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Performance Evaluation Study on The Effectiveness of the SPAM KK Pombewe in Serving the Pombewe Permanent Housing (HUNTAP)

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Abstract: Drinking water is an essential need that must be met sustainably to support domestic activities, health, and the continuity of community life. The performance of a Drinking Water Supply System (SPAM) is evaluated not only through technical aspects, such as production and distribution capacities, but also through its service effectiveness in meeting community needs. This study aims to analyze the operational performance of the Pombewe SPAM in terms of production, distribution, and service continuity to the residents of the Pombewe Permanent Housing (Huntap); assess its service effectiveness based on the quality, quantity, and reliability of water supply; and identify hindering factors to formulate improvement recommendations for enhancing its performance and effectiveness. This research employs a descriptive quantitative approach supported by qualitative analysis. This method was selected to obtain a comprehensive overview of the performance and service effectiveness of the Pombewe SPAM in meeting the clean water needs of the Pombewe Huntap community. The results indicate that the SPAM performance score reached 2.87, placing it in the "Healthy" category as it exceeds the national critical threshold (> 2.8). This demonstrates robust and independent management, free from the risk of severe operational dysfunction. The service is rated highly effective in terms of quality (meeting Ministry of Health standards, exhibiting stable pH, and remaining safe from pathogens) and quantity (the raw water discharge of 24.21 liters/second significantly covers the 2026 projected demand of 11.99 liters/second). However, the service remains less effective regarding continuity due to 1,674 damaged points, including the absence of water meters at 1,516 consumer locations, alongside dozens of pipe leaks and broken valves that disrupt the stability of the water flow.

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I. INTRODUCTION

Developmental growth, particularly in the residential and housing sectors, has driven an increasing demand for clean water across various regions in Indonesia. The availability of clean water, especially drinking water, is a critical fundamental need that supports public quality of life and underpins successful regional development. As an essential requirement, drinking water must be provided sustainably to maintain domestic activities, public health, and community well-being. The Pombewe Permanent Settlement (Huntap Pombewe) is a post-disaster relocation residential area requiring foundational infrastructure support, particularly an adequate drinking water supply. Given the growing population and the urgent, continuous demand for water, the Pombewe District Water Supply System (SPAM IKK Pombewe) plays a vital role in meeting the basic needs of the community in this area.

In 2023, the service performance of SPAM IKK Pombewe remained optimal. The water yield sourced from the Paneki River reached approximately 20 liters per second, serving all end-users relatively evenly with a high degree of supply continuity. These conditions indicated that the system operated well within its operational capacity to meet community requirements.

However, during the 2025–2026 period, service performance degraded significantly. Field observations and public complaints revealed that water distribution was no longer continuous and was instead operated on a rotational (shift) schedule. Furthermore, the discharge received by residents dropped below the optimal capacity of 20 liters per second. This reduction severely compromised both the quantity and continuity of the community's clean water supply.

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A primary factor suspected of driving this performance decline is the proliferation of illegal connections along the distribution network, commonly referred to as illegal tapping. These unauthorized connections contribute to non-revenue water (NRW) losses, reduce hydraulic pressure throughout the distribution network, and cause equitable distribution failures among registered customers. Consequently, the impacts extend beyond technical issues, adversely affecting consumer satisfaction and overall public welfare.

Widespread consumer grievances regarding erratic distribution schedules, irregular service intervals, and reduced water volume highlight fundamental vulnerabilities in the operational framework of SPAM IKK Pombewe. Accordingly, a comprehensive study is necessary to identify the technical and non-technical factors influencing the performance and efficiency of the water supply system.

II. LITERATURE REVIEW

➢ *Performance Assessment*

Performance assessment is a systematic evaluation process used to determine the extent to which a system, program, or activity has achieved its predetermined objectives. According to Mahmudi (2010), performance represents the level of achievement in executing activities to realize organizational goals, while Steers (1985) defines performance as the outcomes attained from resource utilization to achieve specific targets. Accordingly, a performance assessment is an analytical activity designed to measure and evaluate the success of a system against established standards, targets, or operational requirements.

In the context of Water Supply Systems (SPAM), a performance assessment involves a comprehensive evaluation of all system components—ranging from raw water sources and production units to transmission and distribution networks, as well as customer service. This process measures whether the system provides water that meets regulatory quality standards, supplies adequate quantities according to technical benchmarks, applies affordable tariffs, and delivers optimal, sustainable services.

In the context of Water Supply Systems (SPAM), effectiveness refers to the capacity of the water supply system to fulfill community clean water demands in compliance with established technical and operational service standards. The effectiveness of a SPAM is typically evaluated using the national 4Cs framework:

- *Quantity*

Quantitative effectiveness pertains to the adequacy of the produced and distributed water volume relative to customer demand. A system is deemed effective when total water production meets or exceeds daily consumer requirements (Production≥Daily Demand), Non-Revenue Water (NRW) losses are minimized, and distribution coverage extends across the entire service area. Conversely, if supply volumes fall short of demand, overall service effectiveness declines.

- *Quality*

Qualitative effectiveness measures water compliance against established national quality benchmarks (such as Ministry of Health Regulation No. 02/2023). An ideal water supply must be free from microbiological contamination, maintain turbidity levels within regulatory thresholds, and contain no hazardous chemical agents. If water quality fails to meet these mandatory safety standards, service delivery remains ineffective regardless of quantitative sufficiency.

- *Continuity*

Continuity addresses the uninterrupted supply of water. While a 24-hour daily supply represents the ideal benchmark, many District Water Supply Systems (SPAM IKK) experience intermittent flow, pressure drops during high-demand intervals, and supply disruptions in specific zones during peak usage hours. When continuity is compromised, consumer access remains impaired even if the water quality is satisfactory.

- *Affordability*

Affordability evaluates system performance from an economic perspective, requiring that tariff structures conform to municipal water pricing regulations, remain financially accessible to the public, and do not impose an undue burden on low-income households. If tariffs are excessively high, service delivery becomes inherently ineffective as it restricts equitable access across the entire resident population.

➢ *Water Supply Systems (SPAM)*

Drinking water supply encompasses activities aimed at delivering potable water to meet public needs for a healthy, clean, and productive life. It comprises a series of structured measures to develop and manage infrastructure following fundamental management processes to supply drinking water to the public.

The mechanisms for delivering water supply services to communities are broadly divided into two systems:

- *Piped Systems*

Service delivery via piped networks represents the ideal method for distributing clean water to meet community consumption needs in targeted project locations. Generally, piped water supply systems require structured operational management, necessitating qualified human resources to ensure continuous function and long-term sustainability. Another key consideration is the challenge of identifying raw water sources of sufficient quality and quantity that can efficiently reach populations via piped distribution networks.

- ✓ Piped systems typically comprise the following configurations:
- ✓ Spring intake structures utilizing gravity-fed piping networks;
- ✓ Spring intake structures integrated with pumping systems;
- ✓ River intake pumping systems coupled with Slow Sand Filters (SSF) or alternative water treatment processes;
- ✓ Deep tubewells equipped with motor pumps; and

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- ✓ Slow Sand Filters (SSF) or other specialized water treatment units designed to elevate raw water quality to potable standards.

- *Non-Piped Systems*

In general, non-piped clean water facilities are communal infrastructure intended for shared public use and typically do not require specialized operational management. However, inadequate construction or poor environmental maintenance surrounding these facilities increases the vulnerability to contamination. Non-piped water supply infrastructure primarily includes the following types:

- ✓ *Spring Encapsulation Structures (Broncaptering):*

On-site intake structures designed to protect natural springs from landslides and contamination or damage caused by animal activity, while technically engineered to maintain a stable and constant discharge pressure.

- ✓ *Dug Wells:*

Excavated vertical shafts measuring 1–2 meters in diameter, dug to a depth that reaches shallow groundwater tables. Wall construction typically utilizes half-brick to full-brick masonry, precast concrete rings, river stones, or equivalent structural materials.

- ✓ *Rainwater Harvesting Systems (PAH):*

Permanent storage structures designed to capture roof runoff directed through gutter networks attached to eaves. These systems are predominantly deployed in water-scarce areas, such as coastal zones with brackish or saline groundwater, as well as regions enduring prolonged dry seasons (e.g., parts of Kalimantan and other Indonesian territories). Construction materials include ferrocement, brick masonry, ironwood (Eusideroxylon zwageri), fiberglass, or repurposed drums. Rainwater can be harvested continuously during the rainy season for immediate consumption or stored as emergency reserves for dry periods.

The primary objective of drinking water supply is to ensure public access to potable water, thereby enabling healthy, hygienic, and productive lives. However, the availability of consumable water remains severely constrained, experiencing up to a 40% deficit in major urban centers due to deteriorating water infrastructure and pollution. Rapid urban development has further exacerbated clean water scarcity through widespread contamination driven by industrial, domestic, and agricultural effluents. Consequently, clean water has become an increasingly scarce commodity. Clean water demand varies by region, and the growing demand for water provision and distribution services frequently exceeds existing system capacities. To function effectively, water supply systems must simultaneously satisfy quality, quantity, and continuity standards.

- *Quality Aspect*

Water quality standards depend on the specific intended use; criteria for irrigation differ fundamentally from those for drinking water. Drinking water must comply with strict health and safety standards to ensure it is safe, hygienic, and free from infection risks (Aronggear et al., 2019). Maya Evita et al. (2021) classify these requirements into four core categories:

- ✓ *Bacteriological:*

Mandates zero or strictly limited Escherichia coli (E. coli) per 100 mL sample across the distribution network.

- ✓ *Chemical:*

Limits hazardous organic and inorganic substances to prevent health risks and aesthetic consumer grievances (e.g., taste, odor).

- ✓ *Radiological:*

Sets maximum permissible limits for alpha and beta particle radioactivity.

- ✓ *Physical:*

Prescribes acceptable aesthetic standards, including clarity, neutrality in taste and odor, and appropriate temperature.

- *Quantity and Continuity Aspects*

Water quantity represents the baseline volume required for daily domestic and operational needs. Quantitative demand is governed by metering accuracy, socio-economic factors (income, consumption habits), geographic and topographic constraints, and served population size. Fulfilling quantitative requirements requires matching raw water source yields and distribution discharge rates with empirical consumption standards to ensure present and future demand coverage (Perpamsi, 1994).

- ➢ Raw Water Supply Units

In general, raw water intake and supply infrastructure encompasses raw water storage facilities, intake structures, flow measurement and monitoring instrumentation, pumping units, and conveyance systems with associated appurtenances. Typical raw water sources utilized for Water Supply Systems (SPAM) comprise: Natural springs; Groundwater; and Surface water bodies (e.g., rivers, lakes, seawater, reservoirs, and retention ponds).

Raw water unit facilities serve two primary operational functions:

- *Water Storage Structures:*

These structures collect raw water prior to its transmission to the treatment unit. Spring encapsulation chambers (broncaptering) are typically constructed above ground using stone masonry, brickwork, or reinforced concrete. They feature sealed covers equipped with top ventilation pipes, overflow conduits, inlet pipes (where necessary), and service valves. The surrounding area is generally secured with protective fencing, peripheral drainage channels, and vegetative buffer zones.

- *Water Intake Structures:*

Raw water intake systems are categorized according to the hydrologic source:

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- ✓ Spring Intakes: Spring intake structures generally fall into two categories: spring capture chambers and collection sumps/wells.
- ✓ Groundwater Intakes: Groundwater extraction facilities are categorized into shallow and deep wells. Based on hydrogeological settings and subsurface flow dynamics, groundwater sources are classified into general groundwater and subterranean rivers:
- ✓ Groundwater Aquifers: Unconfined (Shallow) Groundwater: Groundwater located within an aquifer that lacks an upper impermeable confining layer, typically accessed via shallow dug wells.
- ✓ Confined (Deep) Groundwater: Groundwater trapped between upper and lower impermeable confining layers, typically extracted through deep tubewells.

- *Subterranean Rivers:*

Subsurface water flows moving through subterranean cavities or fractures as a result of surrounding soil percolation, commonly harnessed using subsurface dams.

➢ *Production Units*

The production unit encompasses the infrastructure and facilities utilized to treat raw water into potable drinking water through physical, chemical, and/or biological processes. It comprises water treatment structures and associated appurtenances, operational units, flow measurement and monitoring instrumentation, and treated water storage reservoirs.

Engineering designs for water treatment unit expansion are developed based on raw water quality evaluations. Process selection is determined using baseline and worst-case water quality scenarios as design benchmarks to reliably achieve target drinking water standards.

The water treatment train typically consists of unit operations and unit processes designed to remove coarse solids, suspended solids, and dissolved constituents, as well as execute neutralization and disinfection. Production units may include coagulation, flocculation, sedimentation, filtration, neutralization, and disinfection processes.

The engineering design of production units generally complies with established technical standards, including:

- SNI 03-3981-1995: Standard Practice for the Design of Slow Sand Filtration Plants;
- SNI 19-6773-2002: Specifications for Conventional Steel-Structured Package Water Treatment Plants; and
- SNI 19-6774-2002: Standard Guidelines for the Design of Package Water Treatment Plants.

➢ *Distribution Units*

Water distribution mechanisms depend heavily on the topographical conditions connecting water sources to consumer areas. Clean water distribution systems are categorized according to their hydraulic conveyance methods:

- *Gravity-Fed Systems:*

Gravity distribution is applicable when a sufficient elevation head exists between the water source and the service area, maintaining the necessary hydraulic pressure without mechanical assistance.

- *Direct Pumping Systems:*

Pumps are utilized to elevate and maintain the pressure required to distribute water from storage reservoirs to consumers. This method is predominantly deployed in flat terrains lacking elevated features suitable for gravity storage.

- *Combined Systems:*

In combined configurations, distribution reservoirs balance system pressure during peak-demand hours and emergency conditions (e.g., firefighting demand or power outages). During low-demand periods, excess pumped water is stored in distribution reservoirs. By using reservoirs to buffer peak demand, pumps can operate continuously at a uniform average discharge rate (Joko, 2010).

Evaluating drinking water distribution systems relies primarily on two key parameters: water demand and hydraulic pressure, supplemented by service continuity and safety considerations. The core function of a distribution network is to deliver potable water to all consumers while satisfying quality, quantity, continuity, flow velocity, and pressure standards, thereby ensuring reliable on-demand availability.

Piped water distribution operates under two main supply regimes:

- *Continuous Supply Systems:*

Water is supplied uninterrupted 24 hours a day. This regime is viable when raw water availability consistently satisfies total service area demand. The primary advantage is round-the-clock water availability and fresh supply at consumer draw-off points; however, drawbacks include higher per capita consumption and increased water volume loss through leaks.

- *Intermittent Supply Systems:*

Water is supplied for limited daily durations (typically 2–4 hours during morning and evening peak hours). This system is implemented when water yields or system pressures are insufficient for continuous operation. While it reduces overall water consumption and limits leakage volumes, it requires households to maintain on-site storage capacity and necessitates larger pipe diameters to convey total daily demand over compressed supply windows.

➢ *Service Units*

Drinking water distribution network evaluations focus primarily on two parameters: water demand and hydraulic pressure, supported by service continuity and safety considerations. The fundamental purpose of a distribution network is to convey potable water to all consumers while maintaining regulatory standards for quality, quantity, continuity, flow velocity, and pressure, thereby ensuring reliable on-demand access.

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Treated water from production facilities is stored in distribution reservoirs (or elevated tanks) to balance supply and peak demand. From these reservoirs, water is conveyed through an interconnected piping network to form the service unit—the point of extraction from the main distribution pipeline for direct end-user consumption. Service units are classified into two primary delivery types:

- *House Connections (HC):*

Comprising the piping and fittings from the main tapping point up to the water meter. The primary functions of house connections are to convey water from distribution mains to individual premises and to measure household consumption. Essential components include saddle clamps, water meters with protective enclosures, isolation valves, and connected piping assemblies.

- *Public Hydrants (PH) / Public Standpipes (PS):*

Designated water withdrawal points from distribution mains to communal collection structures designed specifically to satisfy basic drinking water requirements for specific user groups. Public hydrant services encompass pipework installation, water meter fitting, and required civil works according to technical design specifications.

➢ *Non-Revenue Water and System Losses*

Water losses (leakage) within clean water distribution networks are broadly categorized into two main components:

- *Physical (Technical) Losses:*

✓ Orifices or breaches in pipelines and joint assemblies;
✓ Main distribution line bursts; and
✓ Substandard pipe installation and workmanship.

- *Commercial (Non-Technical) Losses:*

✓ Meter reading and recording errors; and
✓ Data transcription and billing inaccuracies.

System water losses must be factored into demand forecasting to prevent allocation shortfalls. Unaccounted-for water typically ranges between 20% and 40% of total combined domestic and non-domestic demand. Alternatively, water loss is quantified as the volume discrepancy between total produced water and total billed consumption (Udju, 2014).

➢ *Pombewe Permanent Resettlement Area (Huntap Pombewe)*

Permanent settlements (locally designated as Hunian Tetap or HUNTAP) represent post-disaster residential zones constructed under government-led community relocation initiatives. Their primary objective is to provide decent, secure, and sustainable housing. Beyond residential housing construction, HUNTAP development encompasses fundamental infrastructure and auxiliary facilities—such as access roads, sanitation networks, and drinking water supply systems—to enhance the quality of life for relocated populations.

Fig 1 Overview of the Pombewe Permanent Settlement (Huntap Pombewe

The Pombewe Permanent Settlement (Huntap Pombewe) was established following the compound disaster of a major earthquake, soil liquefaction, and tsunami that struck Central Sulawesi Province in 2018. This residential area was designated for displaced households relocated from high-risk hazard zones to safer geographic grounds. Administratively situated in Sigi Biromaru District, Sigi Regency, Huntap Pombewe constitutes part of an integrated new settlement development linked to the central service hub of the Pombewe District (IKK Pombewe). Driven by steady population growth within Huntap Pombewe, securing fundamental infrastructure—specifically potable water supply—has become critical. Adequate water availability across quality, quantity, and continuity dimensions is paramount to safeguarding public health and supporting daily socio-economic activities. Consequently, the area is served by the Pombewe District Water Supply System (SPAM IKK

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Pombewe), designed to deliver sustainable clean water services.

In practice, drinking water service delivery in Huntap Pombewe continues to encounter significant operational challenges. Frequently observed issues include erratic water distribution schedules, declining discharge rates delivered to end-users, and structural distribution network disruptions. Furthermore, unauthorized pipe connections (illegal tapping) compromise overall system performance and impede equitable water distribution.

These operational constraints indicate that despite the existence of baseline infrastructure, the effectiveness of drinking water services in Huntap Pombewe requires substantial optimization. Accordingly, a comprehensive evaluation of the existing service delivery system is necessary to diagnose operational bottlenecks and formulate targeted interventions to improve drinking water service quality for the relocated community.

III. RESEARCH METHOD

➢ *Type of Research*

This study employs a descriptive research design incorporating a quantitative approach complemented by qualitative analysis. This hybrid approach was adopted to provide a comprehensive evaluation of the operational performance and service effectiveness of the Pombewe District Water Supply System (SPAM IKK Pombewe) in meeting the clean water demands of the Pombewe Permanent Settlement (Huntap Pombewe) community.

➢ *Research Location*

The study was conducted at the Pombewe District Water Supply System (SPAM IKK Pombewe), which serves the Pombewe Permanent Settlement (HUNTAP Pombewe). Administratively, the study site is located in Pombewe Village, Sigi Biromaru District, Sigi Regency, Central Sulawesi Province, Indonesia.

Fig 2 Research Location

➢ *Data Collection Techniques*

Data collection was executed through field research involving direct on-site investigation. Primary and secondary data were gathered using five complementary techniques: direct field observation, semi-structured interviews, structured questionnaires, document reviews, and a literature review.

- *Direct Observation*

Field observations were conducted to evaluate the existing operational conditions of SPAM IKK Pombewe. This involved on-site assessments of the water treatment facilities, distribution network integrity, physical infrastructure status, and general service delivery performance.

- *In-Depth Interviews*

In-depth interviews were conducted with utility management personnel and service end-users (residents). This technique aimed to gather qualitative insights regarding system operations, technical and non-technical operational bottlenecks, and consumer perceptions of service quality.

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- *Structured Questionnaires*

Structured questionnaires were administered to residents of the Pombewe Permanent Settlement (Huntap Pombewe) to measure customer satisfaction levels. The survey instrument utilized a five-point Likert scale to quantify user perceptions across service dimensions.

- *Document Review*

Documentary data were collected from relevant government agencies and utility operators, encompassing official technical reports, engineering drawings, spatial maps, water discharge logs, and administrative records pertaining to SPAM IKK Pombewe.

- *Literature Review*

A comprehensive literature review was conducted by synthesizing relevant academic books, peer-reviewed journal articles, statutory regulations, and prior empirical studies to establish the theoretical framework and comparative benchmarks for the evaluation.

➢ *Data Analysis Technique*

Data analysis is a systematic process of organizing and synthesizing data obtained from interviews, field notes, technical measurements, and archival sources to facilitate accurate interpretation and communicate research findings effectively. This analytical workflow involves structuring data, breaking complex datasets into manageable analytical units, identifying patterns, and formulating evidence-based conclusions to answer specific research objectives.

This study employs a mixed quantitative-qualitative analytical framework with a descriptive focus. Collected data were processed and presented to provide a structured diagnosis of system operations. The data analysis was executed through the following sequential analytical stages:

- Demographic Forecasting: Projecting future population growth using demographic forecasting models to evaluate long-term water demand trends within the HUNTAP Pombewe settlement.
- Water Demand Calculations: Projecting total water demand based on national governmental standards.
- Operational Performance Analysis: Evaluating the technical performance of SPAM IKK Pombewe across production capacity, distribution network integrity, and service continuity. System performance was assessed by benchmarking treatment production against actual consumer demand, evaluating pipeline infrastructure status, and measuring daily supply duration.
- Service Effectiveness Assessment: Evaluating service delivery effectiveness across water quality, quantity, and reliability dimensions. This evaluation synthesizes physical field measurements with community perception data obtained via Likert-scale questionnaire surveys.
- Constraint Identification: Diagnosing key technical and non-technical operational bottlenecks based on survey responses from utility operators and consumer households. Collected survey data were processed using statistical software to determine dominant factors impairing system performance and service effectiveness.
- Formulation of Strategic Recommendations: Synthesizing analytical findings to derive actionable technical and managerial recommendations aimed at optimizing the operational performance and service effectiveness of SPAM IKK Pombewe.

➢ *Identification of Constraining Factors*

Descriptive statistical methods were used to identify contraining factors affecting the service effectiveness of SPAM IKK Pombewe. The analytical process comprised three sequential stages:

- Factor Identification Stage: A preliminary questionnaire utilizing a binary Guttman scale was distributed to respondents with direct experience in infrastructure operations to identify potential operational threats and relevant variables. Descriptive analysis was subsequently conducted to compile and categorize these variables into a structured risk identification matrix.
- Factor Assessment Stage: Quantitative analysis was performed to evaluate the identified constraints. Response rates and scores from the sample were compiled to rank the factors based on their impact on service delivery goals (cost, timeline, and quality).
- Risk Categorization Stage: Factors were analyzed qualitatively and structured according to a Risk Breakdown Structure (RBS) framework. Grouping constraints by root causes and primary categories enhances control and targeted mitigation.

To ensure empirical rigor, instrument validity and reliability testing were conducted prior to full data processing. Statistical analysis was executed using IBM SPSS software, leveraging its capabilities for factor analysis, data management, case selection, and file transformation.

Factor analysis was applied to examine interdependencies among variables and reduce a large set of correlated variables into a smaller number of underlying common factors (Suryanto, 1988). Variables exhibiting high inter-item correlations were grouped into shared factor components, simplifying variable structures for subsequent interpretation.

➢ *Operationalization of Variables*

Descriptive statistics were employed to summarize, organize, and present quantitative data using tables, charts, and distribution plots. Respondent attitudes and perceptions were measured using a 5-point Likert scale.

➢ *Data Scoring Framework*

To identify the most significant factors based on probability and impact, respondent scores were analyzed using Likert's Summated Rating (LSR) methodology (Likert, 1932). A 5-point scale was selected to provide clear differentiation across response gradations, defined as follows:

- Score 5 = Strongly Agree

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- Score 4 = Agree
- Score 3 = Neutral
- Score 2 = Disagree
- Score 1 = Strongly Disagree

IV. RESULTS

➢ *Research Results Data*

The Pombewe Sub-district Capital (IKK) Water Supply System (WSS) is a drinking water infrastructure constructed to serve the clean water needs of the community in the Pombewe Permanent Resettlement Area (Huntap Pombewe), Sigi Regency, Central Sulawesi. This WSS was built as part of the post-disaster recovery efforts following the 2018 Central Sulawesi earthquake, tsunami, and liquefaction, which necessitated the relocation of affected communities to the Huntap Pombewe area.

This study was conducted among community members utilizing the Pombewe WSS services residing in the Huntap Pombewe area. A total of 96 respondents were selected based on Slovin's formula analysis in Chapter 3, using the following criteria:

- Registered as a Pombewe WSS customer.
- Have used the service for a minimum of 6 months.
- Reside in the Huntap Pombewe area.

➢ *WSS Performance Assessment*

The performance assessment of the Water Supply System (WSS) in the study area was conducted to evaluate the effectiveness, efficiency, and sustainability of the existing system management. This evaluation refers to the standardized methodology issued by the Agency for the Improvement of Water Supply System Provision (BPPSPAM) - Ministry of Public Works and Public Housing (PUPR), which integrates technical and non-technical aspects using a Balanced Scorecard approach.

Pursuant to the Technical Guidelines for PDAM Performance Assessment established by the Decree of the Head of BPPSPAM Number 002/KPTS/k-G/IV/2010 regarding the Performance Assessment of Water Supply System Provision and Development Services at Regional Water Utilities, WSS performance is categorized into 4 (four) primary aspects with proportional weightings: Service Aspect (40%), Operational Aspect (40%), and Human Resources Aspect (20%), accumulating a total of 13 indicators.

Table 1 WSS Performance Analysis

No	Aspect & Performance Indicator	Scale Score	Indicator	Aspect	Final Value
I	SERVICE ASPECT			0,40	1,50
1	Technical service coverage	3	0,100		0,30
2	Annual customer growth	4	0,100		0,30
3	Complaint resolution rate	4	0,050		0,15
4	Customer water quality	4	0,075		0,38
5	Domestic water consumption	3	0,075		0,38
II	OPERATIONAL ASPECT			0,40	1,03
6	Production efficiency	4	0,120		0,48
7	Water loss rate (NRW)	2	0,070		0,14
8	Service operating hours (hours/day)	1	0,080		0,08
9	Customer water pressure	4	0,065		0,26
10	Customer water meter replacement	1	0,065		0,07
III	HUMAN RESOURCES ASPECT			0,20	0,34
11	Staff-to-1,000-customers ratio	3	0,070		0,21
12	Employee training ratio	1	0,065		0,07
13	Ratio of training cost to employee cost	1	0,065		0,07
	Total Skor Kinerja Akhir				2,87

As presented in Table 1, a final score of 2.87 was obtained, placing this WSS in the "Healthy" category as its value exceeds the national critical threshold (> 2.8). This score indicates that the water utility has strong management, is considered self-sustaining, and is not at risk of severe operational dysfunction.

➢ *Service Effectiveness of the Pombewe Water Supply System*

To measure the service effectiveness of the Pombewe Water Supply System in serving the Pombewe Permanent Resettlement Area, an in-depth evaluation was conducted by examining the three main pillars of national water quality standards: quality, quantity, and continuity. This assessment contrasts field hydraulic technical parameters with standardized rating scales.

- *Water Quality Aspect*

The quality aspect is the most critical parameter in evaluating the service effectiveness of the Pombewe Water Supply System because it directly relates to protecting the public health of survivor communities in the Pombewe Permanent Resettlement Area. To determine this effectiveness quantitatively, the quality analysis is supported by real operational parameters recorded by the plant's digital instrumentation system. Based on the Water Treatment Plant Performance Test Data obtained from the Supervisory Control and Data Acquisition (SCADA) monitor, the findings are presented below:

Table 2 Water Quality Data

No	Time	*Reservoir/Dist*			Air Baku		
		pH	NTU	Sisa Klor	Q (lpd)	pH	NTU
1	09.00	8,2	1,03	0,5	20	8,2	4,78
2	11.30	8,2	1,033	0,6	20	8,2	4,46
3	14.30	8	0,78	0,7	20	8,3	1,76
4	18.30	7,8	0,13	0,6	24	8,3	5,17

- *Physical Parameter (Turbidity)*

The efficiency of turbidity removal at the Pombewe Water Treatment Plant demonstrates superior technical performance. Raw water entering the intake system exhibits turbidity fluctuations ranging from 1.76 NTU to 5.17 NTU at a treatment flow rate of 20 liters per second (L/s).

As water enters the distribution reservoir unit, the SCADA sensors record a very clear final turbidity value ranging between 0.13 NTU and 1.03 NTU. This final figure remains well below the maximum threshold required by Ministry of Health regulations, thereby guaranteeing that the aesthetic quality of water delivered to end-users in the Permanent Resettlement Area is clear and free from suspended solids.

- *Chemical Parameter (pH Level)*

The stability of pH levels plays a vital role in preventing chemical leaching from pipes and internal network corrosion. The data in Table 4.2 show that pH values are maintained consistently across the treatment units. Raw water with an initial pH value ranging from 8.2 to 8.3 is stably maintained up to the distribution reservoir unit within a range of 7.8 to 8.2. This neutral to slightly alkaline pH range complies with national health standards.

- *Biological Parameter (Disinfection Residual Chlorine)*

In a post-disaster relocation area, preventing waterborne disease epidemics is a paramount priority. Biological reliability is evidenced through consistent disinfectant dosing at the post-chlorination unit. Based on the SCADA log data in Table 4.2, the system successfully maintains a Residual Chlorine concentration in the distribution reservoir unit between 0.5 ppm and 0.7 ppm. The presence of residual chlorine kills pathogenic bacteria (such as E. coli and Total Coliform) within the reservoir unit and acts as an active protective agent while water flows through the distribution pipes toward residents' homes in the resettlement area.

- *Water Quantity Aspect*

The quantity aspect is one of the key dimensions evaluated when assessing the effectiveness of drinking water services. It measures the volume adequacy and supply reliability of clean water required to meet the basic daily needs of the community.

- *Basic Water Demand*

Basic water demand represents the absolute minimum volume of water required by each individual or community to carry out essential daily activities for maintaining life, health, and proper hygiene. Within the evaluation framework of the Pombewe Special Area Water Supply System in the Permanent Resettlement Area, analyzing basic water demand serves as a primary parameter to determine whether the capacity of the constructed system is proportional to the served population. The baseline calculations for basic water demand follow national regulations and guidelines issued by the Directorate General of Human Settlements under the Ministry of Public Works and Public Housing. In these calculations, the Pombewe system serves two villages, namely Pombewe Village and Loru Village. The Total Basic Water Demand for the Pombewe system is detailed in the following table.

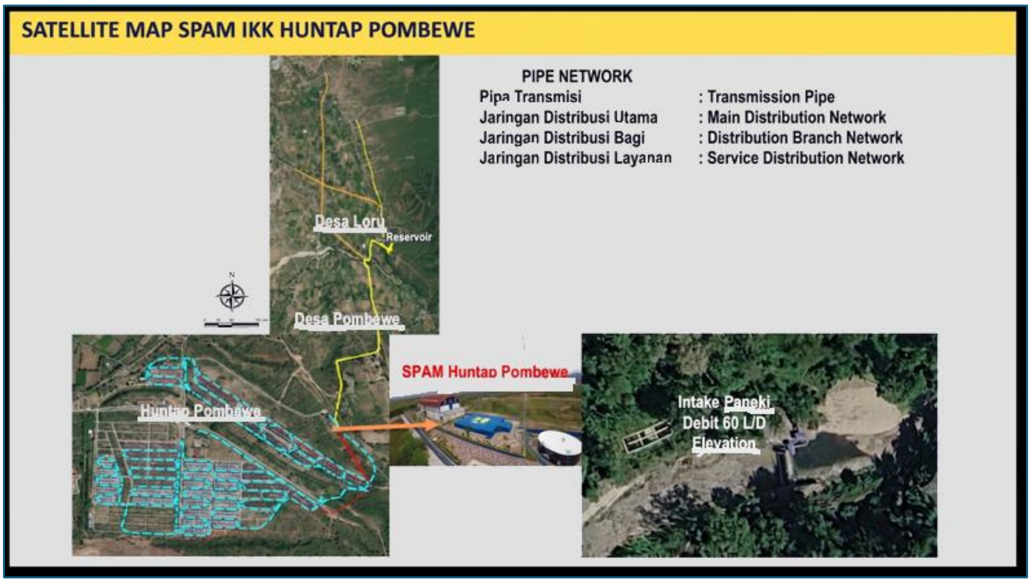

Fig 3 Satellite Map of the Pombewe Permanent Resettlement Area Water Supply System (WSS)

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Table 3 Basic Water Demand

No	Description		Unit	Standar	Projected Year					
					2040	**2041**	**2042**	**2043**	**2044**	**2045**
1	Total Population		Capita		8.895	9.076	9.261	9.452	9.648	9.850
2	Water Consumption									
	a.	Public Hydrant	Liter/capita/day	30,00	70.143	71.567	73.032	74.536	76.083	77.672
	b.	House Connection	Liter/capita/day	150,00	983.530	1.003.509	1.024.040	1.045.138	1.066.819	1.089.103
3	Service Level		%		100%	100%	100%	100%	100%	100%
4	Service Ratio									
	a.	Public Hydrant	%		6,66%	6,66%	6,66%	6,66%	6,66%	6,66%
	b.	House Connection	%		93,34%	93,34%	93,34%	93,34%	93,34%	93,34%
5	Domestic Demand		L/s							
	a.	Public Hydrant	L/s		0,81	0,83	0,85	0,86	0,88	0,90
	b.	House Connection	L/s		15,44	15,76	16,08	16,41	16,75	17,10
6	Non-Domestic Demand		Liter/Detik	L/s	3,25	3,32	3,38	3,45	3,53	3,60
7	Water Demand		Liter/Detik	L/s	19,51	19,90	20,31	20,73	21,16	21,60
8	Water Los		%	20,00%	20,00%	20,00%	20,00%	20,00%	20,00%	20,00%
8	Total Kebutuhan Air		L/s		**23,41**	**23,88**	**24,37**	**24,87**	**25,39**	**25,92**
9	Jumlah Sambungan									
	a.	Public Hydrant	Connections		585	596	609	621	634	647
	b	House Connection	Connections		2.224	2.269	2.315	2.363	2.412	2.462

From the analysis results, the total water demand for the Pombewe system in 2026 was determined to be 11.99 liters per second (L/s), serving a total of 4,479 Public Hydrant connections and 1,022 House Connections.

The Pombewe Special Area Water Supply System (WSS) is designed as an integrated clean water utilization system relying on natural potential energy via a gravity-fed flow system. Based on spatial visualization from satellite imagery, the technical configuration of this water supply begins upstream at the raw water intake structure, namely the Paneki Intake. This intake facility has a significant design dependable flow capacity reaching 60 L/s, which quantitatively far exceeds the total projected peak demand threshold for the Pombewe Permanent Resettlement Area, estimated between 6.95 and 25.92 L/s up to the design year 2045. Theoretically, this condition provides a highly secure raw water supply safety margin for the long-term operational sustainability of the system.

From the upstream Paneki Intake, raw water is transmitted downstream via a transmission pipeline stretching across open geomorphological terrain. Administratively, this macro transmission pipeline traverses Loru Village before entering Pombewe Village toward the central management complex. The raw water flow then discharges directly into the Water Treatment Plant (WTP) of the Pombewe WSS, situated in the transition zone prior to the permanent resettlement area. Within this plant complex, the water undergoes technical quality improvement processes to meet sanitary hygiene standards, after which it is temporarily stored in a large cylindrical communal reservoir to maintain daily flow fluctuation stability.

The internal distribution system of this WSS implements a strict piping network hierarchy to minimize hydraulic pressure loss along distribution routes. This WSS ensures that the quantity of distributed clean water—delivered via both House Connections (HC) and Public Hydrants (PH)—is distributed homogeneously, continuously, and equitably to all residents.

- *Production Unit Capacity*

Based on plant operational data monitored via SCADA control, the Pombewe treatment unit delivers a constant flow rate of 20 liters per second (L/s). With this capacity, clean water production on the reservoir side consistently operates in a surplus condition to serve the total population of the Pombewe Permanent Resettlement Area.

To transform climatological and monthly rainfall data from the Bora Climatological Station into reliable flow estimates at the Paneki Intake source, the F.J. Mock Analysis was utilized. The application of this monthly water-balance-based hydrological simulation model provides a solution for addressing the limitation of direct river flow gauge data at the upstream location. The primary function of the F.J. Mock analysis in this study is to establish a benchmark for water supply capacity, which is subsequently compared against the total projected clean water demand load in the Pombewe Special Area.

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By detecting flow rate fluctuations, seasonal technical deficits caused by extreme dry seasons can be identified. This analysis serves as a baseline for measuring the percentage effectiveness of fulfilling the WSS water quantity reliably and sustainably, as well as anticipating service failure risks during critical months or dry seasons.

Table 3 Water Discharge Analysis Using the F.J. Mock Method

No.	Uraian	Satuan	Keterangan	Jan	Peb	Mar	Apr	Mei	Jun	Jul	Ags	Sep	Okt	Nop	Des	Tahun
I	Data Meteorologi															
1	Hujan Bulanan (R)	mm/bl	data	191,80	364,90	275,80	300,10	2,50	25,50	3,60	73,50	44,40	177,30	153,80	357,90	1971,10
2	Jumlah hari hujan (n)	hari	data	17,0	23,0	27,0	15,0	1,0	4,0	3,0	4,0	5,0	11,0	16,0	26,0	152,00
II	Evapotranspirasi aktual															
3	Evapotranspirasi potensial (ETo)	mm/bl	data	117,81	102,89	114,29	114,53	126,89	107,49	112,65	119,76	127,81	144,28	123,10	94,22	1405,72
4	Permukaan lahan yang terbuka (m)	(%)	data	50	50	50	50	50	50	50	50	50	50	50	50	
5	ETo/Ea = m/20 (18-n)	(%)	hitung	2,50	-12,50	-22,50	7,50	42,50	35,00	37,50	35,00	32,50	17,50	5,00	-20,00	
6	E = ETo x (m/20 (18-n))	mm/bl	(3) x (5)	2,95	-12,86	-25,72	8,59	53,93	37,62	42,24	41,92	41,54	25,25	6,16	-18,84	202,77
7	Ea = ETo - E	mm/bl	(3) - (6)	114,86	115,75	140,01	105,94	72,96	69,87	70,41	77,84	86,27	119,03	116,95	113,06	1202,95
III	Keseimbangan Air															
8	ΔS = R - Ea	mm/bl	(1) - (7)	76,94	249,15	135,79	194,16	-70,46	-44,37	-66,81	-4,34	-41,87	58,27	36,86	244,84	
9	Soil storage (SS)	mm/bl		0,00	0,00	0,00	0,00	-70,46	-44,37	-66,81	-4,34	-41,87	58,27	36,86	132,73	
10	Soil Moisture (SM = SMC + SS)	mm/bl		250,00	250,00	250,00	250,00	179,54	135,17	68,36	64,02	22,15	80,42	117,27	250,00	
11	Water surplus , Kelebihan air (WS)	mm/bl		76,94	249,15	135,79	194,16	0,00	0,00	0,00	0,00	0,00	0,00	0,00	112,11	768,15
IV	Limpasan & Penyimpanan Air Tanah															
12	Faktor (i) nilainya 0,2 - 0,5	0,5	data													
13	Faktor (k) nilainya 0,4 s/d 0.7	0,7	data													
14	Infiltrasi (I)	mm/bl	(11) x (12)	38,47	124,57	67,90	97,08	0,00	0,00	0,00	0,00	0,00	0,00	0,00	56,05	
15	G = 0,5 (1 + k) x I	mm/bl	hitung	32,70	105,89	57,71	82,52	0,00	0,00	0,00	0,00	0,00	0,00	0,00	47,65	
16	L = k. V(n-1)	mm/bl	hitung	97,13	90,88	137,74	136,82	153,53	107,47	75,23	52,66	36,86	25,80	18,06	12,64	
17	Volume penyimpanan (Vn = G + L)	mm/bl	(15) + (16)	129,83	196,77	195,45	219,33	153,53	107,47	75,23	52,66	36,86	25,80	18,06	60,29	1271,31
18	Perubahan simpanan ($\Delta Vn = Vn - V_{n-1}$)	mm/bl	hitung	-8,93	66,94	-1,32	23,88	-65,80	-46,06	-32,24	-22,57	-15,80	-11,06	-7,74	42,23	-78,47
19	Aliran dasar (BF = I - ΔVn)	mm/bl	(14) - (18)	29,54	57,64	66,58	73,20	-65,80	-46,06	-32,24	-22,57	-15,80	-11,06	-7,74	13,83	39,50
20	Limpasan langsung (DR = WS - I)	mm/bl	(11) - (14)	38,47	124,57	67,90	97,08	0,00	0,00	0,00	0,00	0,00	0,00	0,00	56,05	384,07
21	Limpasan (RO = BF + DR)	mm/bl	(19) + (20)	68,00	182,21	134,48	170,28	-65,80	-46,06	-32,24	-22,57	-15,80	-11,06	-7,74	69,88	423,58
22	Luas DAS (A)	km^2	100,82													
23	Jumlah hari			31	29	31	30	31	30	31	31	30	31	30	31	
24	Debit tersedia	m^3/dt	(22) x (23) / bl	2,56	7,33	5,06	6,62	0,00	0,00	0,00	0,00	0,00	0,00	0,00	2,63	24,21

- *Correlation of Water Loss (Non-Revenue Water)*

Water loss, or Non-Revenue Water (NRW), is a critical indicator in evaluating the performance of a Water Supply System (WSS). NRW represents the difference between the volume of water produced and distributed into the network and the volume of water recorded or utilized by customers. A high water loss rate reflects low operational efficiency within the distribution network and has the potential to degrade service quality to customers.

To enhance efficiency and effectiveness in water management at the Pombewe Permanent Resettlement Area WSS, a field survey and spatial mapping of leakage distribution were conducted. Based on the survey findings, various types of network damage and leaks were identified. The detailed findings from the leakage distribution map are as follows:

✓ *Underground Pipe Leakage:*

A total of 16 underground pipe leakage points were identified out of 6,695 total customer connections (0.24%). These leaks have the potential to cause significant water losses before reaching consumers, resulting in distribution inefficiencies.

✓ *Visible Leakage:*

A total of 94 visible leaks were identified, mostly located in front of customer premises, representing 1.40% of connections. These leaks are clearly visible and require immediate intervention to prevent water wastage and localized environmental degradation.

✓ *Absence of Water Meters:*

A total of 1,516 connection points lacked water meters, accounting for 22.64% of the total. The absence of water meters hinders accurate consumption measurement, potentially leading to excessive water wastage and inequitable billing practices.

✓ *Damaged Valves:*

A total of 21 damaged valves were identified, representing 0.31% of the total points. Damaged valves impair the capability to properly regulate water flow, causing leaks and distribution disruptions.

Fig 4 Water Flow Direction and Elevation Profiles

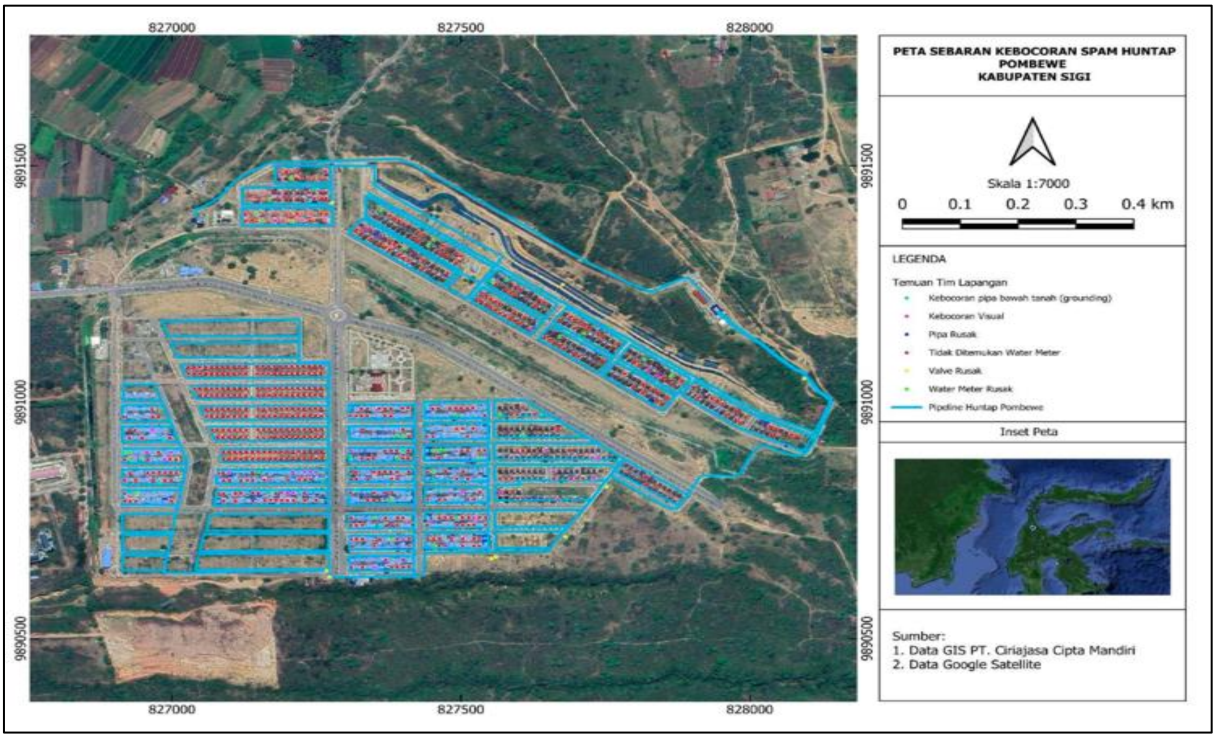

Fig 5 Spatial Distribution Map of Water Losses and Pipe Leakages

To improve operational efficiency and management effectiveness in the Pombewe Permanent Resettlement Area WSS distribution network, a technical survey and spatial mapping were performed across a population of 6,695 customer households. Based on this comprehensive field investigation, a cumulative total of 1,674 physical and administrative anomalies were identified, representing a total Water Loss and Network Damage Rate of 24.60% (~25.0%) across the entire survey area.

➢ *Service Continuity Aspect*

The continuity aspect is the third pillar in evaluating the effectiveness of a water supply system. It measures the guaranteed daily supply duration as well as the stability of

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dynamic energy (hydraulic pressure) delivering water to the furthest consumer taps.

- *Effectiveness Analysis*

Based on questionnaire survey data, service continuity performance was evaluated as Less Effective because it has not achieved the ideal target of a continuous 24-hour supply, with water flowing for less than 6 hours per day.

- *Topographic Contour Variations*

The Pombewe Permanent Resettlement Area exhibits unique characteristics with a hilly terrain topography. As shown in Figure 4.18, elevations vary significantly from 190 meters down to 136 meters above sea level. This substantial elevation gradient between the main reservoir location and residential blocks causes residual pressure deviations within the piping network.

➢ *Analysis of Inhibiting Factors and Challenges to the Service Effectiveness of the Pombewe WSS*

Although the quantitative evaluation using the composite performance indicator matrix classifies the Pombewe WSS into the HEALTHY category, this achievement does not yet reflect an equitable distribution effectiveness level at the consumer level. The inhibiting factors and challenges affecting service effectiveness are as follows:

- *Physical Water Losses (Real Losses)*

Based on the survey and spatial mapping of leakage distribution across the Pombewe Permanent Resettlement Area WSS network, distribution efficiency remains constrained by 626 defect locations. These are dominated by non-technical water loss factors, specifically missing water meters at 567 customer connection points, which triggers billing inefficiencies and inaccurate consumption measurements. This condition is exacerbated by technical water losses (real losses) consisting of 16 underground pipe leakage points, 35 visible leakage points in front of customer premises, and 8 damaged valve units. Accumulatively, these anomalies impair flow control effectiveness, trigger volume wastage of clean water, and disrupt service continuity to consumers.

- *Head Loss Dilemmas Due to Topographical Variations*

Topographical variations across the hilly and terraced terrain of the Pombewe Permanent Resettlement Area represent a major obstacle to achieving equitable flow continuity due to significant head loss dilemmas. This condition creates an unbalanced hydraulic pressure distribution, where service areas at high elevations experience zero pressure that halts water flow during peak demand hours, while low-elevation areas receive excessive pressure (over-pressure), increasing pipe burst vulnerability.

- *Absence of Metering Equipment*

The most fundamental infrastructural constraint within the Pombewe Permanent Resettlement Area distribution unit is the absence of water meters at customer house connections (HC). The lack of volumetric measuring devices triggers two cumulative negative impacts simultaneously:

✓ Acceleration of Commercial Losses: The utility is forced to apply a flat-rate billing system, which administratively widens the gap between the water volume supplied from the main pipeline and the volume billed.

✓ Extreme Water Wastage: The absence of meters eliminates consumer incentive to regulate water usage. Customers tend to over-consume water for non-domestic activities, such as watering home garden plots.

- *Operational Budget Deficit for Human Capital Capacity Building*

Although the staff-to-1,000-customers ratio is evaluated as ideal (1:300 ratio), the competency level of operational unit staff faces major challenges due to the training cost ratio indicator remaining at Scale 1. This minimal budget allocation restricts competency-based training.

V. CONCLUSION

➢ *Based on the Discussion of this Study, the Following Conclusions Can be Drawn:*

- From the results of the WSS Performance Analysis, a score of 2.87 was obtained, placing this WSS in the "Healthy" category as its score exceeds the national critical threshold (> 2.8). This score indicates that the Water Supply System (WSS) has strong management, is considered independent, and is not at risk of severe operational dysfunction.

- The effectiveness of the Pombewe Water Supply System (WSS) in meeting drinking water demand in the Pombewe Permanent Resettlement Area (Huntap Pombewe) is rated as highly effective in terms of quality and quantity, but remains less effective regarding service continuity. Water quality parameters demonstrate superior performance and comply with Ministry of Health regulations through consistent turbidity reduction (0.13 to 1.03 NTU), stable neutral to slightly alkaline pH levels (7.8 to 8.2) to prevent pipe corrosion, and reliable residual chlorine disinfection (0.5 to 0.7 ppm) for active pathogen protection. Meanwhile, water quantity is guaranteed to be fully sufficient due to raw water availability calculated via F.J. Mock analysis reaching 24.21 L/s, which serves a total projected 2026 demand of 11.99 L/s across 4,479 Public Hydrant connections and 1,022 House Connections. However, continuity and distribution efficiency face severe constraints from 626 defect locations, predominantly consisting of non-technical water loss due to missing water meters at 567 customer connections, exacerbated by technical water loss including 16 underground leakage points, 35 visible leakage points, and 8 damaged valves. Accumulatively, these issues reduce flow control effectiveness, trigger billing inefficiencies, and disrupt continuous water supply stability to consumer households.

- The primary inhibiting factors and challenges affecting the performance and effectiveness of the Pombewe WSS in serving Huntap Pombewe stem from an accumulation of technical-hydraulic, infrastructural, and managerial constraints. The greatest challenges are dominated by

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infrastructure and water loss issues, specifically the absence of water meters at 1,516 customer connections, which leads to high commercial water losses due to flat-rate billing while triggering extreme water waste by consumers. This situation is further compounded by physical water losses from 16 underground leakages, 94 visible leakages, and 21 damaged valves. Concurrently, the hilly and terraced topography of the Huntap area creates significant head loss challenges, resulting in unbalanced hydraulic pressure distribution characterized by zero pressure at high elevations during peak hours and over-pressure at low elevations, which heightens the risk of pipe bursts. Mitigating these field constraints is further hindered by an operational budget deficit, as evidenced by a minimal training budget ratio for technical staff (rated at Scale 1), thereby limiting competency enhancement and human capital capacity to perform optimal maintenance and distribution system troubleshooting.

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