Southern Journal of Engineering & Technology – Special Issue, Vol. 01, Issue 01, 2024

Innovative Approaches to Reducing Water Leakages in Industrial Residential Areas: A Case Study

Sheikh Abdul Haseeb Amir[1]*, Arshad Saleem[1], Muhammad Khurram Shahzad[2], Sajjad Ahmad[3]

[1]Fatima Fertilizer Limited Multan, Punjab, Pakistan

[2]Department of Civil Engineering, School of Engineering & Technology, Institute of Southern Punjab, Multan.

[3]Department of Civil Engineering, Faculty of Engineering, Bahauddin Zakariya University, Multan, Punjab, Pakistan.

Abstract. This research aims to identify and address water leakages in residential colonies associated with industrial plants. Through site inspections, maintenance records review, and resident surveys, critical leakage points and their impacts were pinpointed. The study examined piping systems, equipment conditions, structural integrity, and water usage patterns. The primary sources of leaks were identified as aging fixtures, poorly maintained piping systems, equipment malfunctions, structural failures, process wastewater pipelines, air conditioner condensate, and excessive washing machine use. Corroded pipes, faulty valves, and insufficient maintenance were major contributors to water loss. The findings emphasize the need for regular inspections, infrastructure upgrades, automated leak detection systems, and comprehensive employee training to mitigate water wastage and associated costs. These measures can enhance water conservation, improve operational efficiency, and reduce environmental harm. Future research will explore advanced leak detection technologies, sustainable water management practices, and repurposing water from air conditioner condensate to further reduce water loss and enhance resource conservation.

Keywords: Water leakages; Industrial plants; Residential colonies; Leak detection; Water management.

Email address: haseeb.aamir@fatima-group.com,

1. Introduction

Water leakages in industrial environments, including factories and their associated residential colonies, pose significant challenges with far-reaching consequences. These leakages result in the wastage of a critical resource, financial losses, potential environmental harm, and safety hazards. The industrial sector, a major consumer of water in Pakistan, is particularly vulnerable to the detrimental effects of water leakages. Leaks can occur at various points in the water distribution system of the industrial unit, from the initial water supply to its various uses in industrial processes, equipment, and infrastructure.

The implications of unchecked water leakages are profound, affecting not only the operational efficiency and cost-effectiveness of factories but also contributing to broader environmental issues such as water scarcity and pollution. Likewise, the housing colonies have many sources of leakages due to common headers and high-water pressure, which can often damage the underground supply lines, piping networks, and washroom fixtures.

1.1. Problem Statement and Research Objectives

The primary problem addressed in this study is quantifying the magnitude of water leakages in industrial environments and their associated residential colonies. These leakages not only result in the loss of a valuable resource but also pose environmental and safety hazards. The research aims to identify the common sources of these leakages and to develop comprehensive strategies for their mitigation and prevention.

The main objectives of this study are:

i. To investigate the common sources of water leakages in residential colonies linked with industrial plants.
ii. To explore and recommend comprehensive strategies for mitigating and preventing these leakages.
iii. To assess the implications of water leakages on operational efficiency, cost-effectiveness, and environmental sustainability.

1.2. Research Significance

This research is significant because it addresses a critical issue that affects both industrial operations and residential communities. The findings of this study will contribute to the field of sustainable water management by providing insights into the sources and mitigation strategies for water leakages. This study's novelty lies in its comprehensive approach to identifying and addressing water leakages in both industrial and residential settings. By implementing the recommended strategies, industrial sectors and residential communities can achieve improved water management, operational efficiency, and environmental sustainability.

1.3. Literature Review

This literature review examines the existing research on the sources of water leakages in industrial environments and associated residential colonies.

1.4. Piping Systems

Aging or poorly maintained piping systems are a predominant source of water leakages in both factories and residential colonies. These systems experience various forms of degradation over time. Corrosion, especially in metal pipes, gradually weakens the pipes, leading to failure. Joint failures can result from improper installation, thermal expansion and contraction cycles, or mechanical stress (Rajput, 2005). Physical impacts or material fatigue can cause cracks in pipes, leading to significant water losses over time. The consequences of such leakages include direct water loss, damage to equipment and infrastructure near the leak sites, and the promotion of mold growth due to damp conditions, further compromising building integrity and indoor air quality.

1.5. Equipment Malfunctions

Faulty machinery and equipment, such as valves, pumps, and seals, particularly at the pumping and disposal stations of housing colonies, are significant contributors to water leakages. These components are crucial for regulating and directing water flow within industrial processes. Continuous use leads to wear and tear, exacerbated by insufficient preventive and predictive maintenance. Operational errors can also compromise the integrity of these components, resulting in water wastage, production disruptions, and safety hazards (Singh & Sharma, 2014). Regular maintenance schedules are often overlooked or inadequately performed, allowing minor issues to develop into major leaks. The consequences include water wastage, disruptions to production processes, and potential safety hazards for workers.

1.6. Water Leakages in Structural Members and through wastewater pipelines passing through Colonies

Inadequate roofing systems or compromised structural integrity in factory and residential buildings make them susceptible to water ingress during rainfall. Poor design, substandard construction materials, or lack of maintenance can lead to roof leaks. Structural leaks, often harder to detect, can result from ground subsidence, vibrations from heavy machinery, and general wear and tear, causing significant damage to goods, equipment, and infrastructure, and posing safety risks (Allen & Iano, 2019). Water entering through the roof can travel through

walls and ceilings, causing widespread damage within the facility. Structural leaks can lead to significant damage to goods, equipment, and infrastructure, posing safety risks to workers and weakening structural elements over time, potentially leading to catastrophic failures (Crandall & Rainwater, 2009).

The improper management of process wastewater, especially in newly developed housing colonies linked with older ones within industrial areas, is another critical source of water leakages. Leaks from storage tanks, containment systems, and treatment facilities can occur due to structural failures, overflows, or improper handling practices (Metcalf & Eddy, Inc., 2003). These leaks not only result in water wastage but can also cause environmental contamination if hazardous substances are involved. Regular inspection and maintenance of storage tanks and containment systems are necessary to ensure their integrity. Overflows can occur if the capacity of these systems is exceeded, often due to inadequate design or unexpected increases in wastewater volume. Improper handling practices, such as failure to follow protocols for waste disposal and treatment, can also lead to leaks (Kim & Yoon, 2011).

1.7. Water Leakage through Air Conditioner Condensate and Water Losses due to Excessive use of Washing Machines

Air conditioners with a capacity of 1.5 tons can generate approximately 10 liters of water as condensate over a 24-hour period of operation. In a housing society comprising 350 houses with around 800 air conditioners, this results in a significant volume of water leakage per day. These units collectively discharge about 8,000 liters of water daily, assuming 24 hours of operational duration per day. This unmanaged water represents a substantial loss and highlights air conditioners as a notable source of water loss within residential areas. Given the cost of water at PKR 75 per liter, the daily financial impact of this leakage amounts to PKR 600,000. Thus, the continuous operation of air conditioners presents a dual challenge of energy consumption and water wastage, necessitating effective strategies for managing and repurposing this byproduct.

In colonies associated with industrial plants where ample water is available, residents often wash their laundry twice a week and use water in washing machines accordingly. Each cycle consumes approximately 40 to 50 liters of water. This frequent usage is not sustainable, as the water consumed could be better utilized for irrigation purposes, such as watering trees and plants within the community. Encouraging residents to appropriate their washing machine usage as per requirement could significantly decrease water consumption in unnecessary use. By cutting the laundry frequency to half, the water saved can be redirected to support local horticulture efforts, promoting a more sustainable and eco-friendly community.

The reviewed literature identifies several key sources of water leakages in industrial environments and associated residential colonies, including piping systems, equipment malfunctions, roof and structural leaks, and process wastewater pipelines. Each source has unique causes and consequences, ranging from direct water loss and financial costs to environmental contamination and safety hazards. The literature underscores the need for regular maintenance, effective design, and proactive management to mitigate these issues.

However, the existing research has limitations, particularly in the comprehensive understanding of these sources' interactions and the development of integrated mitigation strategies. Additionally, there is a gap in exploring the potential for repurposing leaked water, such as using air conditioner condensate for irrigation, to enhance water sustainability.

2. Research Methodology

The research methodology employed a mixed-methods design, integrating qualitative and quantitative approaches to comprehensively address water leakages in residential colonies associated with industrial plants. This approach was designed to provide a detailed understanding of the sources, impacts, and mitigation strategies for water leakages in these specific settings:

2.1. Qualitative Components

Interviews: In-depth interviews were conducted with key stakeholders, including maintenance personnel, factory managers, and residents. These interviews aimed to gather detailed insights into the sources of water leakages, existing mitigation measures, and challenges faced in addressing these issues.

Observational Studies: Site inspections were performed in the residential colonies to identify visible signs of water leakages, such as damp spots, corroded pipes, and malfunctioning equipment. The condition of piping systems, equipment, and structural components was also assessed.

2.2. Study Focus and Sample Size

The study focused on a residential colony associated with a typical industrial plant. The sample size consisted of 350 residential houses linked with the plant. This sample size ensured a representative analysis of the residential colony's water usage patterns and leakage sources.

2.3. Research Procedure

- ***Site Inspections:*** Comprehensive inspections of the residential colony were conducted to identify and document visible leakage points and potential sources of water loss.
- ***Interviews and Surveys:*** Interviews with stakeholders and surveys distributed to residents gathered qualitative data on their experiences and observations related to water leakages.
- ***Data Collection:*** Quantitative data on water usage and maintenance records were gathered from the residential colony.
- ***Analysis:*** Statistical analysis on the collected data quantified the extent of water leakages and their financial impact.
- ***Mitigation Strategy Development:*** Based on the findings, comprehensive strategies for mitigating and preventing water leakages were developed, considering both technical solutions and behavioral changes.

2.4. Novelty of the Research

This research is novel in its focused and comprehensive approach to addressing water leakages in residential colonies associated with industrial plants. The key innovative aspects include:

- **Focused Analysis:** The study uniquely addresses water leakages in residential colonies specifically linked to industrial plants, a context often overlooked in broader industrial water management studies.
- **Holistic Approach:** The integration of qualitative and quantitative methods provides a holistic understanding of water leakages, combining detailed insights from stakeholder interviews and observational studies with rigorous statistical analysis of water usage data.
- **Detailed Identification:** The research identifies specific sources of water leakages within residential colonies, such as aging infrastructure, equipment malfunctions, and structural failures, and quantifies their impact on water loss, financial costs, and environmental sustainability.
- **Targeted Mitigation Strategies:** The study proposes comprehensive mitigation strategies tailored to the unique needs of residential colonies associated with industrial plants, including regular inspections,

infrastructure upgrades with durable materials, automated leak detection systems, and resident education programs.

- **Sustainability Focus:** The research highlights the potential for sustainable water management practices within residential colonies, such as repurposing water from air conditioner condensate and optimizing water usage to support local horticulture efforts.

By addressing the specific context of residential colonies associated with industrial plants, this research contributes to the field of sustainable water management and offers practical solutions for improving water conservation, operational efficiency, and environmental sustainability in these unique settings.

3. Data Collection and Analysis

The data collection for this study employed a mixed-methods approach, including interviews, direct observations, and surveys, to gather comprehensive information on water leakages in residential colonies associated with industrial plants:

3.1. Interviews

Residents and Maintenance Staff: Structured interviews were conducted with residents of the industrial colonies and maintenance staff of the factory to gather information on the frequency and types of water leakages encountered. The interview questions focused on the most common leak sources, duration of leaks, repair frequency, and perceived impacts.

3.2. Key Personnel

Additional structured interviews were conducted with key personnel, including facility managers and environmental engineers, to gain insights into the underlying causes of water leakages and existing mitigation strategies. The questions were designed to elicit detailed information about maintenance protocols, known problem areas, and effectiveness of current solutions.

3.3. Direct Observations

Visual Inspections: Direct observations were performed to visually inspect the condition of piping systems, equipment, roofs, and structural components. These inspections aimed to identify visible signs of water leakages and assess the overall condition of the infrastructure. The observations were documented using standardized checklists to ensure consistency and reliability.

3.4. Data Analysis

The collected data were analyzed using both qualitative and quantitative techniques:

a. Quantitative Analysis

Statistical Methods: Quantitative data from the interviews and observations were statistically analyzed to measure the extent of water leakages and their financial implications. This included calculating the volume of water lost, estimating associated costs, and analyzing the impact on operational efficiency and environmental sustainability.

Frequency and Impact: The frequency and impact of the water leakages were summarized using descriptive statistics (e.g., frequency of leaks, duration, volume of water lost). Cross-tabulations were used to identify patterns and correlations between different variables (e.g., type of housing and frequency of leaks).

b. Qualitative Analysis

Thematic Analysis: Thematic analysis was used to identify common themes and patterns from the qualitative data obtained through interviews and observations. This analysis helped to uncover recurring issues and insights related to water leakages.

3.5. Limitations of the Methodology

The methodology had several limitations that may impact the results:

- Sample Size: Although diverse, the study's sample size was relatively small, which may limit the generalizability of the findings.
- Self-Reported Data: The reliance on self-reported data in interviews could introduce bias, as respondents might not accurately recall or report their experiences.
- Observational Bias: The observational component, while valuable, was subject to the researchers' interpretations and may not capture all nuances of the water leakage issues.
- Despite these limitations, the mixed-methods approach provided a robust framework for investigating the problem and proposing viable solutions. The combination of qualitative and quantitative data ensured a comprehensive understanding of the sources and impacts of water leakages, enabling the development of targeted mitigation strategies.

4. Results and Discussions

The purpose of this section is to present and discuss the findings of the study on water leakages in industrial environments and associated residential colonies. The study aimed to identify sources of water leakages and evaluate effective control measures. The results are presented in various subsections, each addressing different aspects of the study. This section covers the presentation and analysis of data collected during the study.

4.1. Piping Systems

Aging or poorly maintained piping systems are a predominant source of water leakages. Data collected from periodic inspections revealed multiple instances of corrosion, joint failures, and physical impacts causing significant water losses. Visual assessments, pressure testing, and ultrasonic testing were employed to detect these issues.

Table 1. Inspection findings from piping system

Inspection Method	Number of Issues Detected	Percentage of Total Issues
Visual Assessments	50	40%
Pressure Testing	40	32%
Ultrasonic Testing	35	28%

Fig. 1. Site observations for Underground Piping system leakages

4.2. Equipment Malfunctions

Faulty machinery taps and equipment, particularly valves, pumps, and seals, contributed significantly to water leakages. Insufficient preventive maintenance and operational errors were major factors.

Fig. 2. Site observations for Malfunctioned Water Tap

Table 2. Water losses though Tap leakages in per House (See Annex-A)

Sr#	Losses Condition of water	Losses / day (L)	Losses / month (L)	Price / Ltr. in Pakistan	losses cost per days PKR	Losses cost per Month PKR
1	One drop per second	4.3	130	75	322.50	9,750
2	Two drop per second	14	380	75	1,050.00	28,500
3	Stream Breaking into Drops	91	2650	75	6,825.00	198,750
4	1.6 mm Stream	320	9460	75	24,000.00	709,500
5	2 mm stream	980	29520	75	73,500.00	214,000

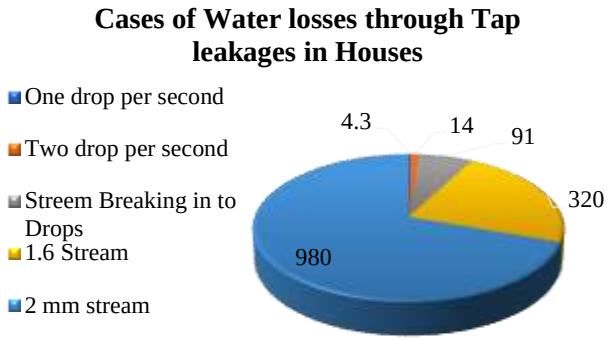

Fig. 3. Cases of Water losses through Tap leakages in Houses

4.3. Roof and Structural Leaks

Inadequate roofing systems and structural integrity issues were identified as significant sources of water ingress during rainfall. Data from structural inspections showed a high incidence of leaks due to poor design, substandard materials, and lack of maintenance.

4.4. Process Wastewater Pipelines

Improper management of process wastewater pipelines led to several leaks, particularly in newly developed housing colonies. Regular inspection and maintenance records indicated that structural failures, overflows, and improper handling practices were prevalent. The bar graph below presents the frequency of these issues.

4.5. Air Conditioner Condensate

The study found that air conditioners produced a substantial volume of condensate water, contributing to water leakage. In a housing society with 350 houses and approximately 800 air conditioners, around 8,000 liters of water were discharged daily. The financial impact of this leakage was significant, amounting to PKR 600,000 per day.

Fig. 4. Site observations for AC water Collection.

4.6. Water Losses from Washing Machines

Frequent use of washing machines resulted in considerable water consumption. Each washing cycle used approximately 40 to 50 liters of water, and residents typically washed laundry twice a week. This subsection presents additional results, focusing on the effectiveness of control measures.

Table 3. The potential water savings from reducing washing machine use

Washing Frequency	Water Used per Cycle (liters)	Total Weekly Water Usage (liters)	Reduced Usage (liters)
Twice Weekly	45	90	45
Once Weekly	45	45	45

4.7. Effective Controls for Water Leakages

Regular Inspections and Maintenance: Implementing a proactive maintenance approach significantly reduced water leakage. Scheduled inspections, including visual assessments, pressure testing, and ultrasonic testing, identified potential weaknesses early. The effectiveness of these measures can be rectified which can be shown in below data of registered complaints.

Table 3. The potential water savings from reducing washing machine use

Sr #	Losses Condition of water	Losses/day (L)	Losses / month (L)	Price / Ltr. in Pakistan	losses cost per days PKR	Losses cost per Month PKR
1	One drop per second	64.5	1950	75	4,838	146,250
2	Two drop per second	210	5700	75	15,750	427,500
3	Stream Breaking in to Drops	1365	39750	75	102,375	2,981,250
4	1.6 Stream	4800	141900	75	360,000	10,642,500
5	2 mm stream	14700	442800	75	1,102,500	33,210,000

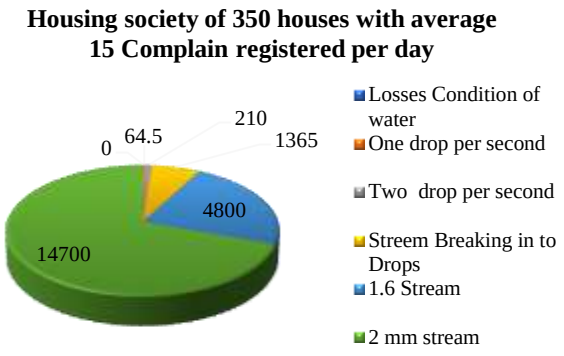

Fig. 5. Housing society of 350 houses with average 15 Complain registered per day

4.8. Investment in Infrastructure

Upgrading aging infrastructure, including replacing old pipes with modern materials and improving roofing systems, showed a marked decrease in water leakages. The chart below illustrates the reduction in leak incidents after infrastructure investments:

Installation of Leak Detection Systems: Automated leak detection systems will enhance the ability to detect and respond to water leakages promptly.

Table 5. Leak detection system and response time

Leak Detection System	Detection Rate	Response Time (minutes)
Acoustic Sensors	95%	5
Pressure Sensors	90%	10
Flow Meters	85%	15

Employee Training and Awareness: Training programs and awareness campaigns significantly improved employees' ability to identify and report leaks. The following bar graph shows the increase in reported leaks after training.

Implementation of Contingency Plans: Developing comprehensive contingency plans for managing water leakages minimized the impact of unforeseen incidents in the industrial units.

Table 6. The effectiveness of plans and their response time (Detailed data has been attached in Annex-A)

Scenario	Response Time (minutes)	Containment Success Rate
Leak in Piping System	10	90%
Equipment Malfunction	15	85%
Roof Leak	20	80%

Use of Air Conditioner Condensate: Repurposing air conditioner condensate for horticultural purposes significantly reduced water wastage. The daily financial impact was reduced from PKR 600,000 to PKR 300,000 by utilizing the condensate water for growing trees.

Water Losses from Washing Machines: Reducing the frequency of washing machine use led to substantial water savings. The community guideline to wash clothes only once a week resulted in halving the water consumption, as illustrated in the previous table.

5. Summary of Key Findings

- Aging piping systems, faulty equipment, inadequate roofing, and poor wastewater management are major sources of water leakages.
- Effective control measures, including regular inspections, infrastructure investments, leak detection systems, employee training, contingency plans, and repurposing water, significantly reduce water leakages.
- Community guidelines and awareness campaigns play a crucial role in promoting sustainable water usage practices.
- The study found that aging infrastructure and insufficient maintenance are primary causes of water leakages. Proactive maintenance, investment in modern materials, and the use of advanced leak detection systems are effective in mitigating these issues. Training and awareness programs are crucial for fostering a culture of vigilance and responsibility among employees.

The findings highlight the need for regular maintenance and infrastructure upgrades to prevent water leakages. Implementing effective control measures can lead to significant cost savings and environmental benefits. The study contributes to the field by providing a comprehensive approach to managing water leakages in industrial environments and associated residential colonies. The results align with previous studies that emphasize the importance of regular maintenance and infrastructure investment in preventing water leakages. However, this study adds to the literature by demonstrating the effectiveness of repurposing air conditioner condensate and reducing washing machine usage.

6. Conclusions

This study investigated various sources of water leakages in industrial environments and associated residential colonies, identifying key issues such as aging piping systems, faulty equipment, inadequate roofing, and poor wastewater management. Effective control measures, including regular inspections and maintenance, infrastructure upgrades, installation of leak detection systems, employee training, and contingency plans, were evaluated. The study also explored the repurposing of air conditioner condensate and reducing washing machine usage to promote sustainable water usage practices. Key findings include:

- Significant water losses were attributed to aging piping systems, faulty machinery, and inadequate structural integrity.
- Proactive maintenance and infrastructure investments markedly reduced leak incidents.
- Automated leak detection systems and employee training programs significantly improved leak detection and response.
- Repurposing air conditioner condensate and reducing washing machine usage led to substantial water and financial savings.

The study's findings are significant in highlighting the multifaceted nature of water leakages in industrial and residential settings. By identifying primary sources of leaks and evaluating effective control measures, the research contributes valuable insights into water conservation strategies. This study enhances the existing body of knowledge by demonstrating the effectiveness of integrating modern technologies, proactive maintenance practices, and community guidelines to mitigate water wastage.

The practical implications of this study are profound, as the implementation of identified control measures can lead to significant cost savings, environmental benefits, and improved operational efficiency. Facilities adopting regular inspections, infrastructure upgrades, and leak

detection systems can expect reduced water wastage and enhanced sustainability. The theoretical implications extend to the field of environmental engineering and management, providing a framework for future studies on water conservation and leak prevention in various settings. The study acknowledges several limitations:

- The reliance on self-reported data from inspections may introduce bias and affect the accuracy of reported leak incidents.
- The scope of the study was limited to specific industrial environments and associated residential colonies, which may affect the generalizability of the findings.
- The study did not account for all potential sources of water leakages, such as underground pipeline leaks, which may require different detection and management approaches.

These limitations suggest the need for more objective measures and expanded sample sizes in future research to enhance the reliability and applicability of the findings.

Based on the study's findings, several areas for future research are suggested:

- Investigate the long-term impact of implementing control measures on water leakages and operational efficiency.
- Explore additional sources of water wastage, such as underground pipeline leaks, and develop specialized detection and management techniques.
- Examine the effectiveness of emerging technologies and materials in preventing water leakages and promoting sustainable water management.
- Conduct comparative studies across different industrial sectors and residential settings to identify best practices and transferable solutions.
- Evaluate the potential of community-based water conservation programs and their impact on overall water usage and sustainability.

These future research directions can build on the current study's findings, contributing to the development of more effective and sustainable water management practices.

Reference

Allen, E., & Iano, J. (2019). Fundamentals of Building Construction: Materials and Methods. Wiley.

Al-Barqawi, H., & Zayed, T. (2006). "Condition Rating Model for Underground Infrastructure Sustainable Water Mains." Journal of Performance of Constructed Facilities, 20(2), 126-135.

Crandall, R. S., & Rainwater, J. (2009). "Roof Leak Detection and Prevention." Journal of Building Appraisal, 5(1), 19-29.

Fiedler, R. (2012). Emergency Planning for Industrial Hazards. CRC Press.

Hunaidi, O., & Giamou, P. (1998). "Ground-Penetrating Radar for Detection of Leaks in Buried Plastic Water Distribution Pipes." Journal of Environmental and Engineering Geophysics, 3(1), 23-32.

Iqbal, A., Zahid, H. A., Zahid, H. A., Aamir, S. A. H., Hussain, A., & Ahmad, S. (2023). Evaluating the Rheological Behavior of Bone-Glue Modified Asphalt. International Journal of Advanced Natural Sciences and Engineering Researches, 7(5), 39–44. https://doi.org/10.59287/ijanser.899.

Kim, S. H., & Yoon, C. G. (2011). "Assessment of Leakage in Urban Sewerage Systems." Water Science and Technology, 64(12), 2484-2491.

Lambert, A., & Taylor, R. (2010). "Estimating the Benefits and Costs of Leakage Management Activities." Water Science and Technology: Water Supply, 10(4), 585-594.

Linsley, R. K., Franzini, J. B., Freyberg, D. L., & Tchobanoglous, G. (1992). Water Resources Engineering. McGraw-Hill Education.

Mathew, R. A., & Fernandez, C. (2012). "Employee Training in Water Management: A Case Study." Journal of Cleaner Production, 30, 114-122.

Metcalf & Eddy, Inc. (2003). Wastewater Engineering: Treatment and Reuse. McGraw-Hill Education.

Montgomery, J. M. (1985). Water Treatment Principles and Design. Wiley-Interscience.

Parker, L. D., & Ritson, P. (2011). Training and Development: Theory and Applications. McGraw-Hill Education.

Rajput, R. K. (2005). Fluid Mechanics and Hydraulic Machines. S. Chand Publishing.

Ratnayaka, D. D., Brandt, M. J., & Johnson, M. (2009). Water Supply. Butterworth-Heinemann.

Singh, A., & Sharma, A. (2014). "Impact of Corrosion on Water Distribution Systems and Its Prevention." Journal of Water Supply: Research and Technology - AQUA, 63(8), 605-612.

Sheikh Abdul Haseeb: Journal of Grey Systems: Theory and Application" Vol 9 No. 3, pp 321-335". https://doi.org/10.1108/GS-01-2019-0002.

Smith, K., & Petley, D. N. (2009). "Environmental Hazards: Assessing Risk and Reducing Disaster." Environmental Hazards, 9(1), 17-25.