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Original Research

Investigating the sustainability of the urban water supply and distribution system in Werabe town, Ethiopia

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Abstract

A reliable water distribution infrastructure is foundational for providing safe and adequate water to urban populations. However, in many emerging regions like Werabe, Ethiopia, these systems often fail to perform due to outdated design and rapid urban expansion. This research evaluates the technical sustainability of Werabe's water supply by examining hydraulic parameters such as nodal pressure and flow velocity. Utilizing tools like WaterGEMS 8Vi and field-based GPS data, the study modeled the existing network's behavior. Findings indicate a peak daily demand of 3,182.87 m³, yet the system exhibits critical failures: 45.76% of pressure points and 81.3% of flow velocities fall outside standard operational limits (15–60m head and 0.6 - 2.0 m/s, respectively). Sustainability metrics further reveal a resilient score of only 0.19 and a high vulnerability of 0.71, highlighting an urgent need for infrastructure rehabilitation to accommodate the town's 4.10% annual growth rate. Further assessment using sustainability metrics yielded low scores for resiliency at 0.19, reliability at 0.28, and vulnerability at 0.71, highlighting significant deficiencies in the system's ability to consistently deliver water under varying conditions. These results emphasize the critical need for comprehensive improvements in Werabe's water supply infrastructure to ensure it can meet current demands and adapt to future growth. Therefore, in this particular study, after checking the sustainability of the existing Werabe water supply system, an appropriate and sustainable water supply distribution system would be redesigned for the proposed town using updated software packages.

Keywords: *Extended period simulation, Pressure, Sustainability, Velocity, Water supply, WaterGEMS 8Vi*

Highlights

- Critical gaps found in Werabe's water distribution.
- Town population expands at a robust annual rate of 4.10%.
- Over half of the system pressure falls outside standard limits.
- Stagnant water risks rise as 91.5% of pipe velocity is too low.
- Non-Revenue Water hits 35%, beating the 20% national benchmark.
- Infrastructure needs a 25-year redesign using WaterGEMS.

1. Introduction

1.1. Background

The provision of reliable and safe potable water has transitioned from a fundamental human requirement to a vital catalyst for public health and regional stability. As of 2024, United Nations data indicates a significant global deficit in meeting Sustainable Development Goal 6 (SDG 6), leaving roughly 2.2 billion individuals without access to secure water resources [1]. This crisis is exacerbated by the combined pressures of rapid urban growth and shifting climates, which have created a 40% imbalance between freshwater availability and community needs. Consequently, the modernization of water distribution networks (WDNs) is now a global imperative to ensure urban infrastructure can withstand these mounting demographic stresses [2].

In Sub-Saharan Africa, these issues are notably severe. Despite the continent's substantial hydrologic potential, over 411 million people face persistent water scarcity [3]. Urban utilities frequently struggle with deteriorating assets, fragmented management, and high levels of Non-Revenue Water (NRW), which often reaches 30% to 60% in major metropolitan areas. These inefficiencies are often linked to a lack of precise hydraulic modeling, which prevents utilities from accurately predicting how geographical expansion affects system pressure and flow rates [4], [5].

Ethiopia, often referred to as the "Water Tower of Africa," epitomizes this paradox of resource abundance versus distribution failure. Despite its vast basins, the country is officially classified as water-stressed, with per capita availability falling below the Falkenmark threshold of 1,700 m³ [6]. Ethiopian urban centers face a double burden: they must manage the impacts of fluctuating rainfall under RCP 8.5 climate scenarios while accommodating an urban population growing at more than twice the rate of infrastructure development [7]. In this context, the technical sustainability of a water system is defined not just by its source, but by its hydraulic integrity the ability to maintain consistent pressure and flow velocity to prevent secondary contamination and physical pipe failure [8].

Werabe Town serves as a critical case study for these overlapping pressures. As a rapidly emerging administrative and commercial hub, Werabe is experiencing a high annual population growth rate of approximately 4.10% [9]. This non-linear expansion, combined with the town's complex topography, renders traditional, static water management approaches insufficient. Current distribution systems are struggling to maintain hydraulic integrity, leading to significant pressure deviations and service interruptions. Understanding the technical sustainability of Werabe's water supply, specifically through hydraulic modeling and reliability metrics, is therefore essential not only for local rehabilitation but also as a blueprint for resilient urban water governance in similar fast-growing secondary cities across the country.

This research takes a closer look at the current state of Werabe's urban water supply and distribution system. By examining technical infrastructure,

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institutional capacity, environmental factors, and social challenges, the study aims to assess how sustainable the system really is and what can be done to strengthen it. The goal is not only to identify weaknesses but also to explore practical solutions that can help Werabe and towns like it build more resilient, inclusive water systems for the future.

2. Methods and materials

2.1. Study area description

The study was conducted in Werabe town, Siltie zone. The town is located in the Siltie Zone of the Central Ethiopia Region. The town has a latitude and longitude of 8°1′N and 38°20′E, respectively, with an elevation of 2,113 meters above sea level and has an average annual temperature of 20 ^{0}C.

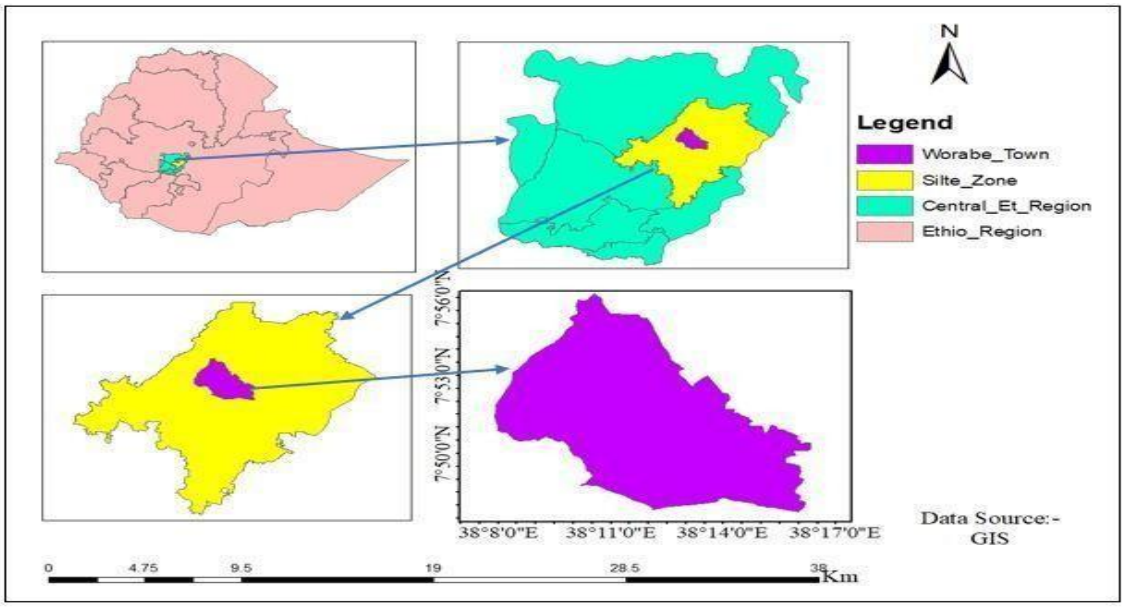

Figure 2. 1. Study area map

2.2. Research framework

To achieve the objectives of the study, a mixed-methods research design was employed, integrating both descriptive and experimental approaches. The primary aim was to assess the sustainability of the existing water supply distribution network in Werabe Town and to experimentally redesign the system using the WaterGEMS 8vi software package. This design combined qualitative insights from community stakeholders with quantitative hydraulic data, thereby providing a comprehensive evaluation of infrastructure performance and service equity.

2.3. Data collection methods

The study employed a dual-phase data collection process involving primary field research and secondary document analysis.

2.3.1 Primary data

The information was gathered through structured household surveys across various neighborhoods to assess consumption patterns and user satisfaction. Additionally, in-depth interviews were conducted with representatives from the Werabe Town Water Supply Office to identify operational bottlenecks.

Household Surveys: Structured questionnaires were administered to a representative sample of households across various neighborhoods. These surveys gathered data on water access, consumption patterns, service reliability, affordability, and user satisfaction.

Key Informant Interviews: In-depth interviews were conducted with officials from the Werabe Town Water Supply Office, local government representatives, and community leaders. These discussions provided insights into operational challenges, governance structures, and policy frameworks.

Field Observations: On-site inspections of water infrastructure, including reservoirs, distribution networks, and water points, were carried out to assess physical conditions and functionality.

2.3.2 Secondary data

To establish a scientifically robust baseline for the hydraulic model, this study integrated secondary data from multiple institutional tiers. This data was essential for calibrating the WaterGEMS 8vi simulation and validating the socio-technical context of the Werabe water system.

In this study, the secondary data were collected from various sources. The temporal data has been collected from the existing documents, annual reports, proclamations, Ethiopian Central Statistical Agency (CSA) reports, and maps that all relevant sources which help with further processing. Thus, the data was from the former Southern Nations, Nationalities and People's Regional State Water and Irrigation Development Bureau, Siltie Zone Water Mine and Energy Department, Department of Siltie Zone Finance and Economy Development, Werabe Town Water Supply and Sewerage Enterprise, Werabe Town Municipality, and Siltie Zone City Administration and Ethiopian Central Statistical Agency.

Document Review: Analysis of existing reports, strategic plans, and performance audits from the Werabe Town Water Supply Office and relevant regional agencies.

Literature Review: Examination of academic studies and policy documents related to urban water supply sustainability in Ethiopia and comparable contexts.

2.4. Sampling techniques

Household Sampling: To get the sampling size of the study, the researchers used a stratified random sampling method to select households across different neighborhoods to ensure representation of various socio-economic groups. The sample size was determined using Yamane's formula (1967), considering a 95% confidence level and a 5% margin of error.

$$n = \frac{N}{1+N(e)^{2}} \quad \text{.....Eq. 2.1}$$

Where n = sample size, N = number of households, population size, e = Margin of error

Key Informants: Purposive sampling identified individuals with extensive knowledge and experience in water supply management and policy implementation within Werabe Town.

2.5. Data analysis

2.5.1. Data analysis tools and techniques

Geospatial mapping was performed using GIS tools to identify service gaps across the town's topography. The core hydraulic simulation was executed using WaterGEMS 8vi software, which allowed for the assessment of nodal pressure, flow velocity, and overall system reliability. Technical sustainability was quantified by measuring the system's ability to maintain operations within the Ministry of Water and Energy (MOWE) standards (15–60m pressure and 0.6–2.0 m/s velocity).

Qualitative data: Thematic analysis was applied to interview transcripts and open-ended survey responses to identify recurring patterns and insights.

Geospatial analysis: Geographic Information System (GIS) tools were utilized to map the spatial distribution of water infrastructure and identify service coverage gaps.

Hydraulic modeling: WaterGEMS 8vi software facilitated the simulation of the water distribution network, assessing parameters such as pressure, flow velocity, and system reliability.

2.5.2. Analysis of sustainability indicator parameters

To measure the technical sustainability of an urban WDS, the performance criteria are Reliability, Resiliency, and Vulnerability [1]. A water-resilient town was well organized to conquer the challenges associated with both too little and too much water; even in the face of crises, water-resilient towns should be adopted to recover quickly. The description of reliability, resiliency, and vulnerability will be as follows.

Reliability: This measures the system's ability to consistently meet water demand. In Werabe Town, the reliability values for pressure and velocity were found to be 0.725 and 0.141, respectively, indicating variability in system performance.

Resilience: Resilience assesses the system's capacity to recover from failures. Werabe's water supply system exhibited resilience values of 0.39 for pressure and 0.06 for velocity, suggesting limited recovery capabilities.

Vulnerability: This indicates the system's susceptibility to failures. High vulnerability values, such as 0.253 for pressure and 0.548 for velocity in Werabe, reflect significant risks in maintaining consistent service.

Resiliency (RES) describes how fast the water supply system recovers from a failure [2].

$$RESx = \frac{\sum \text{Effective value succeeds in-effective}}{\sum \text{all in-effective values}} * 100 \ldots\ldots\ldots\ldots \text{Eq. 2.2}$$

Where: RES represents the sustainability performance indicator parameter of resiliency, and the suffix 'x' is the hydraulic performances, such as pressure, velocity, to determine sustainability.

Investigation of vulnerability would be the method of evaluating susceptibility and/or weakness to express the severity of dissatisfactions of water supply system. Vulnerability (VUL) stands for the magnitude or duration of an unacceptable state of a water distribution system (WDS). Hence Vulnerability is formulated as follows:

$$VULz = \frac{\sum_{i=1}^{n} \text{impermissible Value}}{\sum_{i=1}^{n} \text{all counts}} * 100 \ldots\ldots\ldots\ldots\ldots \text{Eq. 2.3}$$

Where: VUL signifies that the sustainability performance indicator parameter of vulnerability, and the suffix z is the hydraulic performances (pressure, velocity) to determine the sustainability.

Kay (2000) emphasized the performance of a water system with respect to predetermined thresholds of a satisfactory state.

The SI definition proposed by Sandoval-Solis et al. (2010) is used to calculate the SI for WDSs (eq. 2).

$$SIK, = (RELK * RESK * (1 - VULK)^{\frac{1}{3}}) \ldots\ldots \text{Eq. 2.4}$$

Table 1. Determination of sustainability with the sustainability index (SI)

Sustainability index range	Sustainability state
$0 \leq SI < 0.25$	Unacceptable
$0.25 \leq SI < 0.5$	Medium but Unacceptable
$0.5 \leq SI \leq 1$	Acceptable

Source: Sustainability Index and Integrated Water Resources Management (2017)

2.6. Sustainability index for urban water distribution network

The study adopted a multi-dimensional sustainability assessment framework encompassing technical, institutional, and social indicators

Technical indicators: Evaluation of system performance metrics, including pressure adequacy, flow velocity, and infrastructure condition.

Institutional indicators: Assessment of governance structures, policy implementation efficacy, and stakeholder coordination.

Social indicators: Analysis of user satisfaction levels, affordability, and equity in service provision.

The sustainability index in terms of pressure and velocity for each zone was calculated by accumulating the entire SI of the corresponding nodes. Then, for each zone, sustainability indices in terms of pressure and velocity have been combined in order to produce one overall score in order to identify problematic locations of the area (Table 2). Then, technical sustainability assessments would be completed by aggregating the sustainability indices of all zones into one score, which represents the overall technical sustainability in terms of nodal pressure and velocity for the entire network.

Table 2. Pressure and velocity standard

Range	Pressure (m)		Velocity (m/s)
	Normal conditions	Exceptional conditions	
Minimum	15	10	0.6
Maximum	60	70	2

Sources: (MOWE, 2006)

The overall study design is presented in the figure 2 below.

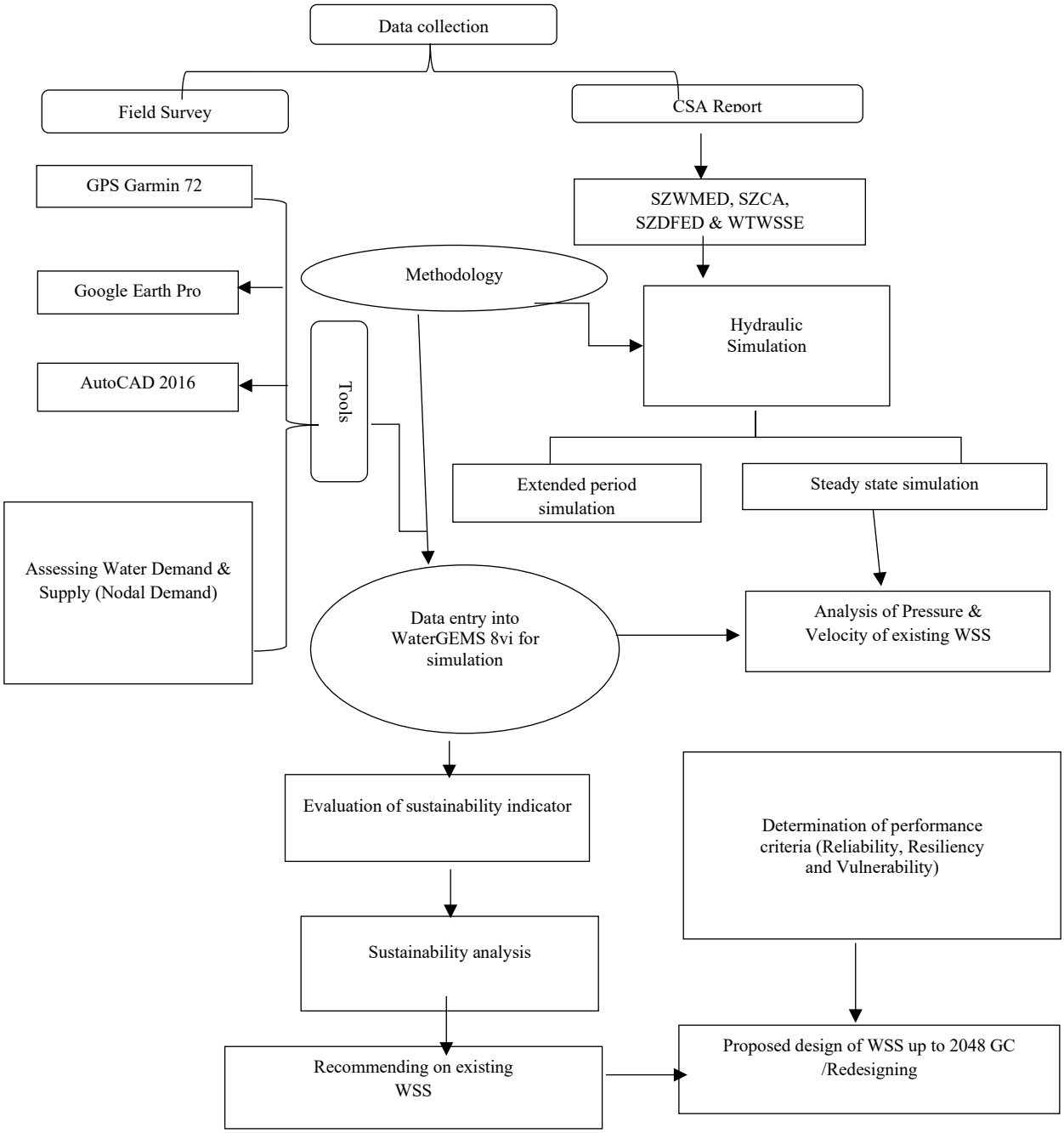

Figure 2. Study design flow

3. Results and Discussions

In this section, the findings from our investigation of Werabe Town's urban water supply and distribution system. Our analysis focuses on several key aspects like the adequacy of water availability, the resilience and functionality of infrastructure, the extent of service coverage, and the level of community satisfaction. By interpreting these results, we aim to understand the current state of the water distribution system and its capacity to meet the growing demands of the town. We also compare our findings with existing studies and standards to highlight areas of success and identify opportunities for improvement. This discussion not only sheds light on the effectiveness of the current system but also provides insights into potential strategies for enhancing its sustainability in the face of urban growth.

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3.1. Socio-demographic result

Table 3 indicates that there are about 55 (41.4%) and 78 (58.6%) male and female respondents out of the entire sampled population. Among all respondents, there is a higher proportion of females. Nonetheless, the fact that women handle the majority of domestic duties is advantageous for the study. They are better positioned to offer information about water consumption and domestic water supply. Such as when using water for personal hygiene, bathing, and laundry regularly.

Table 3. Background of the respondents

S. No	Variable	Categories	Number of respondents	Percentage of respondents
	Sex of respondents	Male	55	41.4
		Female	78	58.6
		Total	133	100.0
2	Age structure of the respondents	20-30	20	15.0
		31-40	48	36.1
		41-50	52	39.1
		51 and above	13	15.1
		Total	133	100.0

Source: Field survey, 2024

3.2. Sources of water for households

The two primary water sources used by the people of Werabe town for water collection are piped and/or non-piped systems. The most trustworthy and safest sources of water are pipeline supplies. In other words, unprotected and dangerous non-piped systems include springs, groundwater, and other unprotected sources. Six boreholes provide the residents with piped water; some of the boreholes are not operational. Not every water user has a steady and consistent supply of water. As a result, the homes used water from communal supplies, springs, private and public taps, and water sellers. Due to concerns about a potential scarcity of water, other water sources were utilized to deliver water through distinct systems, as illustrated in Figure 3 below.

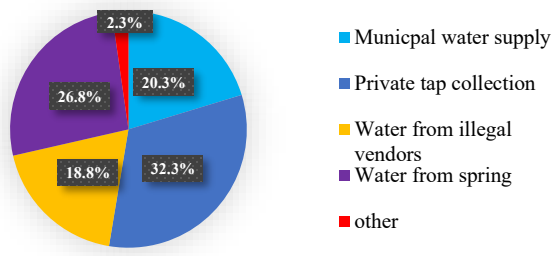

Figure 3. Sources of water for households (Source: Field Survey, 2024)

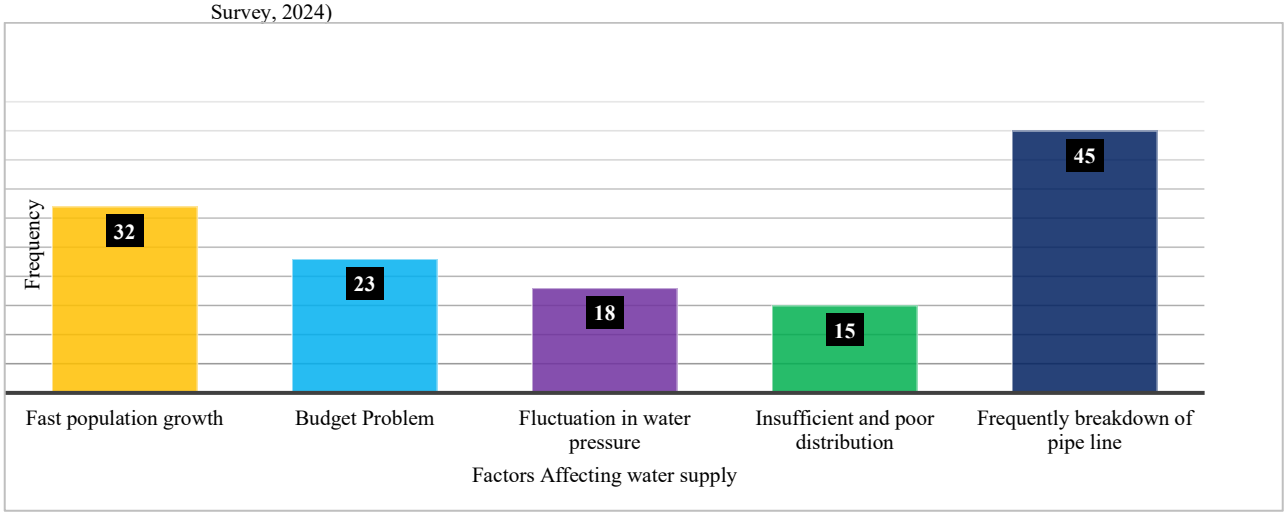

Figure 4. The percentage of causes of water shortage for households (Source: Field survey, 2024)

As illustrated in Figure 4, the majority of respondents expressed that frequent breakdown of pipeline, population size, and budget problems were the main causes for shortages of water supply services in the study area. In line with this, many issues were raised during field observation from residents of the town, among this; mostly lack of water supply, the lack of awareness by government agencies, and the municipality's problems were causes for the shortage of water in the town.

Approximately 50% of the participants do not have access to either private or public water sources, based on the field survey conducted. It was assumed by families in the sample that they used the municipal water supply because it was difficult to obtain a private tap connection. Because of the cost of the connection and the administration problems of the water supply and sewerage service (WSSS), the system of the pipeline is old access to water for domestic chores. Thus, the residents choose or prefer to use a different source. The officers of the WSSS have provided comprehensive information indicating that the town's water supply issues stem from various causes.

3.3. Causes for water shortage in the town

The results of the questionnaire and interview revealed that the community's water usage traditions, rapid population increase, urbanization, and economic development are the main causes of the water scarcity in the research area. Especially, urban population expansion means that maintaining the current water supply is an enormous task. As the population grows beyond the designated capacity, the amount of water supplied per person decreases. This requires the construction of new water supply sources that need significant long-term expenditures or the extension of the current water supply service infrastructure.

3.4. Demographic projection and population forecasting

3.4.1. Rationale for geometric increase methodology

A sustainable water distribution design relies heavily on precise population forecasting. For the current study, the demographic expansion of Werabe Town was modeled over a 20-year horizon using the Geometric Increase Method. While arithmetic models are often suitable for established cities with stable growth, they frequently underestimate the requirements of emerging urban centers. The geometric approach was selected because Werabe is currently a high-growth administrative and commercial hub for the Silte Zone. This

growth is non-linear, driven by significant inward migration and expanding regional infrastructure.

The geometric method was specifically selected because Werabe Town is currently in a high-growth phase, functioning as a primary administrative and commercial hub for the Silte Zone. This growth is not merely linear; it is driven by compounding factors, including high inward migration from surrounding rural districts and expanding economic infrastructure. According to the Central Statistical Agency (CSA), the town maintains a significant annual growth rate of 4.10%.

By employing the geometric model, this study accounts for the "interest-on-interest" nature of population expansion in emerging Ethiopian cities, where a larger base population leads to proportionally higher subsequent growth.

3.4.2. Population growth trends

Data from the Central Statistical Agency (CSA) confirms that Werabe maintains a robust annual growth rate of 4.10%. By applying the geometric model, this research accounts for the compounding nature of urban expansion

Table 4. Population forecasting of Werabe town

Year (G.C)	2007	2016	2023	2028	2033	2038	2043	2048
Annual growth rate %	4.10	3.90	3.70	3.50	3.35	3.10	2.90	2.70
Population	30,893	43,592	55,249	73,007	83,018	89,932	96,934	102,455

As Table 4 illustrates, within the next 25 years, the town's population will nearly double, necessitating the immediate reservoir expansions and hydraulic upgrades discussed in the subsequent sections of this report.

3.5. Evaluation of water demand and supply system

The Empirical data gathered from both primary field surveys and institutional records revealed a significant discrepancy between Werabe's water availability and its population's water demand. The water supply distribution network is currently hindered by a convergence of technical and structural problems. Among the key problems are the town's challenging topographic gradients and an archaic piping infrastructure that fails to provide comprehensive coverage. The situation has been further complicated by a lack of continuity across various international and domestic consulting efforts, which often resulted in complex but unfulfilled design targets. Furthermore, the system is plagued by recurring electrical instability and the use of substandard or aging pipe materials.

Regardless of these infrastructure bottlenecks, the raw supply potential at the source remains theoretically robust. The four existing boreholes maintain a collective safe yield of 90 l/sec, which exceeds the planned pumping discharge of 49.2 l/sec. Under optimal conditions with an 18-hour daily operational window, the system can deliver a total volume of 3194.64 m³/day to the storage facilities.

However, the reliability of this supply is heavily dictated by the energy landscape. While three sources remain vulnerable to frequent water supply network failures, two boreholes (BH-3 and BH-4) are equipped with standby generators. These dual-powered sources contribute 22 l/sec during power outages, ensuring that approximately 1109 m³/day reaches the storage tanks during the typical 14-hour blackout periods. While this backup capacity provides a vital lifeline, it still represents a substantial deficit, effectively a loss of 24.14 l/sec or 2085.64 m³/day compared to full grid operation, further validating the system's current state of technical fragility.

The maximum daily water consumption for Werabe town was calculated to be 3182873.4 l/day, or 3182.88 m^3/day, and was estimated as follows:

Reservoir Capacity=($\frac{1}{3}$*maximum daily demand)…. Eq. 3.1

Reservoir Capacity=($\frac{1}{3}$*3182.88m^3/day)=1060.96 m^3/d

in Ethiopia, where an increasing population base leads to higher subsequent growth increments. This ensures that the projected peak daily water requirement of 3,182.87 m³ serves as a resilient benchmark for future infrastructure capacity.

One of the main factors that affects the accuracy of water demand estimation is the population growth trend of the project area. The CSA (2007) census data of the study area shows that the current population of Werabe town, based on the periodic annual zonal report, clearly shows that, in 2016, it was 43,592 and in 2023 it is 55,249. Therefore, by using the geometric increase population forecasting method parameters, the future population was projected up to the design period and tabulated as follows.

Pn = Po(1+k)^n……Eq. 3.1

Where: 'P_n' is the number of population at the nth year, 'P_o' is the number of population at the initial year, 'K' is the geometric growth rate, and 'n' represents the number of decades.

Thus, in order to meet the current water demands of Werabe Town, the clear water service reservoir was sized with a standard reservoir capacity of 1,100 m^3. However, Werabe Town's current water supply system consists of four service reservoirs: Zone 1, Zone 2, Zone 3, and Zone 4. Each has a capacity of 100 m^3, 100 m^3, 200 m^3, and 300 m^3, accumulation of 700 m^3. It is clear from the town's current (2017) water use that the capacity of its previous reservoirs was much lower, which could be one of the primary reasons for the town's ongoing alternating water distribution. According to this analysis, Werabe Town's water needs exceed the reservoir's current capacity. Therefore, in order to offer a suitable supply of water, the 400 m^3 additional reservoir should be constructed while considering all areas of the town. It is also possible to integrate the 700 m^3 existing reservoirs into the system.

3.6. A computerized model representation of the current water distribution network

3.6.1. Hydraulic performance evaluation

One of the most critical technical barriers to the sustainability of Werabe's water system is the high level of Non-Revenue Water (NRW). For this study, the NRW was determined by performing a water balance audit, comparing the total volume of water produced from the town's four operational boreholes monitored via bulk flow meters against the total billed consumption recorded by the Werabe Town Water Utility over the last fiscal year.

The analysis reveals an estimated NRW rate of 35%. This figure is particularly concerning when measured against national standards; it significantly exceeds the 20% benchmark recommended by the Ethiopian Ministry of Water and Energy (MoWE) for urban utilities of this scale. In practical terms, this means that more than one-third of the treated water is lost to physical leaks (real losses) or commercial inaccuracies (apparent losses) before it reaches the consumer.

This disparity highlights an urgent need to transition from traditional reactive maintenance to proactive asset management. The integration of digitalization, such as GIS-mapped pipeline networks and smart acoustic leak detection, is no longer a luxury but a necessity for Werabe. By digitizing the utility's physical assets, the town can move toward a "Smart Water" framework, allowing for real-time monitoring of pressure surges that lead to bursts, thereby reducing water loss and ensuring the long-term hydraulic and financial viability of the distribution system.

Pressure Analysis: The WaterGEMS simulation revealed that a significant portion of Werabe Town's water distribution network operates outside the

recommended pressure ranges. Specifically, only about 60% of the nodes-maintained pressures within the acceptable range of 15 – 60 meters, while the remaining nodes experienced pressures either below 15 meters or above 60 meters. Such deviations can lead to inadequate water supply in low-pressure zones and potential pipe bursts in high-pressure areas. Similar issues have been observed in towns like Assosa, where 21.05% of nodes had pressures below 15 meters, indicating a common challenge in maintaining optimal pressure levels in Ethiopian urban water systems.

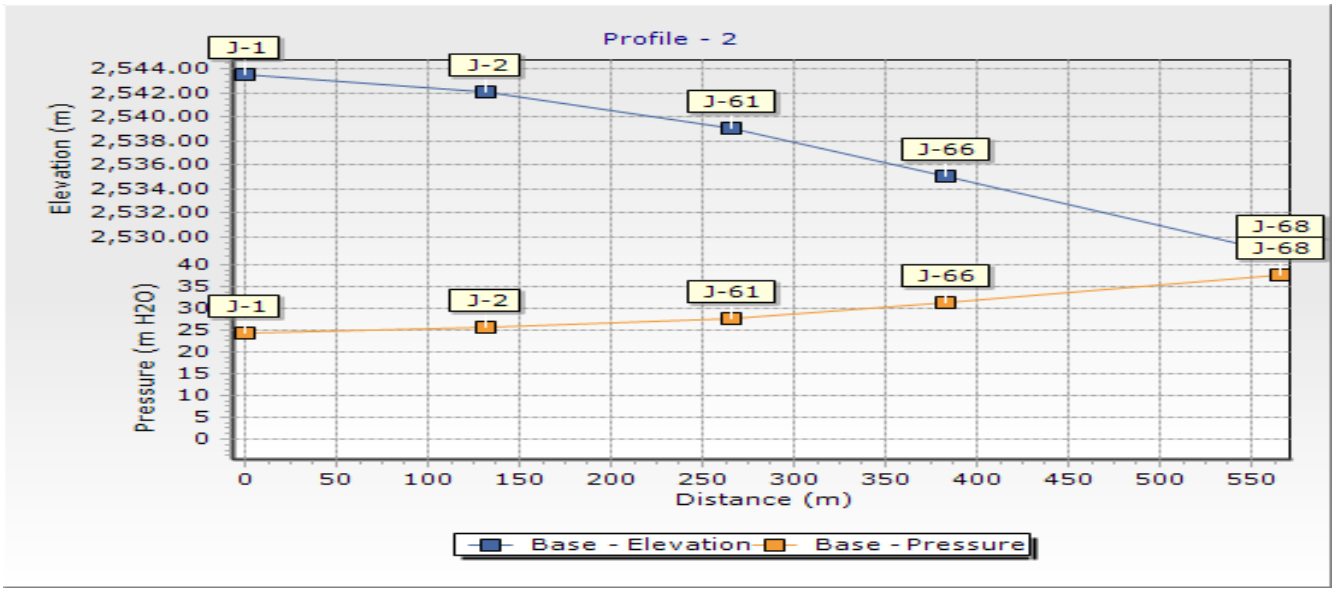

Figure 5. The relationship of elevation with pressure in Werabe town water distribution system

The analysis of the study indicates that pressure ranges fully satisfy the minimum and maximum requirements of Ethiopian urban water supply design guidelines. As elevation decreased, pressure increased and vice versa. The study's findings indicate that low-elevation places had high pressure. By gathering samples from the water supply connectors, the inverse relationship between elevation and pressure is observed (Figure 5). The contour map shows that the pressure decreases from right to left. This decline shows that the ground's elevation rises from right to left.

Velocity analysis: The analysis of the study indicated that approximately 85% of the pipes in Werabe's distribution network had flow velocities below the minimum recommended threshold of 0.6 m/s. Low velocities can result in sedimentation and deterioration of water quality. This challenge is not unique to Werabe; for instance, in Debre Tabor Town, 86.7% of the pipes exhibited velocities below 0.6 m/s, leading to concerns about water quality and system efficiency.

Water loss assessment: The study estimated Werabe Town's Non-Revenue Water (NRW) at approximately 35%, which is significantly higher than the acceptable limit of 20%. This high NRW indicates substantial water losses due to leaks, unauthorized consumption, and metering inaccuracies. In comparison, Muke Turi Town reported an NRW of 37.61%, highlighting a widespread issue of water loss in Ethiopian urban centers.

3.6.2. Hydraulic model analysis

Using surveyed data on pipeline elevation, pipe size, material type, and other relevant criteria, the water supply network is constructed and analyzed using Water GEMS Vi8 software. Elevation, demand, length, pipe size, and material type are all inputs into the model; pressure at each junction and pipe velocity are outputs. The number of residential, business, and public users at each intersection is counted to determine the overall water demand. The town's peak demand periods are from 8:00 AM to 10:00 AM and from 5:00 PM to 8:00 PM, according to the Werabe local water supply office.

The MOWR (2014) design handbook states that the maximum day factor and peak hour factor are determined by the population size. As a result, Werabe town's MDF and PHF are 1.25 and 1.9, respectively. Furthermore, Werabe town has a great deal of development potential. Therefore, the peak hour factor increased to 1.9 by using 1.00 adjustment factors.

3.6.3. Simulation analysis

The existing water supply system of Werabe town was simulated by using WaterGEMS V8i to model the current year's daily average water demand at temporal variation with different scenarios.

3.6.4. Investigation of steady state simulation

This study performed a steady state simulation investigation for average daily water demand, which was the demand at every junction that does not change over an hour. Thus, the simulation was necessitated to run a single period at the commencement of the simulation, to be observed by the model under snap shot situation [3].

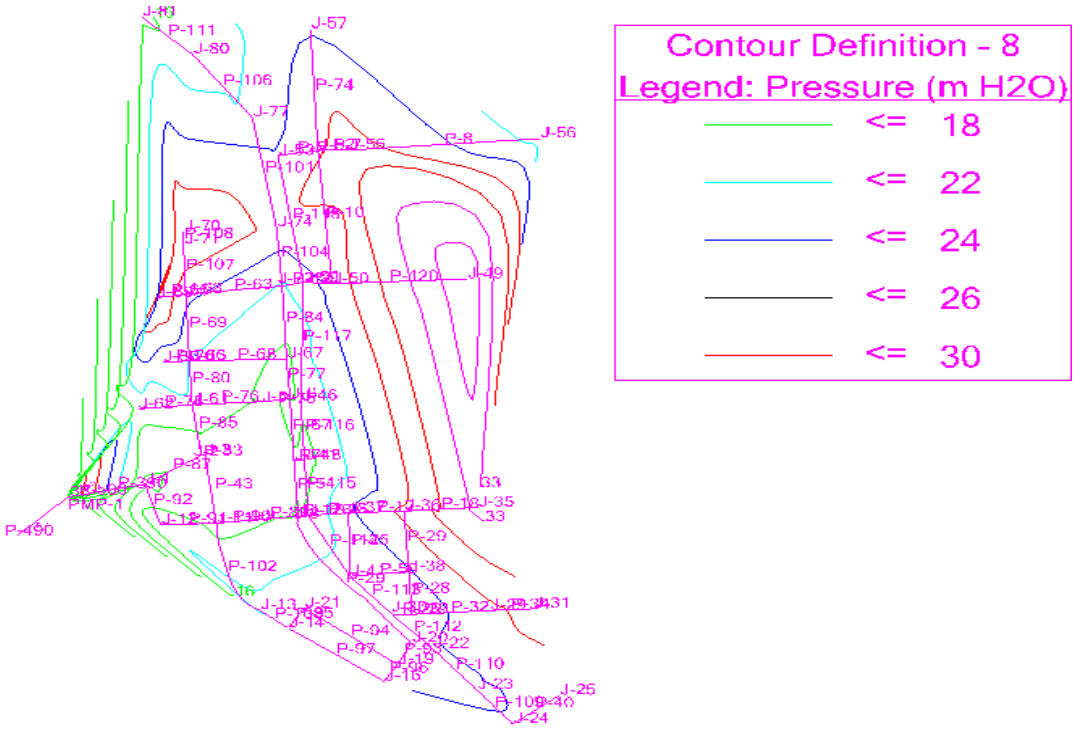

Figure 6. Contour of pressure for Werabe Town water supply

3.7. Synthesis of hydraulic findings

The empirical data from the Werabe network reveal a stark contrast between design intent and operational reality. While the theoretical capacity of the source is substantial, the actual delivery is hindered by a 360.96 m^3 storage gap. This deficit is not merely a numerical shortfall but a systemic failure that compromises the "Reliability" of the town's water access. With a reliability index of only 0.28, the network is essentially failing to provide consistent service for more than 70% of its operational cycle. Furthermore, the prevalence of low-flow velocities (81.3% failing the 0.6 m/s threshold) suggests that the current pipe diameters may be oversized for the current pressure regimes, leading to potential stagnant water zones and quality degradation.

The indexes were computed by reliability, vulnerability and resilience values. As shown in Table 5 the velocity was more susceptible than pressure according to the simulation done by the WaterGEMS 8vi software package as a result of reliability, vulnerability and resilience calculated pressure and velocity were computed.

Table 5. Performance indicators for Werabe Town

	Pressure	Velocity	Average
Vulnerability	0.045	0.074	0.059
Reliability	0.92	0.015	0.47
Resiliency	0.75	0.015	0.38

3.8. Sustainability Analysis

Based on velocity, the sustainability indicator was an unacceptable value, which was 0.061, but most junctions were in the normal pressure range. The overall sustainability was undesirable; the value was 0.46. The Sustainability indexes of the distribution system were classified as unacceptable, medium, but unacceptable and acceptable based on SI.

According to the classification, the overall sustainability index was 0.46, but 0.061 for velocity and 0.86 for pressure. The Overall sustainability index was computed by taking the average value of the velocity sustainability index and the pressure sustainability index. Water should be sustainable if it serves enough amount of water to the customer with appropriate water quality standards. However, in the case of the study area, the amount of water supplied to the consumers was much lower than the amount of water needed by consumers.

3.7.1. Redesign the determination of the demand and supply system of Werabe town

One of the basic concerns for the investigation of any water supply system is the provision of a safe and adequate quantity of good quality water to the community by overcoming some altering factors [2]. According to the Werabe town redesign system, the demand allocation at each junction was based on considering the future population up to the next 25 years. Due to different altering factors like topography of the Werabe town, demography, socio-economic condition, exponential expansion of the town, and recent expansion of governmental huge institutions, the demand system of the town. Therefore, considering different situations, the current water demand of 48.5 l/sec is advanced to the peak hour demand of 138.65 l/sec of the design period of 2048 through WaterGEMS V8i simulation analysis.

The demand distribution is in accordance with topography differences and the area in which the community is populated, and other concerning factors are considered during simulation analysis. Figure 7 illustrates the distribution network of the water supply system for Werabe town for the next 25 years.

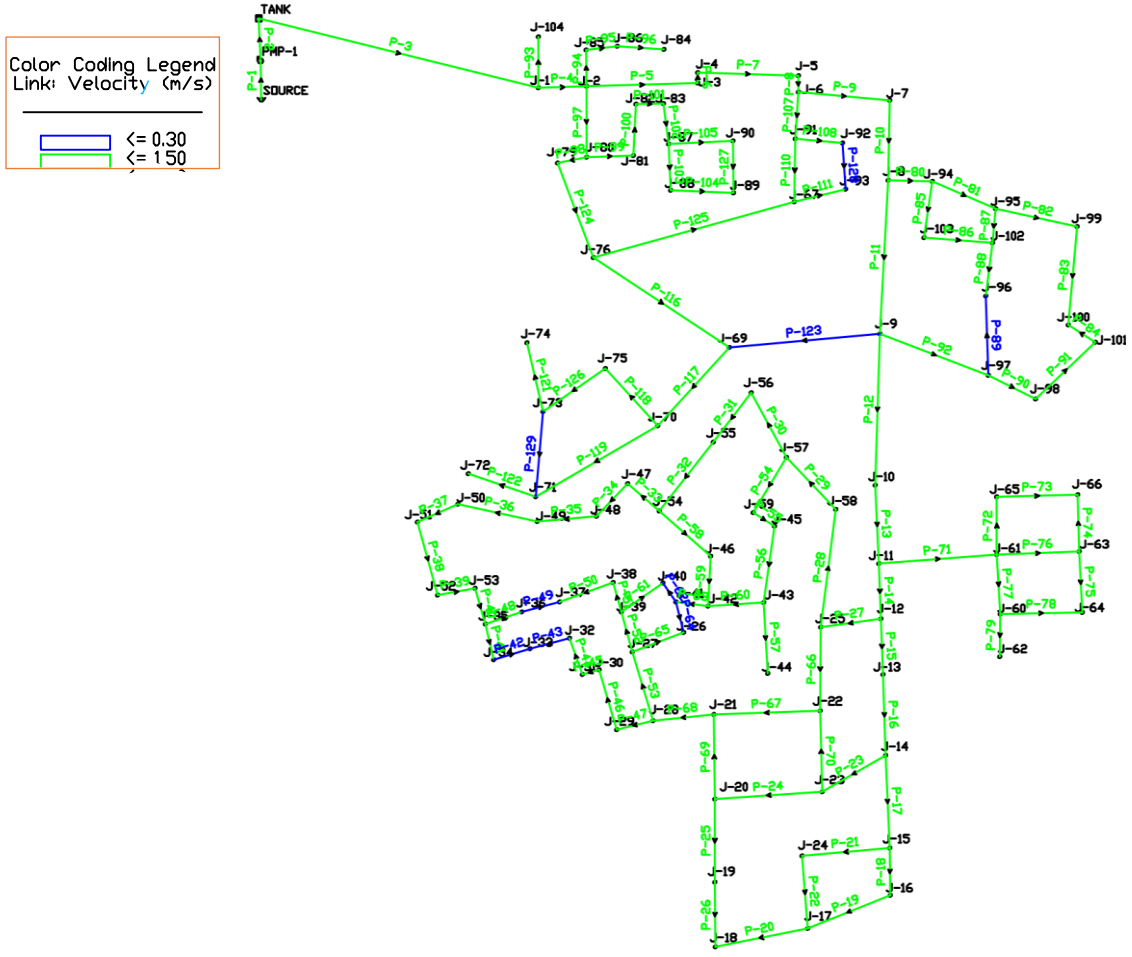

Figure 7. Model representation of the pipeline of Werabe town water supply distribution system

4. Conclusions

This study evaluated the technical sustainability of the water supply and distribution system in Werabe Town, revealing critical gaps between current infrastructure capacity and the demands of a rapidly growing urban population. The results demonstrate that the existing network is struggling to maintain hydraulic integrity under current loading conditions, which directly threatens the long-term reliability of the service.

The hydraulic simulation identifies that 21.3% of flow velocities across the network fall outside the permissible range, with a staggering 18.5% of these low-velocity nodes dropping below the 0.6 m/s threshold. These stagnant flow conditions are primarily concentrated in the periphery of the network, increasing the risk of sediment deposition and water quality degradation. Furthermore, the model highlights significant pressure instability, with 25.76% of nodes failing to meet minimum pressure requirements, and specific zones experiencing a 16.2% pressure deviation from the design standard. These findings are echoed by the system's low sustainability score's reliability (0.28) and resiliency (0.19) and a high vulnerability index (0.71), indicating a system that is highly susceptible to failure and slow to recover from service interruptions.

The Infrastructure Leakage Index (ILI) of 4.31 further underscores the inefficiencies in the system's management and maintenance. Additionally, it was determined that the town's water supply performance was insufficient. Overall, the hydraulic simulation findings revealed that the water supply in Werabe Town was not sustainable. The results showed that demand was not satisfied, and velocity-based sustainability was very low. This analysis of the water pressure and velocity of the extended period simulation result shows that 41.5% of the water velocity is outside the allowable range of 0.6 to 2.0 m/sec, and 36.20% of the pressure head is below and above the suggested range of 15 to 60 mH2O. As a result, it negatively impacts the water supply system's hydraulic performance and results in water stagnation, which permits sedimentation and increases the risk of water-borne disease.

In order to solve the sustainability issue of Werabe town water supply system, targeted interventions must be implemented. These include using sophisticated modeling tools like WaterGEMS 8vi for ongoing monitoring and planning, optimizing pump operations to improve energy efficiency, and rehabilitating infrastructure to fix aged and undersized pipes. Furthermore, NRW reduction tactics like precise metering and leak detection programs are to be given top priority. By following these steps, Werabe Town may improve the sustainability, dependability, and efficiency of its water delivery system, guaranteeing its residents fair and sufficient water distribution.

Declarations

Competing Interests: The authors declare that there is no conflict of interest.
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