consumption should also be undertaken, supported by customer awareness campaigns.
3. Adopt integrated, scheme-specific NRW management and coordination. HOMAWASCO should establish routine water-balance assessments, accurate production and consumption records, and scheme-level NRW monitoring to ensure that interventions are targeted according to local infrastructure conditions, leakage patterns, commercial losses and operational constraints. Coordination with county authorities and other infrastructure agencies should also be strengthened, particularly during road construction and rehabilitation, to minimize damage to existing water infrastructure and associated water losses.

Overall, NRW reduction should be implemented as a continuous, integrated management programme combining infrastructure rehabilitation, leakage and pressure control, meter and billing management, enforcement against unauthorized consumption, institutional strengthening and improved data systems. This approach would enhance operational efficiency, financial sustainability, service reliability and long-term water security.

5.3 Recommendations for further studies

Although this study provided important insights into NRW reduction strategies implemented by HOMAWASCO, several areas require further investigation:

1. Long-term effectiveness of NRW interventions: Future studies should assess the long-term effectiveness, sustainability, and cost-effectiveness of interventions such as District Metered Areas (DMAs), pressure management, smart metering, and GIS-based monitoring in reducing physical and apparent water losses.

2. Customer behaviour and socio-economic factors: Research should investigate the socio-economic and behavioural factors associated with illegal connections, meter tampering, unauthorized consumption, and willingness to pay, thereby informing customer engagement and compliance strategies.

3. Application of emerging technologies: Future research should explore the application of predictive modelling, hydraulic modelling, GIS, machine learning, and Internet of Things (IoT)-based monitoring systems for early leak detection, infrastructure failure prediction, and optimization of NRW management.

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