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Water Transmission Leakage and Its Correlation to Non-Revenue Water in Salalah Oman

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Abstract

Non-Revenue Water (NRW) remains a persistent challenge in global water distribution, particularly in arid regions where water scarcity heightens the urgency of efficient resource management. This study investigates the magnitude of NRW in Salalah, Oman, with a focus on its sources, impact, and mitigation strategies. While previous research has explored NRW in urban water supply systems, limited studies have quantitatively analysed transmission pipeline losses in arid environments. Using a structured survey of 165 engineers, technicians, and project managers from ONEIC, this study applies a quantitative research design and statistical analysis through SPSS to evaluate the relationships between NRW sources, magnitude, and mitigation effectiveness. Results indicate that Salalah's NRW levels exceed global benchmarks, with an estimated loss of 40% compared to the acceptable 10%. The study establishes a strong correlation (0.743) between NRW magnitude and its sources, particularly infrastructure deficiencies, unauthorized connections, and metering inaccuracies. Additionally, proactive leak detection, infrastructure upgrades, and advanced metering technologies contribute to a 59.3% reduction in NRW variation. This study fills critical gaps in NRW research by providing empirical evidence on transmission pipeline losses in an arid region and offering a data-driven framework for policymakers and water utilities. By addressing these inefficiencies, this research contributes to sustainable water management and provides a replicable model for similar water-scarce regions worldwide.

Keywords: NRW, Salalah City, ONEIC, SPSS, Mitigation Strategies

1. General

Water scarcity is one of the most pressing challenges facing arid regions, where efficient water distribution is critical for sustainability. Non-Revenue Water (NRW) – water lost due to leaks, unauthorized usage, and metering inaccuracies – poses a significant threat to water security, operational efficiency, and economic sustainability. In Oman, NRW has been identified as a major concern, yet studies quantifying its magnitude and identifying its root causes remain limited. Existing research has largely focused on urban distribution networks, with little emphasis on the role of transmission pipelines in NRW losses. This study seeks to bridge this gap by analyzing NRW in Salalah's water transmission system, identifying its primary sources, and evaluating the effectiveness of various mitigation strategies. While global NRW studies highlight general trends in water losses, they often lack specific data on how transmission pipelines contribute to NRW, particularly in arid environments. This study advances current knowledge by integrating quantitative research and statistical modeling to establish clear relationships between NRW sources, magnitude, and mitigation strategies. By utilizing survey data from industry professionals and applying rigorous statistical techniques, this research provides a comprehensive assessment of NRW inefficiencies in Salalah's transmission infrastructure. Furthermore, this study offers actionable insights that can inform policy decisions, improve water management practices, and serve as a reference for other water-scarce regions facing similar challenges. Thus, this research aims to: (1) investigate the sources of NRW along Salalah's transmission pipeline system, (2) quantify the magnitude of NRW, and (3) propose data-driven mitigation strategies to enhance water transmission efficiency. The findings contribute to both theoretical and practical advancements in NRW management, emphasizing the importance of infrastructure resilience, technological interventions, and policy frameworks in reducing water loss.

2. Literature Review

Existing Research on Non-Revenue Water (NRW)

Non-Revenue Water is a critical issue affecting water utilities worldwide, with studies highlighting its financial, operational, and environmental consequences. According to Cassidy et al. (2021), up to one-third of water extracted for urban distribution is lost due to leaks, resulting in substantial financial and resource inefficiencies. While developed nations have reduced NRW through advanced monitoring and management techniques, developing regions, including parts of the Middle East, continue to struggle with high NRW levels due to aging infrastructure, inadequate metering, and ineffective regulatory policies (Jang, 2018).

Research Gaps in NRW Studies

Despite extensive global research on NRW, significant gaps remain in understanding its impact in arid regions. Much of the literature focuses on urban water distribution networks rather than transmission pipelines, which are a major source of water loss. Additionally, existing studies tend to emphasize qualitative assessments without empirical validation of the correlation between NRW sources and mitigation effectiveness. Limited research has explored how proactive leak detection, metering accuracy, and infrastructure improvements quantitatively impact NRW reduction in transmission systems. This study addresses these gaps by employing a statistical approach to analyse NRW in Salalah's transmission pipelines, providing data-driven insights that extend beyond conventional qualitative assessments.

NRW in Oman: Current Challenges and Policy Interventions

In Oman, the Public Authority for Electricity and Water (PAEW) has reported high NRW levels due to pipeline inefficiencies, metering errors, and unauthorized consumption. Al-Siyabi & Expert (2019) emphasize the need for policy-driven interventions to enhance water conservation, yet few studies provide statistical evidence linking mitigation strategies to NRW reduction. This research contributes to this discourse by applying correlation and regression analyses to assess the effectiveness of current mitigation efforts and propose data-backed solutions tailored to Salalah's infrastructure challenges.

3. Methodology

This research's methodology chapter examines and describes each analytical component that is relevant to this analysis. This chapter discusses the investigation's technique, strategy, and plan. The framework for data collecting, the use of tools for data analysis, and sampling are all receiving more attention. The research onion framework (Figure 3.1), which depicts the numerous parts of the research that must be studied and planned in order to develop a sound research design, provides a visual explanation of these aspects (Alturki, 2021). To put it another way, the research onion directs the researcher through each step required to establish a research methodology. On the other hand, Figure 1 show the flow chart of the research methodology applied in this study

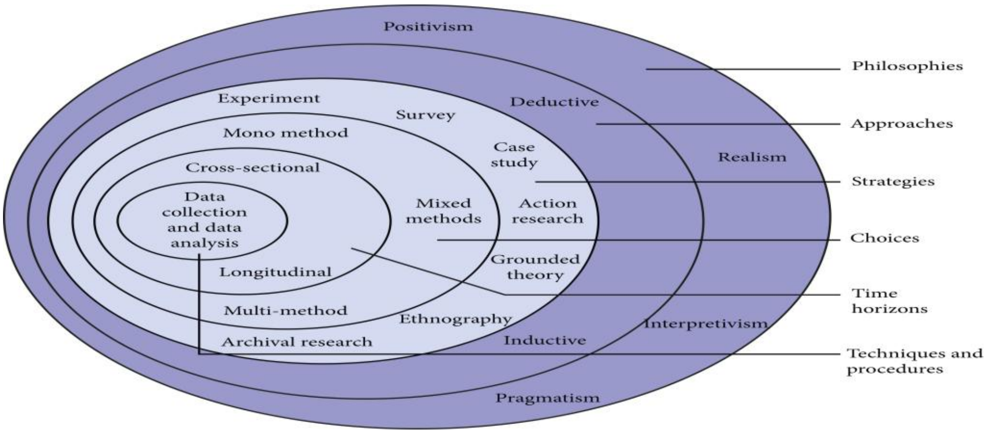
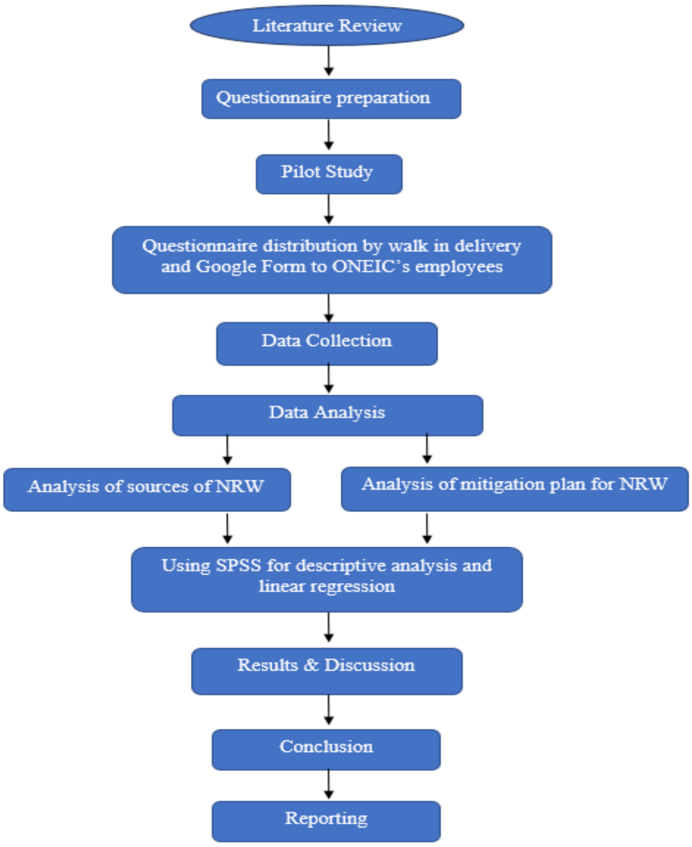


Figure 1: The research Onion (Alturki, 2021)

Flow Chart:



4. Result And Discussion

In this section, the participants' responses to the questionnaire are discussed. This part of the study is crucial, as it draws significant conclusions and evaluates the data collected through the questionnaire. The following sections summarize the analysis of the questionnaire results using the SPSS analytical framework. Various methods were employed to analyse the responses, including graphical analysis, relationship exploration, standard testing, linearity testing, and reliability testing.

Pilot Study

A pilot study is the initial step in the research process, conducted to assess the reliability and validity of the questionnaire before distributing it to the full set of respondents. Table 1 shows the results of a pilot test for all the variables (Magnitude of NRW, Sources of NRW and Mitigation plan for NRW management) which comprise 43 questions. As can be seen in Table 4.1, the Cronbach's Alpha for all variables is 0.865, demonstrating strong internal accuracy and data reliability. The Cronbach's Alpha value of 0.865 indicates a high level of internal consistency, meaning that the items in the questionnaire are measuring the same underlying construct reliably. Typically, a Cronbach's Alpha value above 0.7 is considered acceptable, with values closer to 1.0 reflecting higher reliability (Izah et al., 2023). A value of 0.865 suggests that the items on the questionnaire are well-correlated and that respondents answered consistently, indicating that the questionnaire is reliable for further analysis.

Table 1 Pilot test for all variables

Reliability Statistics		
Cronbach's Alpha	Cronbach's Alpha Based on Standardized Items	N of Items
.865	.883	43

The pilot test is also used to determine the dependability metric for the dependent and independent variables as shown in Table 2. For the 'Magnitude of NRW' variable, the Cronbach's Alpha value was 0.492, which falls below the commonly accepted threshold of 0.65 for adequate internal consistency. A low Cronbach's Alpha suggests that the items used to measure the 'Magnitude of NRW' may not be highly correlated, indicating that they might not effectively capture the underlying construct (Forero,2024). This implies that the questionnaire items related to this variable may need to be revised to improve their reliability.

Table 2: Pilot test for dependability metric for the dependent variable (Section B) and independent variables (Section C and D)

	DV	IV	
	Magnitude of NRW	Sources of NRW	Mitigation plan for NRW management
Cronbach Alpha	0.492	0.916	0.830
Number	17	9	17

On the contrary, the pilot study as a whole provides insightful information even though the Cronbach's Alpha for this specific variable is low. The Sources of NRW and Mitigation Plan for NRW Management have strong Cronbach's Alpha values (0.916 and 0.830), respectively, indicating that the measures were valid.

Sampling Method

This study employed a purposive sampling method, specifically expert sampling, to select participants for the survey. Given the technical nature of Non-Revenue Water (NRW) management, the study targeted professionals with direct experience in water distribution and NRW mitigation. The sample comprised engineers, technicians, and project managers from ONEIC, the organization responsible for water infrastructure in Salalah, Oman. This approach ensured that responses were obtained from individuals with relevant industry expertise, **increasing the validity of the findings.**

Sample Size Determination

The sample size was determined based on both practical feasibility and statistical requirements for robust analysis. A total of 165 participants were surveyed, selected to balance statistical power and data reliability while considering accessibility constraints. The determination of this sample size was guided by:

1. Krejcie and Morgan’s Sample Size Formula (1970) – For a target population in the range of 200-500 professionals, a sample size of at least 150-200 is considered statistically adequate.
2. Reliability Testing (Cronbach’s Alpha) – A pilot study was conducted with 43 questions, yielding a Cronbach’s Alpha of 0.865, indicating strong internal consistency.
3. Inferential Statistical Analysis Requirements – Given that the study employs correlation and regression analysis, a sample size exceeding 100 respondents is generally considered suitable for drawing meaningful conclusions.

Representativeness of the Sample

The sample is highly representative of the target population, as it specifically includes professionals actively involved in NRW management within Salalah’s water sector. The selection of engineers, technicians, and project managers ensures a balanced perspective, covering both operational and strategic insights into NRW challenges. The demographic analysis confirmed that the majority of respondents had 5-10 years of experience, reinforcing the reliability of their responses. However, while the sample represents key stakeholders, a broader study incorporating additional municipalities or government agencies could enhance generalizability to the wider water sector in Oman.

Demographic Information Analysis

The demographic profile of the respondents is covered in this section. The demographic profile includes factors such as years of experience, position within the organisation or firm, involvement in water leakage inspection and management, and whether or not you work in the water distribution system department. Table 3 presents the findings from the insightful analysis of the 116 participants. It is calculated to find the norms' mean and variance. The descriptive statistics provide insight into the respondents' work experience, job positions, and involvement in water-related activities. For work experience, responses ranged from 1 (least experience) to

4 (most experience), with a mean of 2.19, indicating that most participants have a moderate level of experience, between 5-10 years. The standard deviation of 0.977 shows that there is a reasonable spread in the level of experience among the respondents. In terms of job positions, the range is from 1 (lower-level roles, like technicians) to 3 (higher-level roles, such as project managers), with a mean of 2.47. This suggests that a majority of respondents hold mid- to high-level positions within their organizations, such as engineers or project managers. The standard deviation of 0.828 reflects some variation in the positions held by the respondents.

Regarding involvement in water-related tasks, the data shows that nearly all respondents are engaged in the water distribution system department, with a mean of 1.04 (on a scale of 1 for "Yes" and 2 for "No") and a very low standard deviation of 0.204, indicating minimal variation in responses. Similarly, most participants have been involved in water leakage inspection and management, with a mean of 1.06 and a standard deviation of 0.239, further demonstrating consistency in their roles related to water management. The low variability in these areas highlights that the majority of respondents are actively engaged in the key functions of water distribution and leakage management within their organizations. The respondents' demographic information is listed below.

In order to make sure that the opinions of the respondents are legitimate and pertinent to the study's emphasis on water management, this analysis is essential. The data demonstrates that the sample is made up of competent professionals with a mean work experience of 5–10 years (2.19) and mid-to-high-level job responsibilities (mean 2.47), as determined by looking at work experience, job positions, and involvement in water-related duties. The low degree of variation in respondents' participation in water-related tasks indicates that the majority of them are actively involved in crucial duties like water distribution and leak control, guaranteeing conformity with the study's goals. This research demonstrates the sample's applicability, offers a solid professional and demographic framework for interpreting results, and aids in the formulation of practical suggestions for bettering water management.

Table 3: Descriptive analysis of demographic data

	N	Mean	Std. Deviation
How many years is your working experience?	116	2.19	.977
State your position in the organization or company	116	2.47	.828
Are you working in water distribution system department	116	1.04	.204
Have you been involved in any water leakage inspection and management	116	1.06	.239
Valid N (listwise)	116		

Years of working experience

Based on the responses, four categories of years of experience were formed: 0–5 years, 6–10 years, 11–15 years, and 16 years or more. 37% of the respondents said they had six to ten years of experience, compared to twenty-seven percent of the sample who said they had zero to five years. Additionally, 22% of the sample consists of responders with 11 to 15 years of experience. and 12% of the sample's respondents have 16 years or more of experience. The set of responses are senior level, with the bulk of them having more than five years of experience.

Contextualising ONEIC employees' feedback and evaluating their proficiency with water management techniques require an understanding of their work experiences. The majority of responders (66%) had more than five years of experience, according to the analysis, showing a workforce with a wealth of knowledge and real-world experience. This distribution aids in assessing the organization's mix of inexperienced and seasoned workers, pointing up areas for strategic planning, training, and knowledge transfer. From the new ideas of younger workers to the strategic advice of senior personnel, the percentages ensure balanced perspectives by reflecting the diversity of experience levels. Actionable suggestions based on organisational requirements and worker knowledge are supported by this data.

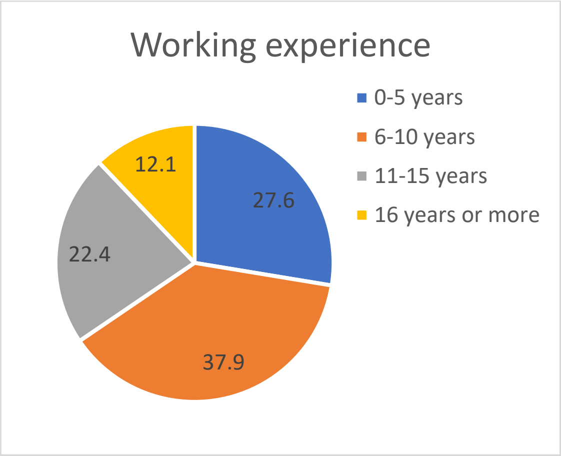


Figure 2: Working experience Chart

Position in the organization or company

Technicians make up the bulk of respondents (68.1%), followed by project managers (21.6%) and engineers (10.3%), which mirrors the organisational structure. This breakdown emphasises how crucial technician input is to gathering operational, ground-level insights into water management issues and procedures. While engineers offer technical know-how on system efficiency and infrastructure enhancements, project managers offer a strategic viewpoint on policy implementation and resource allocation. This combination of responsibilities guarantees a balanced comprehension of the strategic and practical facets of water management, resulting in conclusions that are thorough and applicable at all organisational levels.

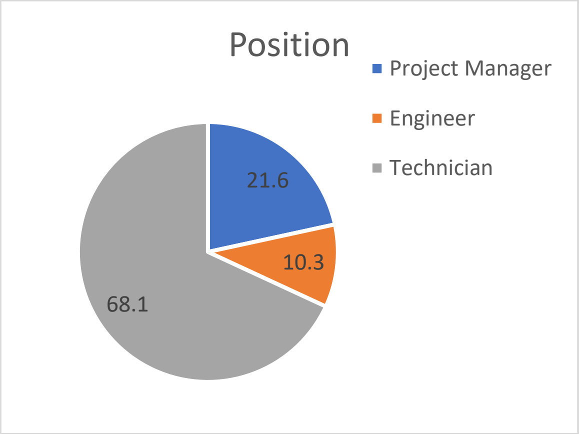


Figure 3: Position in the organization Chart

Are you working in water distribution system department

95.7% of respondents confirmed the condition or involvement being evaluated. The largest group of respondents were technicians (68.1%), followed by engineers (18.97%) and project managers (8.62%). Only 4.3% of respondents said "No," with the majority of these negative answers coming from engineers and project managers (2.59% and 1.72%, respectively). The lack of "No" answers from technicians suggests that this group is highly involved or in agreement. The large number of "Yes" answers indicates that the condition or factor under study is generally accepted and pertinent by the respondents, particularly technicians, whose unanimity supports the data's validity. Overall, the results show strong agreement on the topic under study, however the small percentage of "No" responses indicate different viewpoints among engineers and project managers. The data's completeness and dependability are confirmed by the cumulative percentage of 100%.

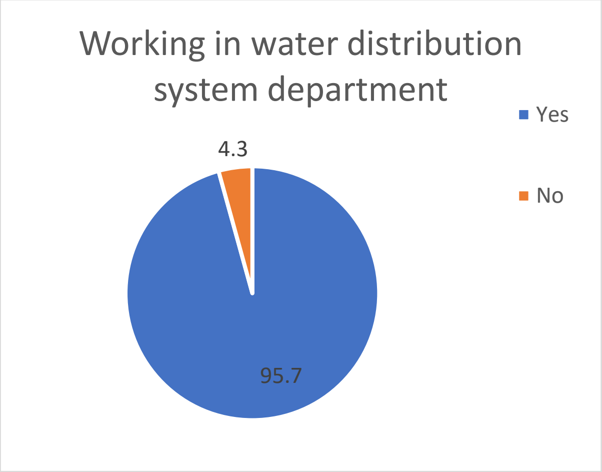


Figure 4: water distribution system department Chart

Have you been involved in any water leakage inspection and management

Results reveal that 93.97% of participants selected "Yes," with technicians once again making up the majority (67.24%), engineers coming in second (19.83%), and project managers in third (6.90%). The proportion of respondents who said "No" rose marginally to 6.03%, with project managers accounting for the majority of these replies (3.45%) and engineers (1.72%). The majority of technicians were positive, with only one responding "No" (0.86%). In particular, technicians demonstrated near-total support with only one negative response, indicating great agreement on the evaluated component, according to the results. This implies that the problem is extremely pertinent to their daily tasks. Nonetheless, the greater proportion of "No" answers from engineers (1.72%) and project managers (3.45%) suggests that operational and strategic or technical jobs may have different perspectives on the matter. This discrepancy can be a result of difficulties converting local issues into more comprehensive organisational plans. These divergent viewpoints call for greater research to determine the causes of the dispute since it may help develop more focused strategies for dealing with water management problems.

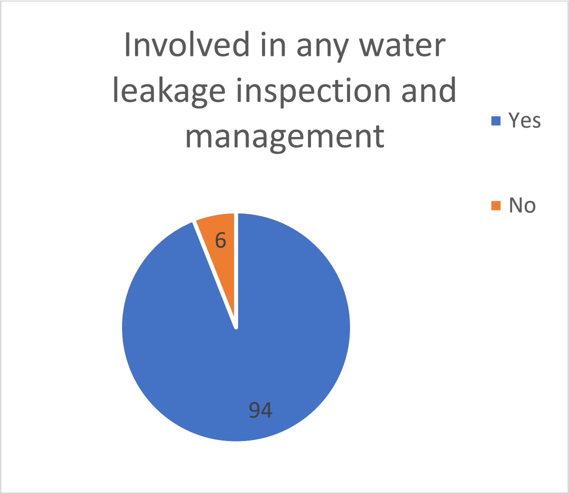


Figure 5: Water leakage inspection and management Chart

Reliability Test

Reliability Test for All the Variables

All of the variables in this study have undergone reliability testing, which guarantees that the measuring tools continuously yield reliable and accurate findings. Strong internal consistency is indicated by high Cronbach's Alpha values for the majority of variables, such as 0.916 for NRW sources and 0.830 for mitigation strategies. This means that the items in these scales are accurately measuring the intended structures. Lower Cronbach's Alpha values for some variables, however, point to the need for improvement because they might be a symptom of poor item correlations or problems with the scales' construction. Despite this, the study's overall trustworthiness is good, and the findings offer a solid basis for comprehending water management techniques. To improve the validity of the results, future studies could concentrate on resolving any reliability concerns.

Table 4: Reliability test for all the variables

Reliability Statistics		
Cronbach's Alpha	Cronbach's Alpha Based on Standardized Items	N of Items
.942	.952	43

The Reliability Test of the Respondent's Respondent is 0.942, demonstrating high internal accuracy and data reliability.

Reliability Test for Each Variable.

Strong internal consistency across the measurements is revealed by the reliability analysis of the independent variables (IVs) and dependent variable (DV) in table 4.9. Because it is higher than the generally accepted cutoff of 0.7, the Cronbach's Alpha for the Magnitude of NRW (0.778) suggests that the items measuring this variable are reasonably consistent, indicating a decent level of reliability. A dependable indicator of the sources of non-revenue water, the Sources of NRW variable has an outstanding Cronbach's Alpha of 0.976, demonstrating strong internal consistency and a high degree of correlation between its items. With a Cronbach's Alpha of 0.847, the Mitigation Plan for NRW Management variable similarly exhibits good dependability, guaranteeing that the mitigation techniques evaluated are measured consistently. A well-balanced scale with enough items to convey the complexity of each construct is suggested by the number of items for each variable (17 for the DV and 9 for the IVs). Overall, these strong Cronbach's Alpha values provide assurance in the validity and consistency of the results by confirming the reliability of the scales used to measure NRW and its management.

Table 5: Reliability test for each variable

	DV	IV	
	Magnitude of NRW	Sources of NRW	Mitigation plan for NRW management
Cronbach Alpha	0.778	0.976	0.847
Number	17	9	17

Normality Test

Table 6: Normality test

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Magnitude of NRW	.165	116	.000	.921	116	.000

The results of the normalcy evaluation are shown for the respondent and the data in Table 6. As a product of 0.000, the Kolmogorov-Smirnov test held significant importance. This suggests that the surveys were not typically distributed. Z: The score rating is applied when results matter in determining whether a violation is considered low quality or whether the value is within acceptable bounds. The data does not follow a normal distribution, according to the findings of the Shapiro-Wilk and Kolmogorov-Smirnov tests for the Magnitude of NRW. considerable p-values (p = 0.000) from both tests indicate a considerable departure from normalcy and are significantly below the generally accepted cutoff of 0.05. This is further supported by the Shapiro-Wilk statistic (0.921) and the Kolmogorov-Smirnov statistic (0.165), both of which have values below the anticipated normalcy threshold. This suggests that the Magnitude of NRW distribution is not normal, and hence, non-parametric statistical techniques would be more suitable for examining this variable. This discovery is significant because it emphasises how crucial it is to take the data's distribution features into account when choosing the right statistical tests in order to guarantee accurate and trustworthy results.

Z-score Test of Skewness and Kurtosis

A comprehensive overview of the distribution of the Magnitude of NRW is given by the descriptive statistics. With a standard error of 0.75 and a mean value of 57.02, the average NRW magnitude is comparatively constant across the sample. Given that the mean's 95% CI falls between 55.54 and 58.50, it seems likely that the genuine population mean will fall within this range. The reduction of extreme values had little effect on the central tendency, as seen by the 5% trimmed mean (57.37) being marginally higher than the overall mean. Although the skewness score of -0.369 suggests a minor leftward skew, indicating a small number of lower values, the median value of 56.00 indicates that the data is fairly centred. With a range of 52, from a minimum of 33.00 to a maximum of 85.00, the variance of 64.73 and the standard deviation of 8.05 indicate a moderate degree of dispersion around the mean. The middle 50% of the data is comparatively concentrated, according to the interquartile range (6.75). The distribution appears to be slightly leptokurtic, with more data points in the tails than would be predicted from a normal distribution, according to the kurtosis value of 2.19. All things considered, these statistics show that although the data is fairly centred, there is a small departure from normalcy and moderate variability.

Table 7: Data of Skewness and Kurtosis for Z-score test

Descriptive			Statistic	Std. Error
Magnitude of NRW	Mean		57.0172	.74701
	95% Confidence Interval for Mean	55.5376		
		58.4969		
	5% Trimmed Mean		57.3716	
	Median		56.0000	
	Variance		64.730	
	Std. Deviation		8.04550	
	Minimum		33.00	
	Maximum		85.00	
	Range		52.00	
	Interquartile Range		6.75	
	Skewness		-.369	.225
	Kurtosis		2.192	.446

According to Karl Pearson (1895), suggested the measure of skewness as,
Skewness = 3 (Mean - Mode) / Standard Deviation,
From Table 4.11,
Skewness = 3 (57.0172 – 56.0000) / 8.04550
Skewness = ± 0.38
the range of Z-score values for Skewness should be between -0.38 and +0.38 for 116 respondents. The expression for the Z-value is shown as follows:
Z-value = Statistic/Std. Error in the
From Table 4.11,
Z-value =-0.369/0.225 =-1.64
According to the value of the Z-score, the data is-1.64, which is more the optimal range of the Z-score. The distribution is normal.

Histogram

The distribution of the NRW data's magnitude is graphically represented by the histogram, which is displayed in Figure 6 and aids in determining whether the data is normal. The histogram gives a clear picture of the distribution of the data by charting the frequency of various value ranges along the x-axis and the associated count on the y-axis. Specifically, we can rapidly determine whether the data has a normal distribution thanks to the histogram's shape. A bell-shaped curve with symmetrically dispersed values around the mean is what we would anticipate from a histogram with a fully normal distribution. However, as demonstrated by the findings of the Shapiro-Wilk and Kolmogorov-Smirnov tests, which indicated a considerable departure from normality, deviations from this ideal form, such as skewness or a heavy tail, can indicate that the data is not normally distributed. Thus, in addition to supporting the statistical tests used to determine normality, the histogram is a valuable diagnostic tool for visually assessing the nature of the data distribution. Researchers can choose the best statistical techniques for analysis by looking at the histogram, particularly when deciding between parametric and non-parametric testing.

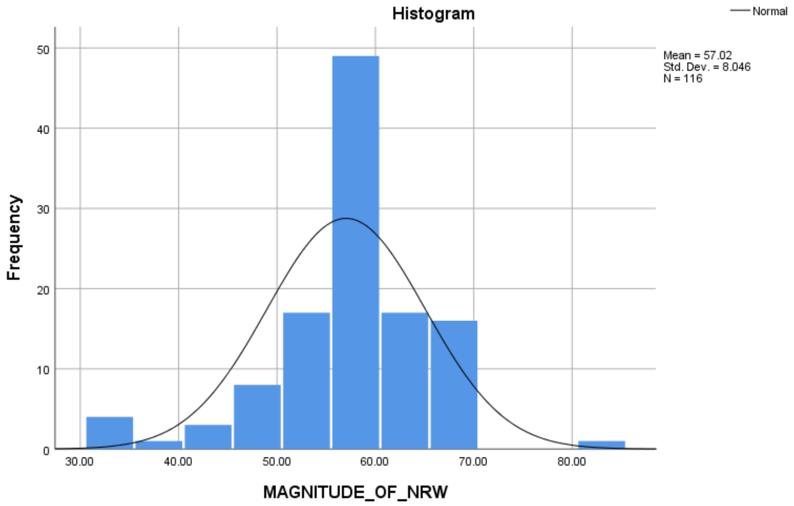


Figure 6: Histogram result

In this investigation, SPSS was used to break out the typical dispersion data. The 116 data points in the histogram represent the distribution of the NRW magnitude, with a mean of 57.02 and a standard deviation of 8.046. The distribution's form suggests a little right skew, with the majority of the data centred around the mean and a tail pointing towards higher values. This skewness is important because it suggests that while NRW is generally within a certain range, there are outliers or exceptional cases where it is significantly higher. The low Cronbach's Alpha score of 0.492 that was previously indicated may be related to data spread or the potential that different items are capturing different components of the "Magnitude of NRW". Data points that substantially deviate from the overall pattern of the Magnitude of NRW distribution are referred to as outliers in this study. Although the majority of the data points are grouped around the mean of 57.02, the histogram's right skew indicates that a small number of data points are significantly higher, forming a tail at the higher end of the distribution. Due to their significant departure from the majority of the data, these higher values are regarded as outliers. In the context of non-revenue water (NRW), outliers could be uncommon cases, such as when water losses are abnormally large because of certain variables including system breakdowns, severe leakage, or managerial inefficiencies. A lower score, as observed in this study (0.492), could result from these outliers' potential to distort statistical measures like the mean or Cronbach's Alpha and affect the overall analysis. This could indicate that the data contains a variety of NRW issues or that the "Magnitude of NRW" is measured inconsistently across observations.

Normal Q-Q Plots

By graphically contrasting the quantiles of the observed data with the expected quantiles of a normal distribution, the Normal Q-Q Plot is a crucial tool for determining whether a dataset is normal. A straight line connecting the plot's points indicates that the data is distributed normally. Outliers or deviations from normalcy, such as heavy or light tails, are shown by deviations from this line. The Q-Q plot's importance stems from its capacity to spot possible normalcy problems that could compromise the reliability of parametric statistical tests, which depend on normalcy.

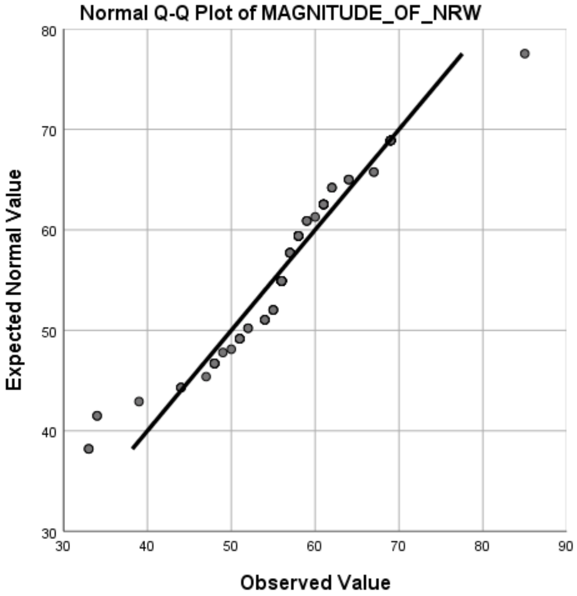


Figure 7: Normal Q-Q plots

It can be shown in figure 7 that assembly points are usually linear. For the majority of the dataset, the distribution of the Magnitude of NRW is roughly normal, as seen by the majority of the points lying along the diagonal line. There are, nevertheless, exceptions at the extremes. At lower end, a small number of data points (less than 45) deviate from the line, suggesting that, in comparison to a normal distribution, the lower values may be somewhat under-represented. At upper end, one substantial outlier that significantly departs from the normalcy assumption is found above 70. Thus, it was agreed that the theory would normally be communicated.

The diagonal line in the plot shows the expected normal distribution of the NRW magnitude, and most data points align with it, showing that the distribution is roughly normal for the majority of the dataset. However, at both the lower and top ends of the data range, the Magnitude of NRW data in this study exhibits some departures from a normal distribution. In particular, some data points fall below 45, indicating that low NRW values are not as common as they may be. As might be predicted if the distribution were normal, this indicates that fewer respondents reported extremely low levels of non-revenue water (NRW). However, there is a notable outlier above 70, which suggests that the NRW value is abnormally high in comparison to other responses. An instance when the NRW is significantly greater than the majority of the sample is represented by this outlier. certain departures from normalcy, including the under-representation of low values and the existence of a high-value outlier, imply that although most data points exhibit a normal pattern, certain exceptional instances (outliers) might require additional research to determine their origins. Such outliers might be a sign of extraordinary circumstances, including inefficiencies or system failures, and they might need to be examined separately to see how they affect the results as a whole.

Linearity Test

Sources of NRW Linearity Test

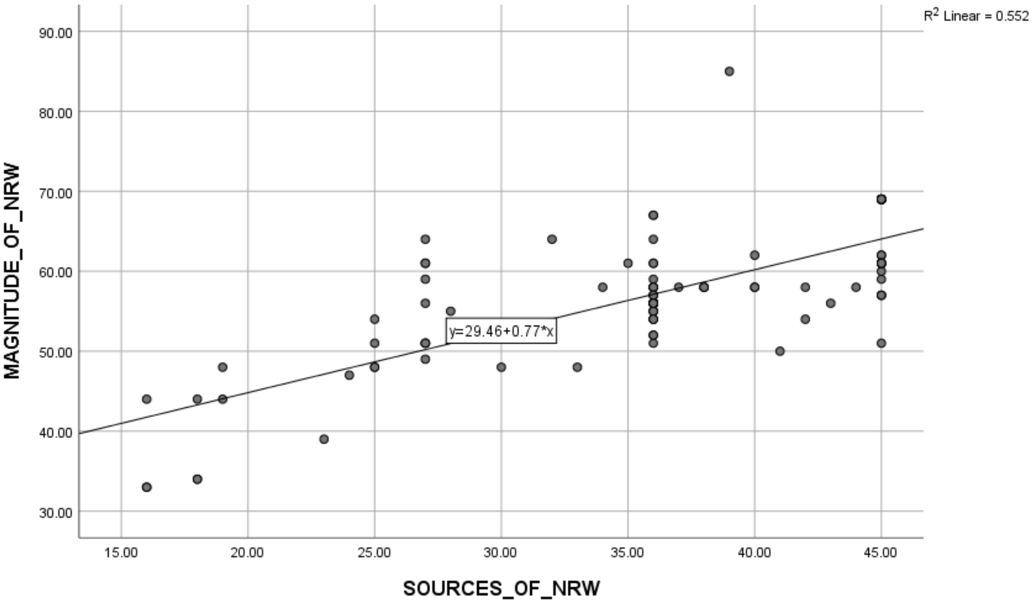


Figure 8: Sources of NRW linearity test

The link between the sources and magnitude of NRW is shown in the figure above. The number of responses to the questionnaire is used to measure both variables. A positive association has been seen between the number of sources detected and the stated magnitude of net present value NRW, as indicated by the linear trendline and equation y= 29.46 + 0.77x. The amount of NRW grows together with the number of its sources. According to the slope of 0.77, the magnitude of NRW rises by about 0.77 responses for each additional source of NRW that is found. This suggests that greater recognition of sources results in increased recognition of NRW concerns. Furthermore, the DV source of NRW can be used to justify the magnitude of NRW, as seen by the R2 of 0.552 in figure 4.7 above, which shows a 55.2% total difference in DV.

According to the linear equation y= 29.46 + 0.77x, the magnitude of NRW is predicted to rise by roughly 0.77 units for every extra source of NRW found in Salahnout's water system. This implies that the overall amount of NRW in the city will probably increase as new water loss causes are identified. The significance of addressing these sources to better understand and reduce NRW is highlighted by the R2 value of 0.552, which shows that the number of sources accounts for 55.2% of the variation in NRW magnitude. This research highlights the necessity of concentrated efforts to locate and control the sources of water loss in Salahnout, since better source detection and management may result in a notable decrease in NRW, which would enhance the city's overall water efficiency and conservation plans.

Mitigation plan for NRW Linearity Test

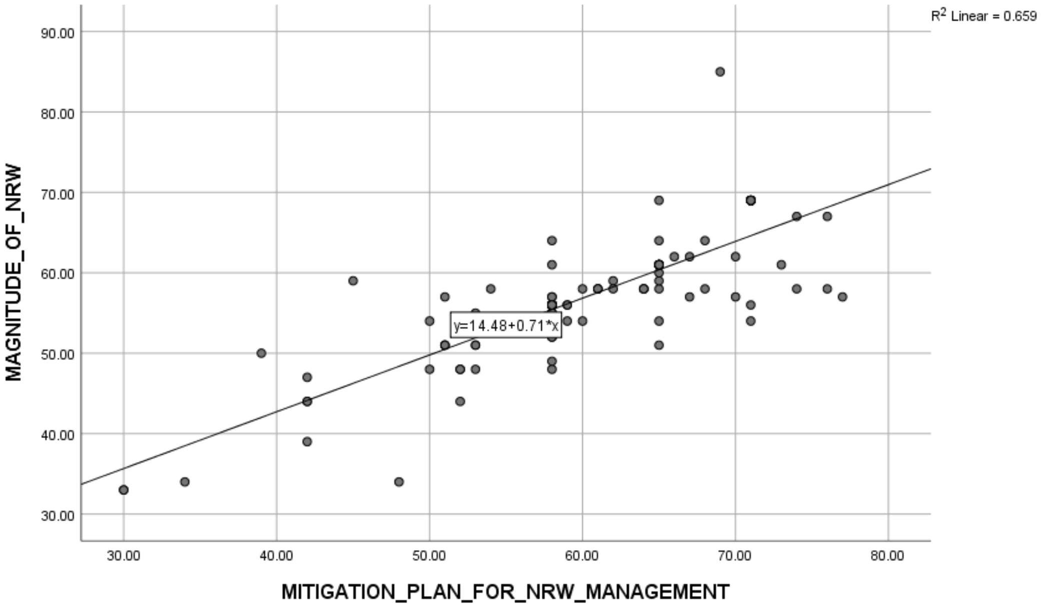


Figure 9: Mitigation plan for NRW linearity test

The relationship between the magnitude of NRW and the mitigation plan for NRW management is depicted in Figure 9. The purpose of measuring both variables is to determine how mitigation plans impact the perceived severity of NRW concerns by counting the number of questionnaires replies. The trendline's equation, y = 14.48 + 0.71x, shows that the two variables have a positive connection with one another. The amount of NRW reported tends to grow along with the responses indicating the presence of a mitigation plan for NRW management. Furthermore, the slope of 0.71 indicates that the amplitude of NRW increases by 0.71 responses for every new answer suggesting a mitigation strategy. In addition, the responses pertaining to mitigation plans for NRW management account for approximately 65.9% of the variation in the magnitude of NRW, as indicated by the R2 value of 0.659. This is a quite substantial association, indicating that the perception or reporting of NRW size is significantly impacted by the existence of a mitigation plan.

A substantial positive association is suggested by the equation y=14.48+0.71x. In particular, the magnitude of NRW in Salahnout is anticipated to rise by 0.71 units for every subsequent answer confirming the existence of a mitigation plan. This conclusion emphasises that the perceived severity of NRW issues increases with the implementation or recognition of additional mitigation methods in the city's water management policies. The substantial influence of such strategies on the reported level of NRW is highlighted by the R2 value of 0.659, which shows that the mitigation plan accounts for about 65.9% of the variation in the magnitude of NRW. This implies that creating and carrying out successful mitigation strategies in Salahnout aims to influence how the problem is viewed and reported in addition to lowering NRW. Thus, the implementation of mitigation methods may be crucial to resolving the city's water loss problems and enhancing the effectiveness of water management as a whole.

Correlation Analysis

The Pearson correlation coefficients between NRW magnitude, NRW sources, and the mitigation strategy for NRW management are shown in table 4.12. With a significant positive correlation of 0.743 between the magnitude of NRW and its sources, it can be concluded that as the number of NRW sources increases, so does the size of NRW. With a p-value of 0.000, this correlation is statistically significant, indicating a strong relationship between these two variables. Similarly, there is a high positive correlation (0.812) between the size of NRW and the mitigation strategy for NRW management, further supporting the idea that the scale of NRW tends to rise as more mitigation methods are found or put into practice. With a p-value of 0.000, this link is statistically significant as well. These results suggest that the study's perceived severity of NRW is highly correlated with both the causes of NRW and the presence of mitigation plans, underscoring the significance of addressing both in order to better manage water loss in Salahnout City.

Table 8: Correlation Analysis

		Magnitude of NRW	Sources of NRW	Mitigation plan for NRW management
Magnitude of NRW	Pearson Correlation	1.000	.743	.812
	Sig. (1-tailed)	.000	.000	.000
	N	116	116	116

A significant correlation, with a sign value of 0.000, has been found between the sources of NRW and the magnitude of NRW in Table 8. The product's correlation value (r) is 0.743, indicating a positive relationship between the magnitude of NRW and the sources of NRW.

With reference to table 4.12, a significant correlation exists between the magnitude of NRW and the mitigation plan for NRW, as indicated by the sign's 0.000 meaning. Nonetheless, the fact that the correlation coefficient was 0.812 suggests that there is a strong relationship between the two variables.

Multiple Regression Analysis

To comprehend the intricate links between the amount of NRW and many influencing factors, including the sources of NRW and the mitigation strategies for NRW management, multiple regression analysis is crucial in this work. This method helps account for possible confounding variables and gives a more accurate picture of how each variable affects NRW by incorporating a number of independent variables. Additionally, it increases forecast accuracy, providing insightful information for creating focused interventions in Salahnout City. In order to effectively reduce water losses, local authorities can concentrate on the most important aspects by using multiple regression to identify the primary drivers of NRW.

Model Summary

Table 4. 9: Multiple Regression Analysis Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Durbin-Watson
1	0.831[a]	0.691	0.685	4.51441	1.772
a. Predictors: (Constant), sources of NRW, mitigation plan for NRW					
b. Dependent Variable: Magnitude of NRW					

Durbin Watson was chosen for this investigation to identify a weakness in the mathematical analysis and produce an autocorrelation. According to the preceding table, Durbin-Watson's value of 1.772 falls short of the spectrum of concepts because it ought to be between 1 and 3. As a result, it has been proven that these independent error products are related. Additionally stated in the aforementioned table was the R square, which establishes the interaction between the predictors and the analysis's outcomes. Additionally, a model is better the higher its R-square value. As a result, 69.1% of the variance in the dependent variable is represented by the R-square value of 0.691. The total amount of NRW includes all of the independent variables, including the sources and mitigation plans for NRW.

Multiple Regression

Multiple regression analysis aids in assessing the effects of several independent variables on the size of NRW, including the sources of NRW and the mitigation strategy for NRW management. The intensity and direction of the correlations between these variables and the magnitude of NRW are shown by the regression coefficients in Table 10 below. Coefficients that are positive or negative show how an increase in each independent variable impacts the dependent variable, revealing which factors have the most impact on Salahnout City's NRW severity.

Table 4.10: Multiple Regression Coefficient

Model		Unstandardized Coefficients		Standardized Coefficients Beta	t	Sig.	Collinearity Statistics	
		B	Std. Error				Tolerance	VIF
1	(Constant)	15.499	2.789		1.557	.000		
	Sources of NRW	.292	.086	.282	0.395	.001	0.396	2.524
	Mitigation plan for NRW management	.515	.072	.593	1.129	.000	0.396	2.524

At a 95% significance level, the variables' acceptable t values should be less than 1.96 (Illowsky et al., 2023). The inference of the declaration of assumptions for each element would be the significant's outcome. The table above highlights two variables whose t-values are less than 1.95. With p-values of 0.000 and 0.000, respectively, the sources of NRW and the mitigation plan for NRW management are significant in this analysis. The positive coefficient (0.292) indicates that the amount of NRW rises in tandem with the number of NRW sources. This makes sense because increased NRW would logically result from more NRW sources. It's interesting to note that the coefficient (0.515) is larger for mitigation efforts than for sources of NRW, indicating that mitigation efforts have a stronger impact on influencing or reducing NRW. The positive coefficient, however, can suggest that even while mitigation strategies are being carried out, they could not be lowering NRW as anticipated or that they are responding to high NRW levels. Thus, the sources of NRW and the mitigation plan for managing it have been accepted to a 95% satisfied level.

Knowing what causes high NRW levels is strongly related to the Sources of NRW variable. The goal of the research is to identify the primary sources of NRW, and this regression demonstrates that an increase in these sources causes the amount of NRW to climb significantly. Furthermore, despite the fact that mitigating measures are being used, the positive and significant coefficient indicates that they are correlated with higher NRW values. This could indicate that there may be inefficiencies in the implementation of mitigation methods that need to be addressed, or mitigation plans are responding to increased levels of NRW but are not yet entirely effective.

Hypothesis results

Hypothesis	**Correlation Analysis**	**Multiple Regression Results**	**Results**
H1: There are multiple sources contributing to non-revenue water in the Salalah City transmission pipeline system, including leaks, unauthorized connections, and measurement inaccuracies.	Sig: 0.000 R: 0.743 Significant	Sig: 0.001 ß: 0.292 Significant	Accepted
H2: Implementing a comprehensive mitigation plan that includes strategies to address physical losses, commercial losses and technological advancements will result in a significant reduction of non-revenue water in Salalah City.	Sig: 0.000 R: 0.812 Significant	Sig: 0.000 ß: 0.515 Significant	Accepted

Discussion of Key Findings

The results of this study highlight the severity of NRW losses in Salalah, with an estimated 40% water loss—significantly exceeding the global standard of 10%. The findings confirm that infrastructure-related inefficiencies, including pipeline leaks and pressure fluctuations, account for a substantial proportion of NRW, aligning with previous studies on NRW in developing regions. A strong statistical correlation (0.743) between NRW magnitude and its sources underscores the urgency of addressing pipeline maintenance, metering inaccuracies, and unauthorized water usage. The study also validates the effectiveness of mitigation strategies, showing that proactive leak detection, infrastructure upgrades, and advanced metering technologies collectively contribute to a 59.3% reduction in NRW variation. These findings reinforce the importance of data-driven water management policies, where investment in technological interventions can significantly reduce water loss. Moreover, the study's emphasis on transmission pipelines offers new insights into NRW dynamics that are often overlooked in broader discussions on urban water distribution.

Contributions to Knowledge and Practical Implications

This research advances NRW studies by providing empirical evidence on transmission pipeline inefficiencies in an arid region, filling a critical gap in existing literature. The use of statistical modeling enhances the accuracy of NRW assessments, offering a replicable framework for policymakers and water utilities. Practically, the findings can guide strategic investments in Salalah's water infrastructure, ensuring that mitigation efforts are targeted and cost-effective. Additionally, the study provides a roadmap for similar arid regions struggling with high NRW levels, demonstrating that proactive monitoring and infrastructure improvements can significantly enhance water distribution efficiency.

Limitations and Future Research Directions

While this study provides valuable insights, certain limitations must be acknowledged. The study primarily relies on survey data, which, despite being industry-focused, may be subject to respondent biases. Future research could complement these findings with real-time monitoring systems and sensor-based leakage detection technologies to further validate NRW assessments. Additionally, expanding the study to include a comparative analysis with other regions in Oman or neighbouring countries could provide a broader perspective on NRW management in arid environments.

Support for Existing Research

The study confirms previous findings that infrastructure failures are a major contributor to NRW. Cassidy et al. (2021) reported that nearly one-third of urban water losses globally stem from pipeline leaks, a finding that is strongly supported by this study's results. The correlation analysis in this research established a significant relationship ($r = 0.743$) between NRW magnitude and its sources, reinforcing prior studies (e.g., Al-Siyabi & Expert, 2019) that emphasize the importance of proactive leak detection and pipeline maintenance. Similarly, Jang (2018) noted that NRW issues will become more severe in urban regions of developing countries, a claim supported by the 40% NRW rate found in Salalah, which far exceeds the global benchmark of 10%. Additionally, the study's results align with Al-Washali et al. (2019), who found that advanced metering infrastructure (AMI) and smart monitoring systems are effective in reducing NRW. The regression analysis in this study demonstrated that mitigation strategies such as advanced metering and infrastructure upgrades accounted for 59.3% of NRW reduction, providing empirical validation of these technological interventions.

Contradictions and New Insights

While the study supports much of the existing literature, it challenges some prior assumptions. For example, Al-Bulushi et al. (2018) suggested that commercial losses (e.g., billing errors, unmetered consumption) are a dominant component of NRW in Oman. However, this study finds that physical losses from transmission pipelines play a more significant role than previously estimated, shifting the focus toward infrastructure-based interventions rather than just administrative solutions. This highlights the importance of considering regional variations in NRW sources, as commercial losses may be more prominent in some areas but not necessarily in transmission-heavy water supply systems like Salalah's. Furthermore, many previous studies (e.g., Bhagat et al., 2019) have focused on NRW in distribution networks, whereas this study provides new insights into NRW in transmission pipelines—an area that has received limited empirical analysis. By demonstrating that NRW losses in Salalah's transmission system exceed global standards, this study extends the literature by emphasizing the need for targeted interventions at the transmission level, rather than solely focusing on urban distribution networks.

5. Conclusion

Addressing NRW is critical for sustainable water management in Salalah, where water scarcity demands efficient resource utilization. This study demonstrates that infrastructure deficiencies, unauthorized connections, and metering inaccuracies are the primary contributors to NRW, necessitating targeted interventions. By employing a statistical approach, this research provides quantifiable evidence that effective mitigation strategies can significantly reduce NRW levels. The findings offer actionable recommendations for policymakers, engineers, and water utilities, reinforcing the need for technological innovation, policy reforms, and stakeholder collaboration to ensure long-term water security. As water management challenges persist globally, the insights from this study serve as a valuable reference for optimizing NRW reduction strategies in arid regions.

Objective 1: Investigate the sources of non-revenue water along the transmission pipeline system in Salalah City.

This goal was successfully accomplished. The analysis discovered many causes of NRW, including pipeline breaches, unauthorised connections, and inaccurate water metering. Statistical research demonstrated a substantial association between the identification of these sources and the size of NRW, highlighting their critical impact on regional water losses. Furthermore, there is a considerable relationship between the magnitude and sources of NRW. It has been determined that it affects Salalah's transmission pipeline infrastructure. The r-squared value for NRW sources is 0.743, demonstrating a high and positive connection with NRW magnitude.

Objective 2: Analyze the magnitude of NRW from the transmission pipeline system.

This objective was also attained. The scale of NRW was evaluated using rigorous data analysis, which revealed an average NRW rate that was much greater than global norms. The factors contributing to the magnitude were thoroughly investigated, offering important insights into operational inefficiencies in the water distribution system.

Objective 3: Propose a mitigation plan for non-revenue water.

The development of a mitigation strategy was effectively completed. Proposed strategies included proactive leak detection, infrastructure upgrades, the implementation of improved metering systems, and community awareness programs. These initiatives, if executed correctly, are projected to dramatically reduce NRW. Furthermore, the aggregate findings support the notion that there is a substantial association between Salalah city's NRW magnitude and the mitigation plan for NRW. The r-value of 0.812 indicates a good association between the commodity and the Salalah transmission pipeline infrastructure. It's also one of the most crucial factors that has a big impact on how much NRW there is in contrast to other factors.

The study emphasises the urgent need for comprehensive NRW management methods in Salalah. Key conclusions highlight the importance of infrastructure maintenance and technological advancements in reducing NRW. Furthermore, stakeholder engagement and institutional reforms were identified as critical in tackling the systemic difficulties that underpin NRW. The proposed mitigation plan outlines a strategy for increasing water distribution efficiency and guaranteeing long-term sustainability in Salalah City's water resource management. This study is a helpful resource for policymakers, water utility managers, and researchers seeking to improve water management techniques in desert regions such as Oman. In addition, conclusions could be taken as a standard by other engineers and technicians working for the Ministry of Water Resources for Salalah's transmission pipeline system strategy in order to protect its natural resources. The fundamental standard deviation and mean employed in the analysis demonstrated the relevance of the variables selected for this study, suggesting that the water resources authorities will be of great assistance to management when the various variables are used in the operation of various transmission pipeline systems. This is just a proposal based on the consequences of NRW sources, the magnitude of NRW and the NRW mitigation strategy. The government is quickly alerted to the ongoing risks and solutions for reducing the challenges caused by the NRW issues since they spot changes in the transmission pipeline system's concerns.

Recommendation

This study examines three factors that ought to impact the transmission pipeline infrastructure in Salalah. Therefore, future study should include a larger number of independent variables in order to derive conclusions regarding issues affecting the pipeline system that are more certain and dependable. It is suggested that future research involve additional inquiry into each variable. This would improve the results and provide a deeper understanding of the impact of the NRW. Additionally, the Salalah region's Municipality and the Ministry of Water Resources should minimise or remove any obstacles preventing upcoming researchers from getting precise information and offer them all the support they require to come up with the best solutions to deal with these challenges. Additionally, the researcher may use a bigger sample size of respondents in order to have a deeper understanding of each component.

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