SSRG International Journal of Electrical and Electronics Engineering
ISSN: 2348-8379/ https://doi.org/10.14445/23488379/IJEEE-V10I6P103

Volume 10 Issue 6, 23-32, June 2023

Original Article

Probing to Reduce Operational Losses in NRW by using IoT

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Received: 30 March 2023 Revised: 13 May 2023 Accepted: 05 June 2023 Published: 30 June 2023

Abstract - *Water losses in the distribution networks are the significant challenges the urban local bodies face. Distribution of water is costly, making it difficult to meet consumer demands. Utilities encounter a significant challenge in maintaining reasonable and accessible water tariffs because of non-revenue water. Non-revenue water differs between water put into the distribution system and billed to customers. In the region's villages, NRW averages 35% but can go much higher. The recommendation is to improve or optimize the NRW levels in a water utility. Non-revenue water (NRW) is a severe problem affecting many countries worldwide, particularly in developing countries. NRW refers to water lost during distribution due to leaks, theft, meter inaccuracies, and other factors. The loss of this valuable resource not only contributes to the water crisis but also results in significant economic losses. This research paper provides an overview of NRW in major developing countries and focuses on India's situation. It also examines the various policies and action plans initiated by the Indian government to reduce NRW and suggests some recommendations.*

Keywords - *IoT, ILI, LoRa, NRW.*

1. Introduction

Water availability encourages wasteful use, leading to poor conservation. The revenue collected must be sufficient to maintain Operation & Maintenance costs. Water supply schemes to operate effectively, there is now a significant amount of non-revenue water (NRW) in developing countries. The volume of NRW as a share of water produced is the most utilized indicator for calculating NRW.

The need for water is growing daily because of population growth, urbanization, agriculture, industrialization, etc. Due to massive overpumping with strong pumps, the groundwater table is fast declining worldwide. According to assessments by WHO and UNICEF, the globe is experiencing a "Silent Emergency" as billions of people struggle without access to clean water or basic sanitation. Over 40% of the world's population, more than 2.6 billion people, does not have access to clean drinking water [1], [14].

As per the estimation by worldwide bank Non-revenue Water (NRW) costs utilities globally an estimated $14 billion annually. Developing countries are major contributors to this, and reducing the losses by half in developing countries will possibly take around US$ 2.9 billion, which can additionally provide 90 million people. NRW is a global problem that affects many developing countries. According to a report by the World Bank, NRW ranges from 25% to 75% in developing countries, while it is around 15-20% in developed countries. In India, the NRW percentage varies from state to state, ranging from 40% in Uttar Pradesh to 10% in Kerala. NRW is a complex issue that requires a comprehensive approach to tackle it.

To address the issue of NRW, many developing countries have implemented various strategies, such as improving infrastructure, using modern technology, and training staff. For example, in the Philippines, the government has implemented a water loss reduction program that includes installing new pipes and meters, repairing leaks, and replacing old infrastructure. In Indonesia, the government has introduced a policy of converting water loss into revenue by reducing NRW. The policy has been successful in reducing the NRW rate from 40% to 30%.

All states of India have widespread water scarcity [2] and [3]. According to a study by Seureca Consulting Engineers, the components of NRW include between 1.5 and 3.5% public use, between 3.5 and 6.5% illegal/unmetered connections, between 10 and 15% under registered meters, and between 75 and 85% leakages [4], [15], [16].

Table 1. Comparison of India's cities' water utility performance

Measure	Indicator	Jaipur	Bangalore	PCMC
Service Level	Water supply coverage	82 %	94 %	87 %
Asset Maintenance	NRW	50 %	35-40%	40 %
Financial Stability	Recovery of O&M Costs via Tariff	32 %	94 %	70%

In India, the government has also initiated several measures to reduce NRW. The Ministry of Jal Shakti has started the Jal Jeevan Mission, which aims to give all households safe and sufficient drinking water by 2024.

The mission has a focus on the improvement of water supply infrastructure, including reducing NRW. The Indian government has also launched several policies and schemes to tackle the issue of NRW. For instance, basic infrastructure is intended to be provided under the Atal Mission for Rejuvenation and Urban Transformation (AMRUT) programmed services to urban areas, including water supply, and the National Rural Drinking Water Programme (NRDWP) intends to supply rural areas with safe drinking water.

Clean drinking water continues to challenge many water companies in Asia and the Pacific. In Asian cities, problems with water delivery frequently include the sources and usage of raw water, erratic supply, and the quality of tap water at the consumer's end [5], [17]. Since many water utilities in Asia are not accustomed to generating a water balance, knowing how much of a split between physical and business losses is unusual. The other problem is that data on average supply times, average pressure levels, and average service lines are frequently unreported and unknown [6]. As a result, it is virtually impossible to calculate meaningful NRW performance indicators. Under the smart city mission, the Indian government are sponsoring and encouraging many Indian cities' Urban local bodies to adopt advanced technologies like AMI, WNMS etc., to reduce their NRW losses and improve water quality and energy optimization [7].

2. Problem Formulation

When a utility's product results in lost treated water, water collection, treatment, and distribution costs increase while water sales decrease. Water loss, a significant contributor to non-revenue water, has been one of the key issues in managing water utilities worldwide, and it is challenging and critical in developing nations. NRW is produced water that is "lost" before it reaches the customer.

Actual losses and apparent losses are two distinct categories of losses. Actual losses are those brought on by leakage, often known as physical losses. (For instance, because of theft or inaccurate metering).

High levels of NRW negatively impact the water quality and the financial viability of water utilities. Choosing the right course of action to decrease NRW is problematic because it is simply unknown how exactly NRW components and sub-components are broken down in various utilities. Water use measurement at critical points in the distribution network and at the production level (wells, bulk water delivery).

Customer meter under-registration, meter inaccuracy, data handling mistakes, and water theft in various forms are the leading causes of commercial (or apparent) losses.

Unbilled approved consumption includes giving water out for free to specific consumer groups, such as slum regions, or using it for utility functions like extinguishing fires. One of the elements of leakage reduction management solutions is infrastructure management [8], [18]. The most important factor influencing the degree of leakage in any water network is the general state of a water system's mains, service pipes, reservoirs, and other fittings.

3. Different Methodologies

One of the biggest problems for water supply utilities worldwide is non-revenue water (NRW). It refers to water lost before reaching the end consumer, leading to an enormous economic loss for the water supply companies. NRW is a combination of apparent losses, actual losses, and commercial losses. This paper aims to provide an overview of NRW and its different types and explore the technical solutions available to tackle each factor. Moreover, it discusses government actions on NRW and how they can help reduce water loss.

Water is a scarce resource, and it is crucial to conserve it. NRW is the loss of water before it reaches the consumer. It is a significant problem globally and a considerable economic burden on water supply utilities. NRW is made up of commercial losses, genuine losses, and seeming losses. IWA defines NRW as "the difference between the amount of water put into the distribution system and the amount billed to customers." The water that's lost in this difference is classified into the following types:

3.1. Apparent Losses

Apparent losses occur due to metering inaccuracies, data handling errors, and unauthorized consumption. These losses are called apparent as they are caused by factors that affect the apparent consumption of water. Apparent losses account for a significant portion of NRW in many utilities worldwide. The following technical solutions can help reduce apparent losses:

- Regular calibration of meters: Meters should be calibrated regularly to ensure their accuracy.
- Installation of leak detection systems: Leak detection systems can identify leaks and unauthorized consumption.
- Implementation of customer management systems: Customer management systems can help identify and manage unauthorized consumption.

3.2. Real Losses

Actual losses are water losses due to distribution system leaks and bursts. These losses are caused by ageing infrastructure, inadequate maintenance, and high-water pressure. Actual losses are the most significant contributor to NRW in many utilities. The following technical solutions can help reduce actual losses:

- Asset Management: Utilities should regularly inspect their infrastructure to identify and repair leaks and bursts.
- Pressure Management: Utilities should reduce water pressure to minimize the occurrence of leaks and bursts.
- Replacement of Old pipes: Utilities should replace old and corroded pipes to reduce leaks and bursts.

3.3. Commercial Losses

Meter manipulation, unauthorized connections, and invoicing problems can result in commercial losses. These losses are intentional and result in the theft of water. Commercial losses are significant in developing countries and urban slums. The following technical solutions can help reduce commercial losses:

- Installation of tamper-proof meters: Utilities should install tamper-proof meters to prevent meter tampering.
- Implementation of revenue protection teams: Utilities should have revenue protection teams to identify and investigate illegal connections and billing errors.
- Improvement of billing and data management systems: Utilities should improve their billing and data management systems to reduce billing errors.

3.4. Physical Losses

Water treatment plant losses and storage tank leaks cause physical losses. These losses are relatively small and are not significant contributors to NRW in many utilities. The following technical solutions can help reduce physical losses:

- Improvement of water treatment plant operations: Utilities should improve their operations to reduce losses.
- Regular inspections of storage tanks: Utilities should conduct regular inspections of their storage tanks to identify and repair leaks.

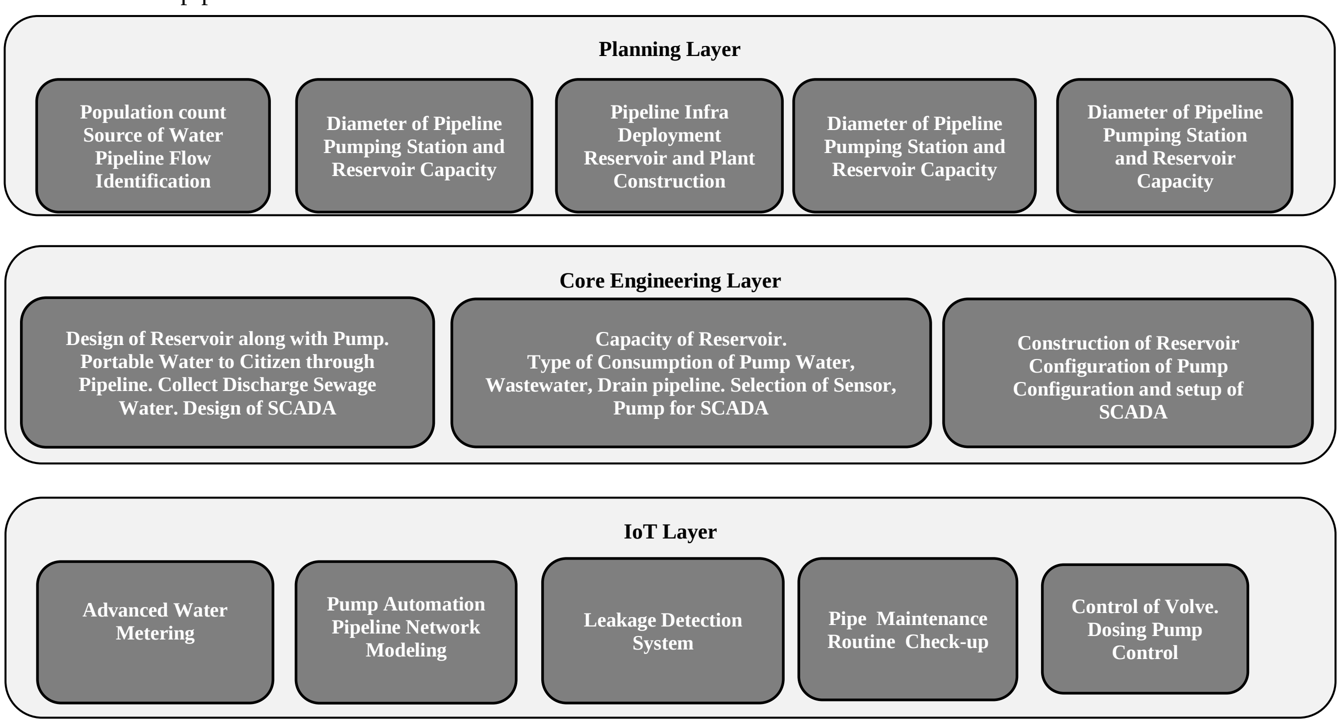

Fig. 1 Layer architecture

4. IoT-Based Layer Architecture for NRW

The planning and Core Engineering Layer is an existing layer, and we are deploying the IoT layer for NRW calculation and optimization. The ioT layer is further divided into four different layers:

4.1. Data Collection Layer

Gather information from flow meters, pressure sensors, GIS maps, customer billing, and SCADA systems. Put the gathered information in a centralised database for processing.

4.2. Data Processing Layer

Statistical models, machine learning techniques, and data visualisation tools are used to process the gathered data. Find trends, patterns, and anomalies that can be used to improve the water distribution system. Create reports and dashboards to share the data's illuminating insights.

4.3. Decision Support Layer

Create simulation models that replicate various scenarios and forecast how interventions affect NRW. Utilize data analytics to assist water utilities, regulators, and stakeholders make decisions.

4.4. Action and Monitoring Layer

Consider taking action, such as mending leaky pipelines or developing customer education programs, based on the insights learned from the preceding levels. Keep an eye on the interventions' success and make any necessary revisions. Continue gathering data to update the models and enhance the precision of the forecasts.

5. Calculation of NRW

The idea of using NRW as an indicator to compare actual losses of water utilities has come under fire as being flawed, mainly since actual losses depend to some extent on factors like topography, network age, network length per connection, and water use per capita, which are mainly outside of the utility's control. It has been developed to use an Infrastructure Leakage Index (ILI) to quantify actual losses more accurately. The definition of the ILI, which considers the three variables, is the difference between avoidable annual actual losses (UARL) and current annual real losses (CARL). NRW is a combination of functions that can address.

Actual losses and apparent losses make up Non-revenue Water (NRW), the difference between the amount of water produced and the amount billed to customers. Actual losses are caused by physical losses like leaks, broken pipes, and overflows, whereas commercial losses like inaccurate metering, unauthorised connections, and incorrect billing bring on apparent losses. A significant performance indicator used to assess the physical state of the water delivery system is the Infrastructure Leaking Index (ILI). It is determined by dividing the length of the leaking pipes by the total length of the network's pipes, and it indicates the proportion of the network's overall leaky length.

The bare minimum level of losses that can happen in a distribution system, even when all the pipes are in good condition and are kept up to date, is known as unavoidable annual actual losses. These losses are due to evaporation, meter inaccuracies, and flushing, and they are calculated based on the network size, pressure, and temperature. The calculated annual actual loss is the entire amount of water lost in a distribution system because of physical losses like leaks, burst pipes, and overflows. It is computed by deducting the total amount of non-revenue water from the actual annual losses that cannot be prevented.

Figure 2 is a flowchart that outlines the calculation of NRW, including the Infrastructure Leaking Index, Unavoidable Annual Real Losses, and Calculated Annual Real Losses. Spatial Asset Management is the combination of Asset Management with Geographical Information Systems. All too often, water utilities look at the System of Engagement (like only the GIS) as the tool to use to analyse the problem rather than getting to the root of the issue related to data registration. The data source is frequently siloed, which contains information on tangible assets, financial losses, ageing and damaged pipe distribution systems, inadequate operations, bad management, and a lack of visibility and systematic asset and activity management.

Enterprise-wide Spatial Asset Management solution to form a complete picture is a must. It is complemented by critical business systems such as ERP (including WFMS), CIS, hydraulic, leak logger or sensors and SCADA.

The reactive process approach is the process that includes different types of data that should be available to calculate NRW correctly. It is a cyclical repeating process that must be constantly executed and monitored.

6. Optimization of NRW

Advanced Water Metering Infrastructure: Smart meters (and related communication modules), a communication network, and AMI back-office information technology (IT) systems are the three main parts of the AMI system. These systems control the two-way communications made possible by AMI.

With Advanced metering infrastructure (AMI), new advanced water meters communicating over RS485, LORA, GPRS etc. are installed, which record the bi-directional water flow and transmit it to the ICCC Meter Data Management System (MDMS) [9, 10, 19, 20]. By implementing Smart Water Metering, considerable improvement was seen in the billing efficiency, thus improving collection efficiency and the massive decrease in OPEX.

Additionally, utilities and customers are receiving real-time information about the patterns of water consumption [9], [19], [20]. This real-time data also facilitates diagnosing faults in the water distribution system. Real-time data also helps understand the current load on the water infrastructure in the local area and thus helps the utilities augment the network in advance, i.e., via new ESR etc.

Water Leakage Detection System: Water loss affects not only the operational procedures but also the utility's financial, social, and environmental aspects, which is why it is a big problem for most water utilities worldwide. Actual (physical losses) and perceived (economic or commercial losses) are two categories for water losses. Actual water losses caused by distribution system leaks, reservoir overflows, washouts, etc., reflect water lost from the network but not utilized. Here, we focus on actual water losses by identifying leaks (or leakages) in transmission and distribution mains, where most network water is physically lost. Physical loss of water shares a significant portion of the NRW losses. Thus it becomes essential to reduce water losses by implementing advanced technologies like the analogy of a Flow meter and Pressure transmitter in the water distribution network. Three main parts comprise a water leakage system: smart sensors (flow meters and pressure transmitters), a communication network, and application software to control the two-way communications made possible by AMI.

According to leakage control practitioners, recent prepositions show that actual losses constantly occur in the system. Unavoidable Annual Real Losses (UARL) are the smallest amount of actual losses per year that are conceivable for a managed system, as represented in Figure 3 & Figure 4; potentially recoverable actual losses set CARL (big rectangle) apart from UARL (small rectangle).

The concept of UARL is helpful because it can reasonably predict the minimum technical annual actual losses for any combination of different parameters, such as mains length, number of connections, and customer meter location at current operating pressures, assuming that the system is kept in good condition, that actual losses are managed with high standards, and that there are no financial or economic constraints.

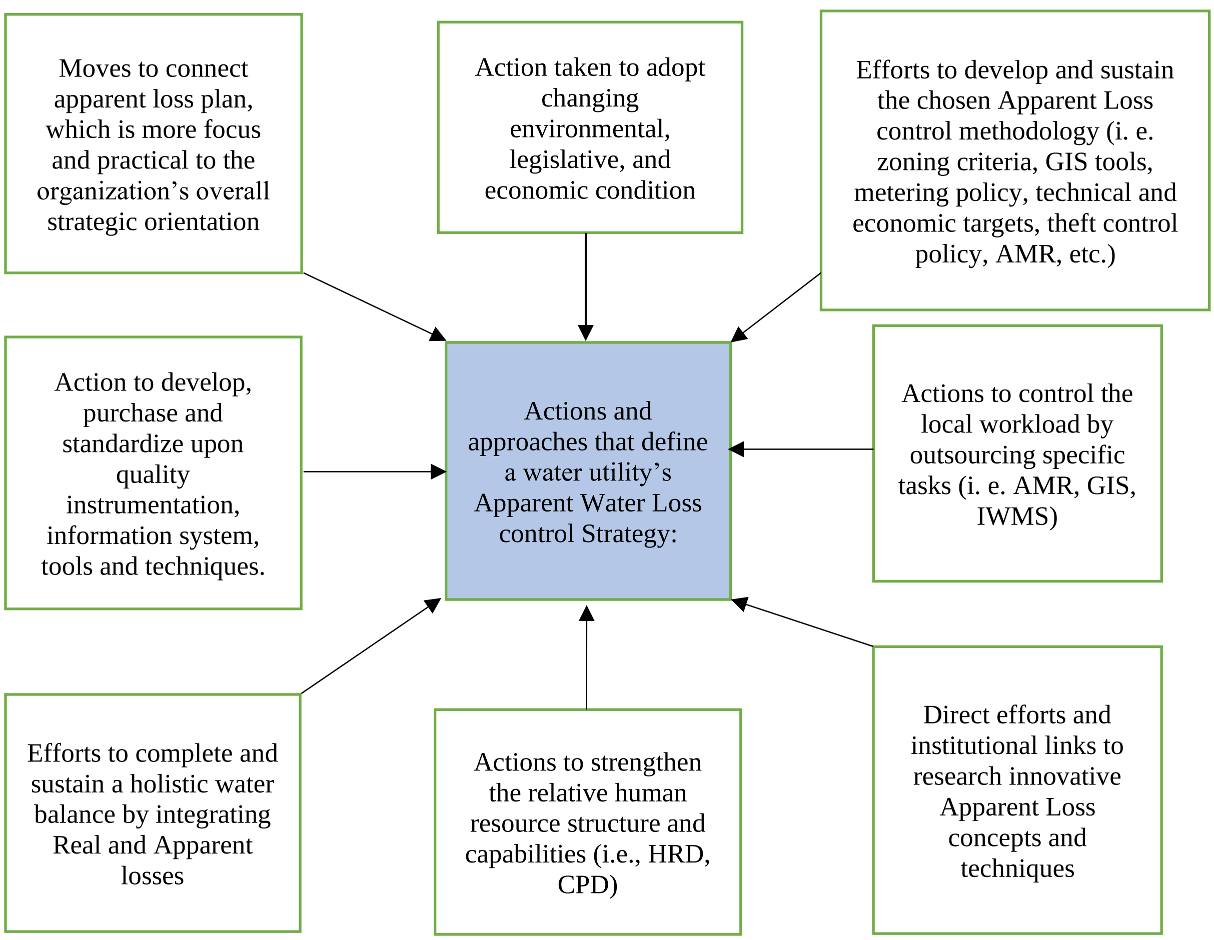

Fig. 2 Optimization of apparent losses

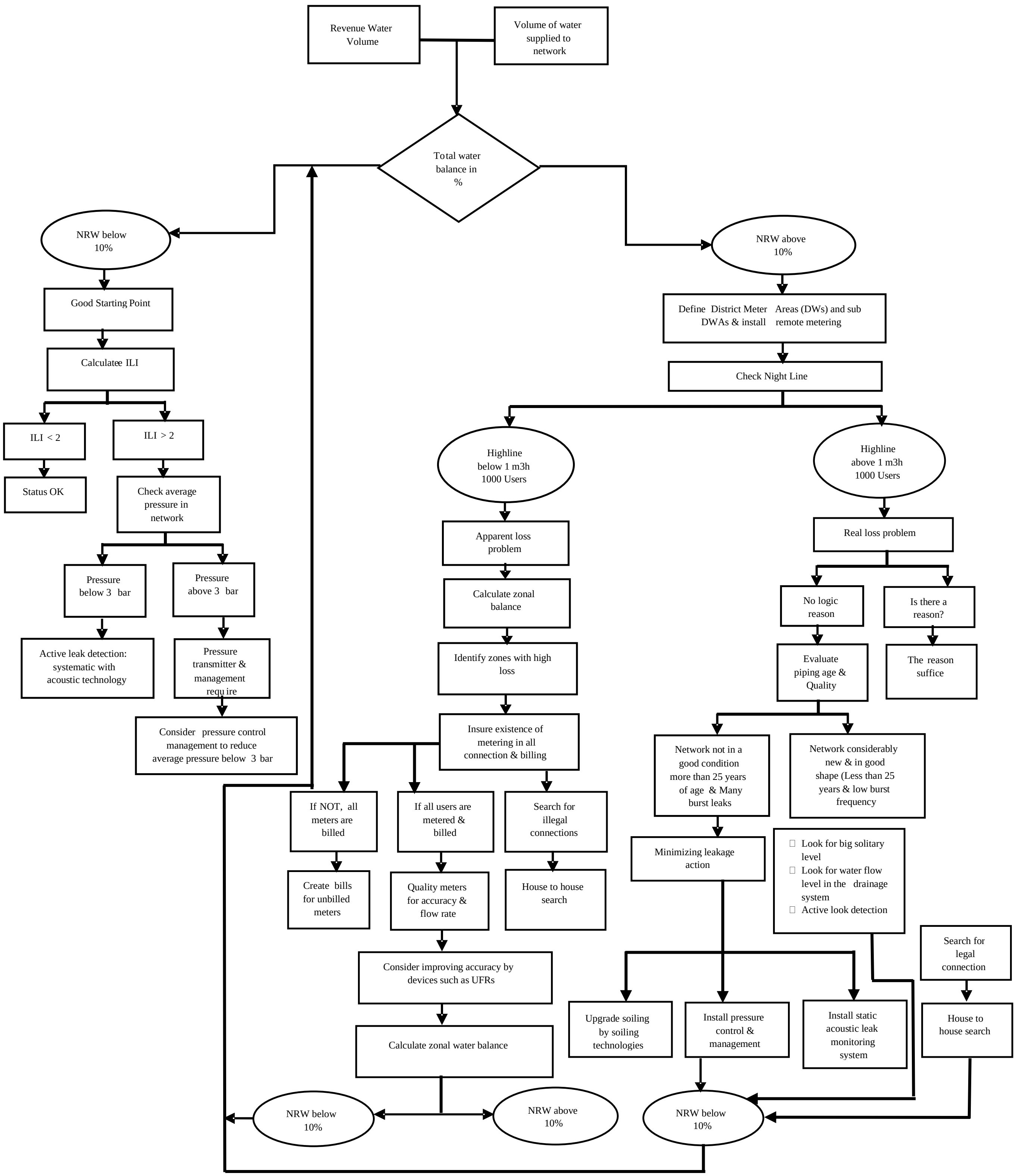

Fig. 3 Process of the proper way to calculate NRW

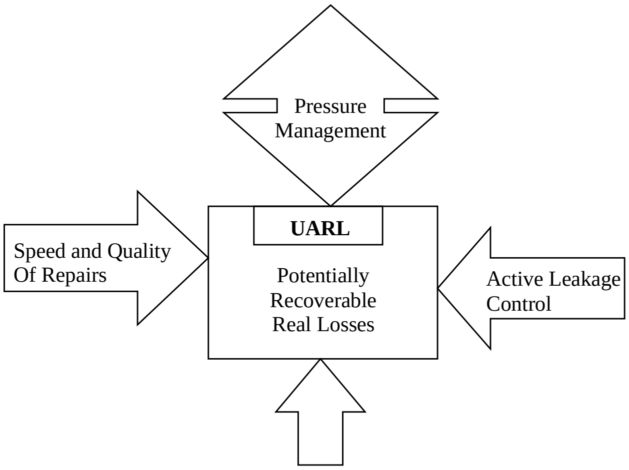

Fig. 4 Optimization of physical losses

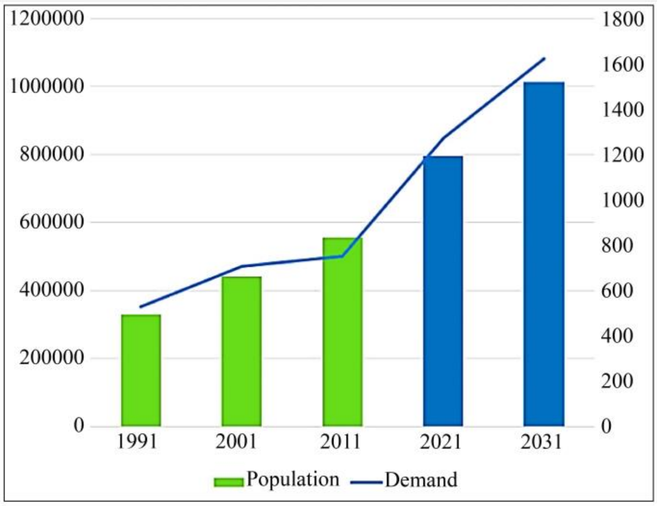

Fig. 5 Population and water demand for ahmedabad

7. Case Study

7.1. Ahmedabad City

Ahmedabad's population is growing, and the city's water needs are also growing. Thus, attention must be paid to expanding new water sources to meet the city's growing needs. Population or to enhance the current water distribution infrastructure by incorporating clever approaches that can cause NRW to drop. Considering the present and future water needs is crucial to understand and prepare for the water demand. We have approximated the water for several decades for this [11], [21], [22].

The graph drawn in Figure 5 demonstrates the main area of worry for Ahmedabad residents. Between 1991 and 2001, there was a rise in water consumption between 2001- 2011, then the rate declined. However, as the population grows in the following years, there is a dramatic increase in water consumption from 2011 to 2031. Ahmedabad's water consumption will significantly increase between 2011 and 2031; this need can be met by either increasing new water sources or minimising illegal tapping or unaccounted water, which helps to optimize the NRW. With an estimated 1623MLD of water needed by 2031 compared to the current average daily supply of 1030MLD, Ahmedabad's population will have severe concerns about water availability [11], [21].

Forty samples were collected from central Ahmedabad neighbourhoods like Kalupur and Maninagar and newly constructed neighbourhoods like SP Stadium and Bokadev. Surveys were carried out.

- How much water does the municipal corporation deliver to these homes each day?
- What sources of water supply are there in these places?
- How much water is provided by underground and OHT reservoirs?
- How long will there be a supply of water?

A bucket survey was carried out in the places previously mentioned to determine the transmission losses and other losses occurring throughout the entire water distribution system. Both the supply and demand end of the process were considered. After evaluating the variables, it was determined that the NRW percentage is at its highest in Ahmedabad's central business district while being at its lowest in the new west zone. The reason could be that the pipeline network in Ahmedabad's historical core was constructed more than 100 to 120 years ago and has not undergone any modifications or additions. In addition, one of the most extensive water treatment facilities, Kotarpur, is situated far from Ahmedabad's historic core, which would have resulted in significant transmission losses [11], [21].

7.2. Chiplun City

A review of earlier studies on water supply improvements and the utilization of essential information to analyse the presently used water supply system in the area of the Chiplun Municipal Council. The area is divided into five zones and 20 administrative wards, and population data has been collected from the census report to determine the demand for water in the area. This information will prepare a development plan for the town of Chiplun [12], [23], [29].

Water demand is essential when preparing a development plan for any municipality. In the case of Chiplun town, the water demand has been determined using various conventional methods as outlined in the Development Plan report. These methods may include population projections, water consumption rates, and estimates of Non-revenue water or the water lost due to leaks, theft, or other factors. By analyzing these factors, planners can determine the current and future demand for water in the area and develop strategies to meet that demand while ensuring the sustainability of the water supply system.

Installing every source and intake of every water district with ultrasonic flow meters (UFMs) is a standard method for measuring the total inflow to a water supply system. These devices use ultrasonic waves to measure the velocity of the water flowing through a pipe, which can then be used to calculate the flow rate and total volume of water passing through the pipe over a given period. It can now precisely measure the total inflow to the system and the inflow to each water district in the Chiplun municipal council area by placing UFMs at each source and inlet of each water district. This information can be used to monitor the performance of the water supply system, identify any leaks or other issues that may be affecting the flow of water, and make adjustments to the system as needed to ensure a reliable and sustainable supply of water to the residents of Chiplun town[12], [23], [30].

Water Used in the Entire System: 13.13 MLD (100%)

Total Water Revenue: 7.58 MLD (58%)

5.55LD (42%) of total non-revenue water

Any water audit procedure must include an analysis of the audit outcomes. This entails identifying recoverable losses, assessing their value, estimating the expense, and putting remedial measures in place. This data is then utilised to create a cost-benefit analysis and an implementation action plan. The results are monitored, and the audit is updated continuously, which is a continuous process. Updating the master plan is also an essential part of this process.

The benefits of conducting a water audit are numerous. One of the most significant benefits is the reduction of water losses, which can lead to significant financial improvement for the water supply system. By identifying and correcting losses, the system becomes more efficient, and the existing supply can be used more effectively.

This, in turn, helps to safeguard public health and safety, improve public relations, and reduce legal liability. Finally, the audit results provide a yardstick for the performance of the operations and maintenance (O&M) team. Overall, conducting a water audit is crucial for guaranteeing the effectiveness and sustainability of a water supply system [12], [23].

7.3. Nagpur City

The city of Nagpur, with a population of 2.35 million, is the second capital of Maharashtra State and is located central region of India. The Nagpur Municipal Corporation (NMC) oversees a 470 mld treated water supply with a yearly budget of roughly 95 crores (expenditure) and just 50 crores in actual revenue. According to the preliminary audit assessment, 50% of the purified water is unaccounted for (UFW), a significant loss for the water supply system.

Three sources of raw water are available to NMC: the Kanhan River headworks at Kamptee, the Pench Right Bank Canal off-take at 48.5 km chainage at Mahadula (PRBC from Pench Dam), and the Gorewada Tank. The NMC purchases roughly 625 mld of raw water from the Gorewada Tank and the Irrigation Department [13], [24-28]. Despite purchasing a sizable volume of raw water, NMC only produces 490 mld of treated water from all its water treatment facilities, which is less than half of their rated 470 mld output. Furthermore, according to billing records, NMC only sells 241 mld of water, significantly less than the amount of treated water generated. This indicates a potential loss of revenue, a need for further investigation into the billing system, and the possibility of water theft or illegal connections.

Overall, the audit report highlights the need for NMC to address the high levels of unaccounted-for water and the potential loss of revenue. This can be achieved by implementing measures to reduce water losses, improving the billing system, and investigating potential illegal connections.

Based on the preliminary audit report, Nagpur Municipal Corporation (NMC) should take immediate action to reduce unaccounted-for water (UFW) and increase revenue. It is advised to take the following course of action, which will have payback duration of under a year:

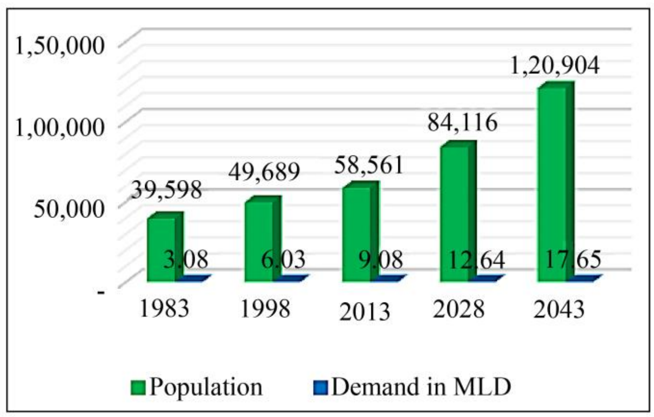

Fig. 6 Population and water demand for chiplun

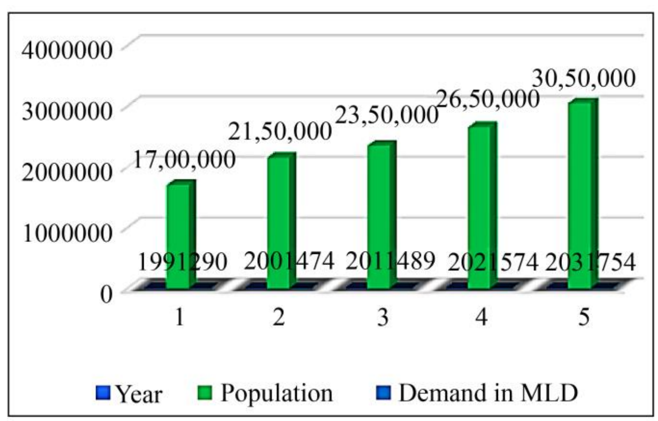

Fig. 7 Population and water demand for nagpur

Replace Canal by Close Conduit Pipe: NMC should replace the canal with a Close conduit pipe used for raw water transfer to conserve 100 to 250 mld at the very least of precious freshwater.

Install Flow Meters: To reduce the cost of raw water by about 20% and to improve accountability of water usage at the zonal and sub-zonal levels, NMC should install flow meters at all raw water, pure water transmission main and ESR/GSR inlets.

Recover Water Losses: The water losses at the WTP's/Gorewada tank should be recovered by NMC to 22 mld or more. Priority should be given to repairing leakages that have been detected and implementing the slum policy for water supply to reduce unauthorised use. By implementing these actions, NMC can reduce UFW, increase revenue, and provide equitable distribution of water while safeguarding public health and the environment [13], [24], [26].

8. Conclusion

NRW is a significant challenge that affects many developing countries, including India. The water loss due to NRW has serious economic, environmental, and social consequences. The issue requires a comprehensive approach to tackle it. The Indian government has launched various policies and schemes to reduce NRW, but there is still a long way to go. The government should invest more in infrastructure, implement new technologies, and promote public awareness to reduce NRW.

Water demand in urbanized India is forecasted to skyrocket from 31% in 2000 to 42% by 2025 and 61% by 2050. This paper highlights the importance of the AMI system for Urban local bodies (ULB) for reducing and maintaining their respective Non-revenue water.

Implementing the AMI system helps manage demand management and thus enhances consumer satisfaction, mitigating system degradation. With AMI, utilities can now predict the new augmentation with the help of real-time data and can revise the water tariff accordingly. Most of the Indian cities under the smart city Mission adopted the AMI technologies for both water and electricity, and its evidential impact in the reduction of losses can be witnessed in their reports.

Acknowledgement

I want to thank my family, especially my wife and children, for their understanding and support. I want to thank my mentor Dr Prakash Devale for encouraging me to write this article based on my 22 years of expertise in the area and for aiding me in various disciplines.

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