ADDIS ABABA UNIVERSITY

COLLEGE OF TECHNOLOGY AND BUILT ENVIRONMENT

School of Civil and Environmental Engineering

Assessment on sustainability of Rural Water Supply System in the case of Gimbichu Rural Woreda, Ethiopia.

A thesis submitted to the School of Graduate studies in Partial Fulfillment of the Requirements for the Degree of Master of Science in Civil and Environmental Engineering.

(Specialization: Water Supply and Environmental Engineering)

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APPROVAL

This is to certify that the thesis prepared by Midekso Dale, entitled '**Assessment on sustainability of Rural Water Supply System in the case of Gimbichu Rural Woreda, Ethiopia`** and submitted in partial fulfillment of the requirements for the Degree Master of Science in Civil Engineering (Specialization: Water Supply and Environmental Engineering) complies with the regulation of the university and meets the accepted standards with respect to originality and quality.

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ABSTRACT

All life as we know it on Earth depends on water, which is the basic need. Because of this, it is essential to maintain the sustainability of the water supply system. Protecting water resources requires using efficient water management techniques, such as conserving water supply sources and avoiding the disposal of trash and waste in bodies of water that could contaminate the water and disturb natural ecosystems.

General Objective: The general objective of this study is to assess the sustainability of rural water supply system and factors affecting them in rural areas of Gimbichu Woreda.

Methods: Data analysis methods, this research used was collect and analyzed relevant data on sustainability of the existing rural water supply system condition in the study area and factors affect them using descriptive, exploratory, ArcGIS with Arc Swat and Water GEMS.

Result: The study reveals that hydraulic performance, functionality, and management sustainability of rural water supply systems in Gimbichu Woreda were evaluated in this study. The results show that major hydraulic and institutional flaws seriously jeopardize long-term sustainability, even though some schemes have strong structural elements. The Haftu Seftu system model output results are characterized by elevated head loss gradients and reduced flow velocities in certain pipes, indicating that the system is unable to sustain water delivery effectively under the present conditions. The hydraulic performance of the Kersey Riga and Kersa Kemise systems has been performing better, however, the flow is regulated and hydraulic high levels are stable. Nonetheless, over time, localized high head losses and negative pressures continue to jeopardize energy efficiency, safety, and reliable service delivery. Shallow wells fitted with hand pumps and deep well generators/electric power are more than 50% likely to fail, the highest % of non functionality in the water supply system. Even if the hand-dug wells powered by solar energy function much better, no technology is reliable since there is no power bank to store energy during cloudy season. The improper governance of the community, lack of technical skills, insufficient source of funding, difficult access to spare parts, and the mismatch of local capacity with technology’s complexity are the major issues that obstruct sustainability.

The study finds that for Gimibichu woreda sustainable rural water supply an integrated hydraulic optimization approach to technology selection along with strong institutional and community structures is essential. Some key recommendations are improving the negative pressure zones, resizing pipes, upgrading the storage and pumping system capacity, and implementing regular hydraulic monitoring.

Encouraging solar and easily manageable technologies, strengthening local technical and financial capacity, decentralizing spare parts supply chains, empowering Water User Committees, and integrating demand management, groundwater recharge, and rainwater harvesting are all equally important. To guarantee resilient, equitable, and long-lasting water services in Gimbichu Woreda, such comprehensive interventions are crucial.

Kew word: Sustainability, Technical determinant, social determinant, and Environmental factors.

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Acronyms

FDRE………………………………………………...Federal Democratic Republic of Ethiopia

JMP………………………………………………..Joint Monitoring Program

MDGs……………………………………………..Millennium Development Goals

MOWE……………………………………………Ministry of Water and Energy

RWSS……………………………………………..Rural Water Supply System

SDGs………………………………………………Sustainable Development Goals

UNICEF…………………………………………United Nations Children's Fund

WASH……………………………………………..Water Supply, Sanitation and Hygiene

WHO………………………………………………World Health Organization

BCM………………………………………………..Billion cubic meter

GIS…………………………………………………Geographic Information System

NGOs……………………………………………….Non Governmental Organization

WASH………………………………………………Water sanitation and hygiene

WUCs………………………………………………Water User Committees

GPS…………………………………………………The Global Positioning System

MoWE………………………………………………Ministry of Water and Energy

FGD…………………………………………………Focus group discussions

KII…………………………………………………...key informant interviews

HHs…………………………………………………..House Holds

SWAT……………………………………………….Soil and Water Assessment Tool

HDPE………………………………………………..High-density polyethylene

HGL…………………………………………………..Hydraulic Grade Line

KPa……………………………………………………Kilo Pascal

J………………………………………………………Junction

L/s…………………………………………………….Liter per second

m/s…………………………………………………….Meter per second

m/km………………………………………………….Meter per km

HRU…………………………………………………..Hydrologic Response Unit

LU/LC…………………………………………………Land use/land cover

DEM…………………………………………………..Digital Elevation Model

UTM…………………………………………………………..Universal Transverse Mercator

MM………………………………………………………......Millimeter

Q…………………………………………………………….Cubic meter

SURF……………………………………………………….Surface run off

PRECIP…………………………………………………….Précipitation

ET…………………………………………………………..Evapotranspiration

PET………………………………………………………… Potentiel Evapotranspiration

PPU…………………………………………………………Précipitation Prédiction Uncertainity

CHAPTER ONE

1. INTRODUCTION

1.1 Background of the study

Ethiopia is geographically located in East Africa where the climate is complimented with relatively high annual rainfall and known as water tower in east Africa. The country receives high annual rain fall and rich with surface water sources such as rivers and lakes. However, the Ethiopian surface water bodies such rivers and rainfall patterns unevenly distributed in the geographic areas of the country. Most of the river water bodies are located in the western parts of the country such as Abay, Baro Akobo, Mereb and Setit Tekeze are parts of Nile basin which makes 70% the country`s renewable surface water resources through Abay basin and receives high annual rainfall unlike the northeast through Awash basin and east-flowing rivers through Wabi Shebelle and Genale-Dawa basin that receive normal to low annual rainfall. Therefor water supply source is more concentrated in western parts of the Ethiopia (Abay basin) and water stress is highest in the eastern parts of the country (Awash, Wabi Shebelle and Genale-Dawa basins). The country has 122 billion cubic meter (BCM) of river water,70 billion cubic meter (BCM) of lake water and 40 billion cubic meter (BCM) of ground water resources. ((Kidanewold, 2014).

Even though the water is a vital component of public health and development. So safe, sufficient, and easily accessible water is a fundamental human right (WHO, 2021). Despite the abundance of water resources and their importance to human existence, millions of Ethiopians, especially those living in rural areas are still do not have fair access to this sufficient and safe water supply ((UNICEF), 2020). The goal of this study is to evaluate the sustainability of rural water supply system in the Oromia region of Gimbichu rural woreda. It is essential to assess these systems' efficacy in rural areas for a number of reasons: Due to a number of issues, such as deteriorating infrastructure, low management techniques, lack of community involvement and many rural water supply projects struggle with long-term sustainability (Gerard J. van den Berg, 2018). Therefore, sustainability assessment of the rural water supply system determines its strengths and weaknesses in order to identify and recommend actions that will guarantee the system's long-term viability. However, in order to safeguard public health and safety, it is critical to evaluate the sustainability effectiveness of rural water supply systems in providing adequate, safe, and equitable water for public. In Ethiopia, unequal access to sufficient and safe water supply, particularly in rural areas can make already-existing social disparities worse.

So evaluation of sustainability of rural water supply system is also beneficial to determine inequalities in the provision of services and implement corrective measures to ensure that everyone has fair and reliable access to clean water. Water resource managers and policymakers can benefit greatly from data-driven evaluations. Using this data, water supply systems could be improved by setting investment priorities, allocating resources as efficiently as possible, and creating focused interventions((Moriarty P. , 2018). In order to maximize sustainability of rural water supply system, assessment aids in identifying areas that require improvement such as infrastructure design, ineffective rural water delivery systems, financial and environmental management techniques. Even though Ethiopia has made great strides recently, there are still issues with providing its rural residents with access to a sufficient and clean quantity of water. Thus, Ethiopia's Gimbichu rural woreda serves as an example of this difficulty. Even with the efforts of the government to improve the water infrastructure in rural areas, the sustainability of rural water supply systems is still an issue.

The study assessed the current water supply sources of the system (e.g., springs, boreholes, hand dug/shallow wells, deep wells etc.) and their capacity to service the growing demand of the system in a rural Gimmick district. An examination of the water pumps, pipelines, storage facilities, etc. closer to the site of the project was conducted to check if they are functional and meet the minimum requirements or not. The access, quantity, and quality of water, conforming to national and international standards and criteria, were rated as a vital aspect of a sustainable rural water supply system overall. The analysis considered funding sources and cost recovery strategies, community affordability of water services, the level of community participation in decision-making, a suitable system design, and user satisfaction with quantity of water and disruption of service. The sustainability of the rural Gimbichu woreda Ethiopian rural water supply system may be enhanced through various techniques' of assessment. The assessment results were significantly useful to stakeholders, project managers, and legislators involved in the rural water supply projects in Ethiopia.

The results of the study have made the identification of the possible weaknesses and the recommendations provided can contribute to improving the long-term sustainability of the present rural water supply scheme at Gimbichu rural woreda through understanding its strength and weaknesses. Gimbichu rural woreda sustainability status of water supply system of the area were evaluated with respect to four indicators. The four factors under consideration were system design, management perspective, technical and environmental impact and finally customer participation.

1.2 Statements of Problems

The provision of safe, sufficient and reliable water supply remains one of the constant challenges in rural Ethiopia. While the government has done much to tackle this work through the Universal Access Plan (UAP), One WASH National Program (OWNP) and SDGs framework. It is known that a significant portion of the rural population still relies on water sources that are not safe and adequate such as rivers, ponds or other unprotected springs. The challenge of rural water supply sustainability is especially critical in places like Gimbichu rural Woreda where systems built over the last decades have experienced frequent breakdown and very low levels of functionality. This scenario was negative effect to the health, productivity and general welfare of rural settlers. Ethiopia is rich in water resources with 12 main river basins, but its rural areas suffer from persistent water shortage. National statistics show an upward increment in the rural water supply over the years, with low levels of functionality rates for the completed schemes that range from 60–70 per cent (MoWE, Rural Water supply system coverage, 2021). A large proportion of the systems cease to operate soon after they are commissioned (maintenance is inadequate, system design is faulty and spare parts are unavailable) and there is insufficient sense of ownership by the community. In consequence, households that once benefited from better systems backslide into drinking water from unsafe sources, wasting public health gains and investments.

These national trends are clearly observed in Gimbichu rural Woreda. From the communities they were usually, lack of water, breakdown of systems and long distances to walk to access water points particularly during dry season. Its rural homesteads and kebeles rely on boreholes, hand-dug wells, and spring developments. Yet, most of these systems either work under capacity or no longer function because of inadequacy in maintenance, oldness facilities (infrastructure) and/or lackluster institutional follow-ups. As a result, women and children particularly are dedicating several hours a day for fetching water from unsafe and remote sources. Because of this, the communities/customers are left vulnerable to water washed and water-borne diseases and with less time for learning and earning.

Sustainability of rural water supply systems has been one of the largest challenges in Ethiopia WASH sector. Sustainability encompasses more than the ongoing physical operation of the water supply system; it also includes its institutional, financial, environmental and social elements over time. Renewed research and sector analysis has shown that 1 out of 3 water facilities in many rural regions of Ethiopia fail within a few years after being constructed. Such superimposing of poor water supply system projects on previously bad systems, known to fare poorly (and thus more about repeating the same cycle of investment over and again with no real gains), exhausts the already-scarce public health problem.

In Gimbichu Woreda, records in the woreda water office show that a large number of the water schemes especially hand pumps and shallow wells are non-functional. Pumping failure, pipe leakage or depletion of the source have led to complete collapse of some systems. Some others experience irregular supplies owing to power hindrances, unavailability of essential spares and absence of trained caretakers. The situation is only getting worse, with growing demand Outstripping the original systems' capacity owing to the growing population. With growing population, per capita water availability is declining leading household to depend on unauthorized and unsafe water sources. Factors which make rural water supply systems unsustainable are multiple and interlinked. Poor construction quality, low quality work, bad design are all technical factors that matter quite a bit. Many systems were built without hydrogeological studies, resulting in lesser yield or complete short time failure.

The supply chains for maintenance and spare parts are weak and routine inspections are infrequent. The technical shortcomings are often exacerbated by an accompanying set of institutional and managerial issues, such as the lack of capacity of local water offices, uncertainty over the roles of different WASH actors or the absence of follow up after completion of the water supply project. The community's ownership and involvement is another crucial factor. Water committees (WASHCOs) are established in many rural regions, but often lack the technical expertise, financial responsibility, or motivation to manage the systems. WASHCOs occasionally fail to operate, their bank accounts are dormant, or the irregularity of user fee collection is inadequate to meet operating expenses. When no one owns the ownership of the water supply system, communities are less likely to do simple repair or preventative maintenance, which leads to systems rapidly deteriorating.

The sustainability of the rural water supply system is constrained by socio economics. O&M budgets are generally insufficient. The worada water office lacks sufficient funds, and the user fees collected from households hardly cover the full maintenance or spare part costs. Rising inflation, soaring energy prices, and disengagement from the private sector are worsening the rural WASH situation. Consequently, minor breakdowns can go unresolved for months, keeping systems down for a long time. Water source reliability is influenced by environmental and natural factors like declining groundwater level, climate variability and land degradation. Due to dry seasons and repeated droughts, the yield of springs and shallow wells is reduced. Depletion and contamination of water sources due to overuse without protective recharge effort threaten sustainability. Deforestation and soil erosion on the catchment areas in Gimbichu rural Woreda aggravate the problem by reducing infiltration and groundwater recharge.

The impact of unsustainable water supply systems is very intense. When drinking-water systems break down, households are forced to rely on unsafe sources like ponds, rivers or unprotected springs, putting them at risk of water-borne and water washed diseases such as diarrhea, cholera, typhoid fever and trachoma respectively. Women and children are predominantly responsible for collecting water. As a result, they face the greatest burden walking long distances for several hours to fetch water on a daily basis.

Both of these have adverse impacts on health and safety, as well as the time available for education and livelihood. The absence of sustainable water services also deters rural economic growth Small enterprises, livestock and irrigation greatly depend on assured availability of water for productive activities. The disruption caused by systems failure of these activities perpetuates poverty as well as food insecurity. In Gimbichu Woreda, a number of people report eating less during the dry months, indicating water is interconnected with rural meal preparation. Despite interventions by government and development partners, there is limited empirical research done to systematically study the sustainability of rural water supply systems at local level in Ethiopia. Most studies only look at national figure or performance of the general sector which is of little help to show in details down to the woreda level. There is a need for an assessment that is evidence-based and localized to identify the technical, institutional, financial and environmental factors impacting sustainability for specific cases. In the case of Gimbichu Woreda households, while many water supply systems have been constructed with the help of NGOs and government projects, there is lack of sufficient data in terms of their current functionality status, the effectiveness of the management structures and the reasons for their failure or success. Unless such an assessment is not carried out, it would put local authorities and stakeholders to fix the design interventions or policies to ensure the long-term delivery of services. There is a need for a detailed study of the sustainability of these systems and lessons that can be scaled up to similar rural settings.

Ethiopia's development goals and the global SDGs, especially Goal 6: Ensure availability and sustainable management of water and sanitation for all, depend heavily on a sustainable water supply, that is why this research is so urgent. A sustainable rural water delivery, whatever profession it may, injects justice, gender equity, and rural development in addition to public health. Despite numerous efforts, Gimbichu Woreda, like other rural areas in the Oromia region, faces water shortages. Grasping the reasons behind system failure and the criteria to ensure their sustainability is key to directing investments.

In addition, an evaluation of Gimbichu Woreda rural water supply schemes provided valuable information on functionality and fitness to meet local demand. Roadblocks in the system's performance are caused by technical, financial, and managerial constraints. extent of community participation, ownership, and cost recovery.

The impact of various variables on long-term service delivery. To ensure rural population access to sufficient and safe water, the findings of the evaluation assist government agencies, NGOs, and community structures in improving their planning, monitoring, and support the systems.

Consequently, thorough evaluation of the sustainability of rural water supply systems in Gimbichu rural Woreda becomes essential. In order to improve the resilience and longevity of Ethiopia's rural water supply systems, this study found the underlying factors influencing system performance, exposed operational and management gaps, and offered evidence-based recommendations.

1.3. Research Objective

1.3.1. General Objective

The general objective of this study is to assess the sustainability of rural water supply system and factors affecting them in Gimbichu Woreda rural areas.

1.3.2. Specific Objectives

The specific objectives of this study will be the followings.

- To analyze the design of rural water supply system to meet adequate water supply for the current and future projected daily water demand of rural population in rural Gimbichu Woreda.
- To assess the current functionality status of rural water supply system in Gimbichu rural Woreda.
- To analyze the technical and socioeconomic factors influencing the sustainability of rural water supply system in Gimbichu Woreda.
- Sources of ground water balance estimation and determination of environmental impacts on its sustainability of water supply system in Gimbichu rural woreda.

1.4. Research questions

The following research questions will be aimed to address each specific objectives of the study

- Does the design of rural water supply system adequate to serve current and future projected daily water demand of rural population in rural Gimbichu Woreda?
- What is the current operational status of the rural water supply system in Gimbichu Woreda?
- How do the technical and socioeconomic factors influence the sustainability of the rural water supply system in Gimbichu Woreda?
- How to estimate sources of ground water balance and determine environmental impacts on sustainability of rural water supply systems in Gimbichu rural woreda?

1.5. Scope of the study

Geographical Scope: The research was focused on Gimbichu rural Woreda, Ethiopia, covering selected rural kebeles and communities within the woreda.

Thematic Scope: The study addressed various dimensions of rural water supply sustainability, including infrastructure, socioeconomic factors, and environmental impacts.

Limitations of study: The availability of trustworthy information, inaccessibility to specific locations specifically to area bordering to the north of the woreda for the security reason and resource limitations were some of the limitations that hindered data gathering and assessing water quality part respectively. Security issues rendered two kebeles inaccessible for this study’s data collection from Gimbichu rural worked. As a result of constraints of funding, the water quality component, which requires laboratory testing, is not addressed in this research.

Temporal Scope: This study covered both functional and nonfunctional assessments of the sustainable rural water supply system of Gimbichu rural woreda.

1.6. Significance of the Study

The research study on the sustainability of rural water supply systems in Gimbichu rural woreda is very important both for local development and for the general knowledge of rural water management in Ethiopia. Similar to other parts of the country, the rural community of Gimbichu suffers from water shortage, breaking down of current programs, and unequal access to drinking water. This study provides helpful information to communities, practitioners, and policymakers by examining these issues.

An important area of concern in the design of water delivery systems is the constraints. Many rural water supply programs were built without much technical investigations in the first place. So, they are not suitable for long-term use. Moreover, changes in the environment also affect these rural programs. Highlighting design flaws can help future planning and make water delivery infrastructure more robust, flexible and sensitive to local conditions. The study is essential for enhancing customer involvement. Infrastructure alone cannot guarantee for sustainability of rural water supply system but users must also become actively involved in operations and maintenance, decision making, management practices, as well as land use and land cover. As per the study that has surveyed how the degree of involvement is very critical in enhancing ownership and group accountability towards reducing the system's failure and ensuring a fair service delivery.

The increasing of the population has created high demand load on water supply system. Many rural systems have failed to adapt to demographic changes as they have been developed for smaller populations. This leads to excessive use, constant damage and deteriorating water quality. As a result, guide strategies for upgrading and expanding water schemes to meet current and future demands is mandatory. Due to the poor institutional arrangement, deficient maintenance and lack of accountability, rural water supply systems often have short lives. Low-quality water management also contributed to environmental degradation, like groundwater mining, and erosion around water bodies. This is an evidence for strengthening regional management frameworks and encouraging ecologically friendly behaviors that could be provided by this study.

All things considered, the importance of this study resides in its capacity to provide useful ideas that improve the long-term efficiency, fairness, and environmental sustainability of rural water supply systems in Gimbichu rural Woreda.

1.7. Summary of the Research

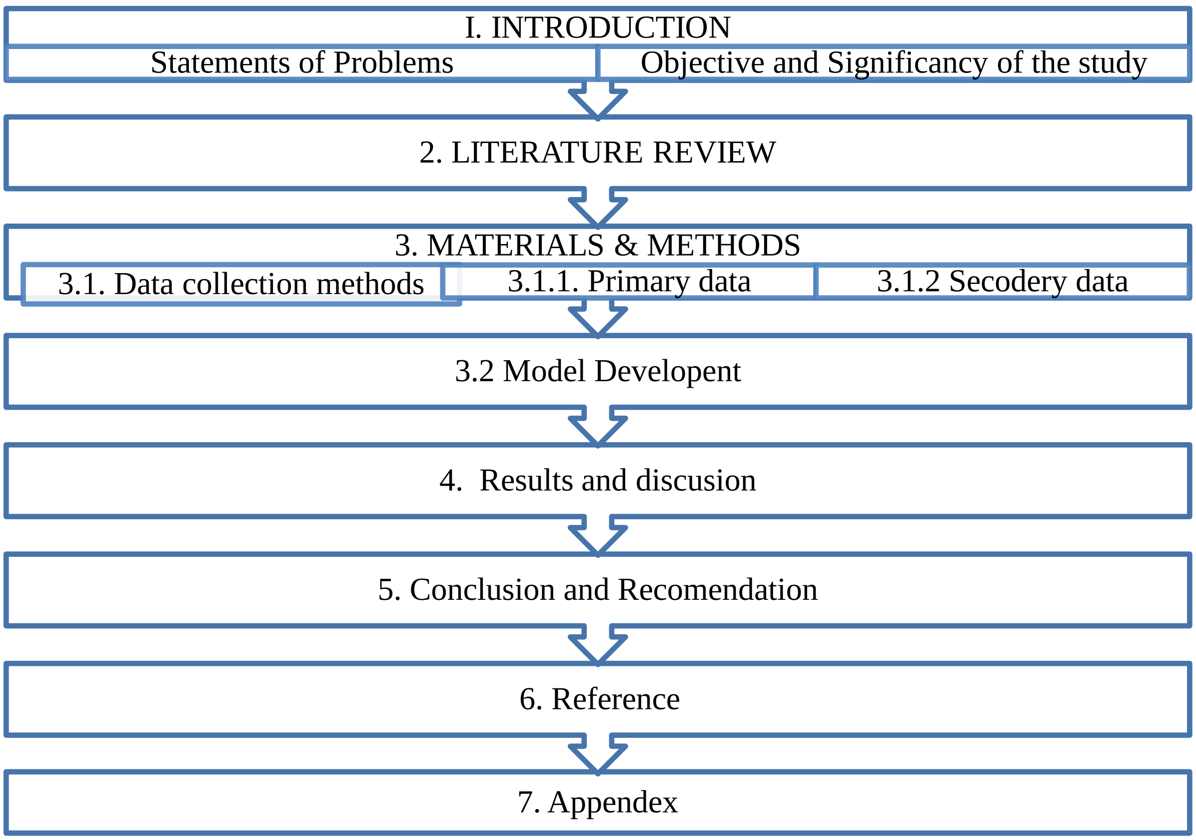


Figure 1. Summary of Research

CHAPTER TWO

2.LITERATURE REVIEW

2.1 Sustainability of Rural Water Supply Systems

Numerous studies on the sustainability of water supply systems have been published in the water supply literature. The essential components that characterize the sustainability of water supply systems are determined, including design of the system, service accessibility, user satisfaction ratings, water usage, household water fee levels, system management, operation stability, critical asset managing and organizational sustainability (e.g., the organizational structure, leadership capabilities, and human resource, standards of the system((Ewa Ociepa *, 2019). Several studies also highlight the conditions that must be fulfilled to ensure the long-term sustainability of the water supply and usage system, such as the sustainability of input water sources; The ability to design well designed system; the ability to manage resources; the ability to progress technology; and the ability to regularly access water, generalized those criteria to form technical, social, environmental, financial, and organizational sustainability dimensions. To emphasize the importance of sustainability((Akhbari, 2011) , declared that in order to reach the goal of ensuring that everyone has access to clean drinking water, the sustainability concerns with water supply infrastructure must be recognized. Therefore, academics have paid close attention to how to evaluate the sustainability of water systems.

But the water supply system's sustainability is a major factor in determining the sustainability of the water supply, as well as the financial stability of system operations. The risk to the water supplier's survival will increase if the operator of the water supply lacks the necessary source of finance to maintain or enhance the quality of the water service, build up capital for reinvestment, or update the system. Insufficient finances for Operation and maintenance, rehabilitation, repair, and replacement of the system will lead to ineffective service provision, which will have an adverse effect on water consumers. A vicious loop in the water supply can be caused by underperforming water systems. In a vicious cycle, the quality and frequency of the water supply service are not guaranteed, so people do not trust to use it frequently. This results in low revenue, low profit, and a lack of capital to invest in or buy necessary services and equipment. Consequently, regular maintenance and repair of machinery and equipment is not implemented, which prevents the water systems from operating profitably and efficiently (Gibson, 2020).

2.2 Characteristics of Sustainable Water Supply Services

What customers get is what matters to sustainability. The delivery of services is significantly more involved than the delivery of infrastructure. Among the daily concerns involved in providing a water service are monitoring the service provided, testing the quality of the water, repairing, upgrading, and replacing. Securing the service over the long run involves planning, regulation, charge setting, financing, performance monitoring, upgrading after the design period. That is an extremely difficult task that involves management, governance, the creation and implementation of policies, capacities, and transparency. That is far more complicated than installing and/or changing individual infrastructure components. But there is not another option.

A sustainable water service is one that continues to provide users with access to both adequate quantity and quality of water ((Planning and Design of Sustainable Mohammad Karamouz, 2019). The following are the particular markers of sustainable water service:-Amount, expressed in liters per capita per day (l/pc/d), Quality as measured by one or more distinct chemical and biological quality parameters , The distance between a home or the community center and a water source, The quantity of individuals sharing a resource, sometimes known as "crowding or queuing time," In terms of the percentage of time the service operates at its designated level, reliability((Allan, 2018).

The fundamentals of providing services in a more sustainable manner. In their opinion, the following foundational elements must be in place in order to provide a sustainable water supply service: professionalization of community management; increased awareness of and support for alternative service provider options; sustainability indicators and targets; post-construction assistance for service providers; capacity support for decentralized government (to the service authorities); learning and sharing of experiences; asset management planning specially critical assets; financial planning frameworks to cover all life cycle costs; regulation of rural services; and service providers((Tortajada, 2018).

According to, for the sustainability of a rural water supply service, the supply should be increased from 20 to 25-40 l/c/d; isolated source schemes should give way to rural water schemes with distribution; and tariff models should guarantee that the costs of providing rural water services, not just operation and maintenance, are covered (Energy E. M., 2022)

2.3 Tools of analysing sustainability of rural water supply system

Measuring the sustainability status of any infrastructure is a complex job and offers many opportunities for argument. The long-term functional sustainability is a desired output expected in the infrastructure sector and is complexly governed by several factors and sub factors ((Peter Reed, 2017).

2.3.1 Gender Analysis Snapshot (GAS)

The GAS was established by the international NGO CARE to look into the relationships between project effectiveness, WASH sustainability, and gender parity in Northern Ghana. The twenty-two indicators that make up the GAS focus on four areas: water resources, household decision-making, women's empowerment, and access to public places and services.

Each indicator's final score for the community is determined by averaging the individual scores, which are then combined to provide an overall value that can vary from 21 to 90. Greater scores signify greater gender equity in the community, whereas lower values signify less gender equity. The GAS tool's questions are straightforward, the procedure may be incorporated into planning and monitoring efforts to guarantee that the viewpoint of the community is reflected, and it can provide information on how men and women perceive gender empowerment and equity. These are a few advantages of the tool. Uncertain assumptions behind the sample framework's scoring patterns, the requirement for a specialist with training in participatory processes and facilitation approaches, and the potential for the GAS to be overly simplistic when used alone are some of the limitations of the GAS Tool.((Biswas C. T., 2017).

2.3.2 The Governance into Functionality Tool (GIFT)

The Governance into Functionality Tool, which consists of 20 questions, assesses how well community governance organizations maintain public water points in four areas: involvement, accountability, transparency, and cost recovery. Key informant interviews or focus groups can be used to answer the twenty indicator questions. The values of each indication range from one to three. An area score, which can alternatively be displayed as an overall score (percent), is produced by adding these scores together. The GIFT's participatory process, which solicits feedback from stakeholders at the community level, is one of its benefits. After scoring, its simple aggregation process can be managed by non-WASH professionals. GIFT's shortcomings include its narrow emphasis, which might be expanded upon, and the method by which the indicators are scored to the community level((Vairavamurthy, 2014).

2.3.3 Water Aid's Sustainability Snapshot Tool

The global non-governmental organization Water Aid developed the sustainability snapshot tool in 2003 as a fundamental screening tool for sustainability. By rapidly assessing the fundamental technical, financial, and equipment-spare parts aspects of a rural water supply service in a comprehensive but condensed manner, this tool generates a score that offers a brief overview of the sustainability state of the service. One of its shortcomings is the lack of integration and breadth of industries beyond the financial and technological sectors. One of its advantages is its ability to quickly evaluate the sustainability status of a rural water distribution business((Alegre, 2017).

2.3.4 WASH Life-Cycle Assessment

It is used to assess finished water and sanitation projects and was created by McConville as part of a master's thesis. Its framework consists of a matrix with five project life stages (needs assessment, conceptual design and feasibility, design and action planning, implementation, operation and maintenance) and five sustainability factors (sociocultural respect, community participation, political cohesion, economic sustainability, environmental sustainability((Angelakis, 2018).

The methods of scoring include a checklist consisting 100 sustainability recommendation questions (4 per matrix element), a rating (0-4) for each matrix element that provides an overall sustainability score on a scale of 0-100 and a score for each project life stage and each sustainability factor (out of possible 20 points) presented on a radar diagram (Lundqvist, 2018).

The instrument has been used in completed projects involving water and sanitation in Uganda, Benin, Mali, and Honduras. The tool's advantages include being simple to use, helpful for evaluating projects after they have been implemented, and able to evaluate a project's sustainability at every point of its life cycle using a life cycle thinking approach (Sharma, 2019). The tool's drawbacks include its separate planning of each life stage and its omission of sustainability factor weighting from the scoring system.

2.3.5 Sustainability Assessment Tool (SAT)

The Swiss community of practice, AGUASAN, developed the SAT, which is a tool for assessing program interventions that are currently underway and helps with the planning of upcoming WASH projects. The SAT has twenty-two indicators with two to eight sub-indicator questions for each of the economic, environmental, institutional, knowledge, social, and technological components of the WASH program intervention. A pilot test of the tool was conducted in 2010 as part of an assessment of Kosovo's rural water systems One of the benefits of the SAT is that it shows how a sector should be improved to promote sustainability because of its comprehensive coverage of the examination of knowledge, institutional, social, economic, environmental, and technological variables. The SAT's limitations include its vast number of indicators and sub-indicators (22 and 110) and its restricted use((Singh, 2019).

2.4 Tool for Planning, Predicting & Evaluating Sustainability (TOPPES)

TOPPES was established in Ghana by WSA (Water and Sanitation in Africa). The TOPPES forecasts the sustainability of service delivery for WSA projects based on technical, financial, O&M, institutional, socioeconomic, water resources/quality, and environmental requirements. There are twenty-three indicators in total for each aspect, and they are scored by answering ninety-two yes/no sub-indicator questions. Scores are weighted after the field test according to the importance assessments made (Programme, 2022).

The communities where data will be gathered are chosen from a comprehensive list of localities with projects using a case study technique and a judgmental sampling strategy. After that, data is collected through focus groups with water committees, physical inspections, and, in some cases, district-level data integration. The outputs produced by TOPPES are derived from the sustainability score results that are categorized as sustainable, partly sustainable, or not sustainable. The instrument's strengths include its comprehensive assessment of the several sustainability criteria and its capacity to serve as both an evaluation tool at the end of the project and a planning tool during the pre-project phase. One of the tool's drawbacks is that it can only be used for water distribution, ignoring hygienic considerations (Kumar, 2007).

2.4.1 Sustainability Index Tool (SIT)

USAID and Rotary International established the SIT in 2012. The SIT assesses the sustainability of WASH services from an institutional, management, financial, technical, and environmental standpoint. Each factor consists of sub-questions that are not weighted. Data collection approaches include site inspections, household and key informant interviews, service, district, and national focus groups, policy document evaluations, and technical standards and norms. After the data is collected, the results are shown graphically as aggregate scores. Because it provides a comprehensive quantitative assessment and integrates both urban and rural activities, it has the potential to be scaled.

2.4.2 Water GEMS Software

A Bentley Water GEMS is for hydraulic modeling simulation for water distribution systems, Water Gems v8i offers improved interoperability, geographic model development, and network optimization. Water Gems V8i offers engineers a user-friendly environment for designing and analyzing water distribution systems.

The computer program Water Gems v8i simulates hydraulic and water quality behavior in pressurized pipe networks using a long period of time. Pipes, nodes (i.e., pipe connections), pumps, valves, and storage tanks or reservoirs make up a network. Water Gems displays the pressure at each node, the height of water in each tank, and the flow and velocity of water in each pipe. Calculated residual chlorine can be analyzed at every node.

In Water Gems V8i software diameter of the pipe has been designed using Darwin designer tool. Input parameter of Darwin designer tool: maximum pressure (80 m), minimum pressure (10 m) and pressure constrain elements (i.e., nodes of distribution network), minimum velocity (0.3 m/s), maximum velocity (1 m/s).

2.5. Types of variables

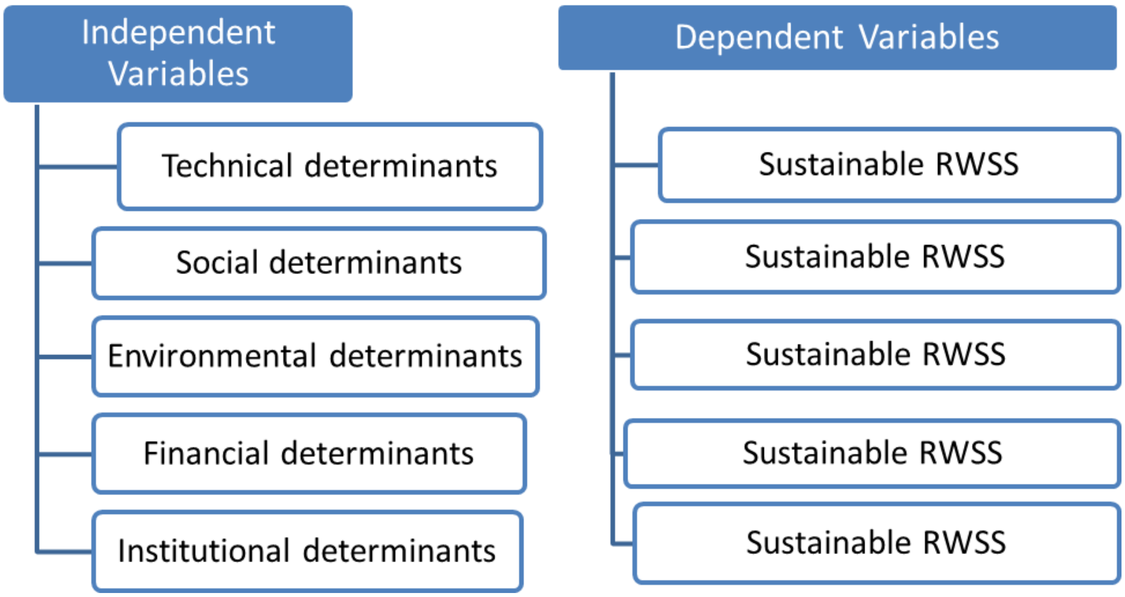


Figure 2: Independent and dependent variables

The five main areas of sustainability of WASH services are referred to as the "FIETS" (financial, institutional, environmental, technical, and social elements), according to the Dutch WASH Alliance (DWA)(DWA, 2014).

2.6 Identifying indicators of sustainability

A survey of the literature on the sustainability of water supply systems and component groups, as well as current indicators, was used to choose the index's components and indicators(Guppy, 2014). Therefore, five representative components served as the foundation for the creation of the rural water supply system sustainability indicators technique in this study. Water shortage, water use, and water access are influenced by a variety of technological, institutional, economical, social, and environmental factors.

2.7 Technical determinants

The world bank report (World-Bank, 2012),declared that 15% of water loss for non-revenue water should be taken into account while building a rural water delivery infrastructure. It goes on to say that the water pressure should be between 3 and 70 meters, and the head loss should be between 0.50 and 10 meters every 1,000 meters. According to Ethiopian design guidelines, a public tap's high pressure should be brought down to the permitted range of 2 to 5 meters by using a pressure-reducing valve or break pressure tank (MOWR, 2006).Well siting and construction such proper geological assessment and well siting which ensures to access sufficient and sustainable ground water sources while avoiding contamination risks. Selecting appropriate water source (Spring, boreholes) is dependent on factors like water yield, local geology, and community needs. Careful consideration ensures a system that meets current and future water demands. In terms of material selection and construction quality, the durability of the system depends on the use of suitable, long-lasting materials during construction. System failure and malfunctions were caused by subpar materials. Water delivery systems should be constructed with climate variability in mind in order to be climate resilient. This can entail installing rainwater harvesting systems or drought-resistant technologies. Asset management includes things like asset location, customer service agreement level, life cycle costing, and key assets. New technologies like solar panels use electricity instead of fuel.

2.8 Financial determinants

The World Bank's national tariff-setting guideline states that a tariff is appropriate if it doesn't exceed 5% of the household's income. It offers additional elucidation. Tariffs of about 0.40$ per m3, or about 8 Ethiopian birr per m3 at the current exchange rate of 21 birr for every USD, are sufficient to cover O&M expenses in low-income sub-Saharan countries like Ethiopia. The average household income in the service region shall not be more than 5% of the tariff rates.

There is a substantial finance gap in the first level of WASH financing, which results in non-functional water systems since there are insufficient resources for operation and maintenance (O&M). It is necessary to investigate important cost recovery strategies. Effective water user fees collection and a willingness to pay are necessary for covering O&M. Planning for Life Cycle Costs (LCC): Future maintenance and repairs are not adequately budgeted for when LCC planning is lacking. Monitoring system functionality that enhances Ethiopia's rural water supply financing

Functional monitoring systems lower overall costs by enabling early problem identification and ensuring prompt interventions to avoid system failures. The availability of spare parts is enhancing Ethiopia's rural water supply financing. For prompt repairs and system maintenance, a dependable supply chain for spare parts is necessary, reducing downtime and related costs. Effective O&M depends on the financial stability of the Water User Committees (WUCs) in charge of overseeing water points. Funding gaps can be filled in part by government grants or subsidies, especially for low-income communities.

2.9 Social Aspects

According to Ethiopia's universal access plan for rural water supply, the community should be consulted on all proposed water supply services, including public discussions, agreement on the service, selecting preferred alternatives among feasible options, consulting women regarding the location of the water point, and community commitment to share investment costs. According to the Rural UAP, the neighborhood shall contribute at least 5% in cash and 5% in labor and in-kind.

2.10 Institutional Aspects

The monopolistic control of a region by certain drilling corporations, the discriminatory licensing or registration procedures chosen for drilling companies, the skewed use of monitoring data (such coverage) for political or financial gain, The analysis conducted by indicates that the shift to local-level procurement under decentralization poses a substantial risk of corruption. framework of laws and regulations. For water resources to be managed sustainably, a robust legal and regulatory framework is necessary. Laws and rules governing pollution control, water quality, water allocation, and water use efficiency should all be part of this framework. The ability to create and carry out efficient water management plans must be possessed by the institutional capability in charge of managing water resources. This means having the necessary money, workforce, and technical expertise. It is essential to plan, develop, operate, and maintain water supply systems with community participation. If possible, this will ensure that the systems are durable and responsive to community needs. It is essential for the public to be made aware of the importance of water. This can be achieved through public education and communication campaigns. The cost of service must be reflected in the water tariff. It would make it easier to prevent the wasteful use of water and ensure efficiency.

Sufficient resources to upgrade and maintain water delivery infrastructure. In order to resolve disputes over water resources, conflict resolution procedures must be in place. This will make it easier to guarantee that water is distributed fairly and that disagreements don't get in the way of managing water resources sustainably.

2.11 Environmental Aspects

More than half of rural households are expected to have used boreholes, springs, tube wells, and protected wells by 2020. Of these sources, only boreholes and tube wells are believed to be climate change resistant. If not properly maintained, these sources might not be sustainable even though they can survive climate change. According to the country's One WASH national program, rural residents must have access to 25 liters of water per day within a 1.5 kilometer radius.

CHAPTER THREE

3.MATERIALS AND METHODS

3.1. Description of the study area

Gimbichu is the woreda found in east shoa zones, Oromia Region, Ethiopia. It is 41km far from Capital City Addis Ababa and bordered on the south by Lome, on the southwest by Ada'a Chukala, on the northwest by the Amhara Region, and on the east by the Afar Region. Its administrative center is Chefe Donsa.

According to 2015 national census report, the total population of Gimbichu woreda is 86,902, out of which, 80,572 are rural and 6330 of its pop are urban dwellers of whom 45,126 were men and 41,776 were women.

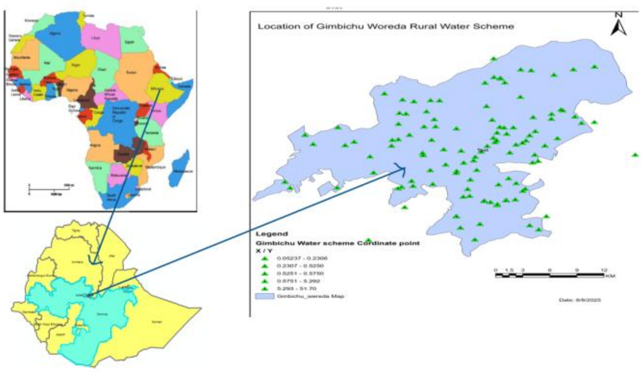


Figure 3: Map of Gimbichu rural Worda with water scheme location

The altitude of Gimbichu woreda ranges from the 2700m to 3100m above sea level. It consists of three Argo-climatic zones. These are Mountain, Temperate and warm semi-desert which comprise about 52 %, 27 % and 21 % of the area of the woreda respectively.

The Woreda's surface pattern is somehow diversified, and it consists of all types of landforms namely, deep valleys (13 %), plains and plateaus (85 %) and mountains (2 %). The widely observed landforms of the woreda are plateaus. The highest mountain in the woreda is Boka Mountain with the elevation of 3100m above sea level which share boundaries with Bui Dengago Ganda.

The Gimbichu Woreda used four sources of water for drinking purpose and a total 244 water schemes. These sources of drinking water are fifteen deep well (borehole) fitted with fuel generator and electric power, 158 hand dug well, thirty-five shallow well fitted with hand pump, ten shallow well fitted with solar system and twenty-six on spot springs with gravity system. The coverage of water supply coverage for Gimbichu rural woreda is 71 %.

3.2. Research Design

The systematic sampling methods was used in this research which employed descriptive and exploratory methods together to generate, and analyze relevant primary and secondary data which was reviewed on the current water supply system situation in study areas of Gimbichu rural woreda. The data incorporated factors affecting sustainability of rural water supply system which was provide safe and adequate water for the rural community. Descriptive, exploratory and software such, excel, 10.5 version of ArcGIS with Arc SWAT 2012, and Water GEMS 2024 version was used.

Descriptive research is a foundational methodology in scientific inquiry that aims to provide a detailed representation of a population, situation, or phenomenon. Unlike explanatory research which seeks to understand cause-and-effect relationships, descriptive research focuses on the what rather than the why. By employing various methods like surveys, observations, and case studies, researcher gathered data on characteristics, frequencies, and trends within the subject of study of sustainability of rural water supply system. Building a rich understanding of its current state and laying the groundwork for further investigations.

3.3. Data type

In this research both quantitative and qualitative data were collected from water supply system(schemes),households and secondary data review with structured questioners by using KOBO TOOLBOX and GPS coordinate system which was uploaded on smart phone integrated with observation, daily rainfall data such as Temperature, humidity, solar radiation, wind speed and precipitation were taken from national metrology agency office and daily flow rates of Mojo and Kesem rivers were taken from Ethiopian MoWE office. Qualitative data were obtained through structured open-ended questioners by using data collection tools such as focus group discussions/FGD/,observations and key informant interviews/KII/.

3.4. Data sources

All the sources of required data for the study of sustainability of rural water supply system were obtained from both from primary and secondary data sources. Primary data were collected from 318 households, water supply scheme observation, focus group discussions/FGD/ and key informant interviews/KII/ with stakeholders and customer representatives. Additionally, valuable insights were obtained through discussions with water users. The sources of secondary data on sustainability of rural water supply system were gathered from secondary data review from Gimbichu woreda rural water office, daily flow rate of Mojo and Kesem rivers from Ethiopian MoWE to calibrate Arc SWAT model output. Temperature, humidity, solar radiation, wind speed, and precipitation were obtained from national metrology office. Water scheme data such as well depth, elevation, reservoir capacity and elevation, pipe diameter and junction/tap stand elevation were obtained from secondary data review, measurements conducted on the field and collected through GPS coordinate point by using KOBO Collect Tools.

3.5 Sampling Techniques and sample size

The study was carried out on one hundred fifty-two water schemes (one hundred functional and fifty-two non- functional) schemes were selected by simple random and purposive sampling methods. A household survey concerning the demand responsiveness of customer satisfaction in water access, quantity, fetching time, fee collection and customer participation during site selection, Pré construction, during construction and post construction phase was conducted at 393 households by using finite Sample size since the population is less than 50,000.

Sample size calculation for House Holds

$$SSHH = \frac{Z^2 \times (p) \times (1-p)}{C^2} = \frac{(1.96)^2 * (0.52)^2}{(0.0488)^2} = 403$$

$$\text{New SSHH} = \frac{SSHH}{1 + \frac{(SSHH - 1)}{\text{Pop in HH}}}$$

$$\text{New SSH} = \frac{403}{1 + (403 - 1)} = 393\text{HHs}$$

Sample size for water supply system/scheme.

$$SSWS = \frac{Z^2 \times (p) \times (1-p)}{C^2} = \frac{(1.96)^2 * (0.5)^2}{(0.0488)^2} = 403$$

$$\text{New SSWS} = \frac{SSWS}{1 + \frac{(SSWS - 1)}{WS}}$$

$$\text{New SSWS} = \frac{403}{1 + (403 - 1)} = 152\text{WS}$$

15554HH 244WS

Where= P= 50% of participation level of the community, a conservative Proportion which yield maximum sample size.

C= Confidence interval(C=0.0488),

Z = critical value at 95% confidence of certainty(=1.96)

From water supply scheme, 152 water schemes were selected to be surveyed for this research and each scheme categorized as follow by stratified sampling method.

These were ten deep wells (borehole), ninety-eight hand dug wells, twenty-two shallow well fitted with hand pump, six shallow well fitted with solar system and sixteen on spot springs with gravity system.

But since the cases were similar, three deep well (borehole), thirty hand dug well, seven shallow well fitted with hand pump, two shallow well fitted with solar system and five on spot springs with gravity system were proposed for this research.

3.6 Data collection Techniques

Weather data such as Temperature, humidity, solar radiation, wind speed and precipitation were obtained from national metrology to evaluate effects of land use-land cover on water source and daily flow rates two rivers were taken from Ethiopian MoWE office for calibration of Arch SWAT. Data on factors that may hinder the sustainability of rural water supply system were gathered through employing multiple methods including structed questionnaire, Focus Group Discussion/FGD/, Key Informant interview/KII/ and observation to existing water supply problems in the study area. Prior to the actual data collection, pre-testing of the KOBO Collect Tools with questioners including GPS coordinate point was installed and uploaded on smart phone. Also its ability to capture GPS coordinate for each sample HHs as soon as possible was checked and validated before to start actual data collection.

3.7. Data Analysis

To analyze the data collected, a combination of quantitative and qualitative analysis methods were employed. Data collected from water scheme to evaluate hydraulic design such as pipe length & diameter, well depth, pump position, reservoir capacity and elevation, Junction/Tap stand demand and elevation, pump definition, types of valve and pipe materials were analyzed by using Water GEMS software models. Hazen–Williams Equation was used during Water GEMS model analysis.

$$H=10.65\frac{Q^{1.85}}{C^{1.85}}\frac{L}{d4.87}$$

Where

H – head loss in m

Q – flow rate in L/sec or m3/sec

L – length of pipe in m

d – diameter of pipe in cm

C – Hazen-William's coefficient (dimensionless) and

150-C Values used since most HDPE pipes are olde.

The Hazen–William's equation is an empirical relationship which relates the flow of water in a pipe with the physical properties of the pipe and the pressure drop caused by friction.

Population projection equation was used for projection water demand and to check whether there was the plane to upgrade the current water scheme for future population projection using Geometric

Geometric population projection method

$P_n=P0*(1+r)^n$

P_n =Forecast population after n decades from the present population

P_o =Population at present

R= Percent of population growth rate

n = Number of decades

Quantitative data, which generate from household survey was analyzed using descriptive statistical tools like frequency percentages using micro soft excel. The qualitative data collected by using Key Informants Interview/KII/, Focus Group Discussion/FGD/and observation were analyzed through description and exploratory. Document review of secondary date was analyzed using description and exploratory. Daily weather data such as Temperature, humidity, solar radiation, wind speed, precipitation, and daily flow rates of two rivers were used for calibration and validated using 10.5 ArcGIS with Arc SWAT software models to evaluate water balance and Environmental impact in under ground water source.

3.8. Data Presentation

The data was analyzed and presented with narrative, graphs, charts, Model output/result tables, graphs and photos using power point. Overall methodological Approaches for assessment of sustainability of rural water supply system by chart.

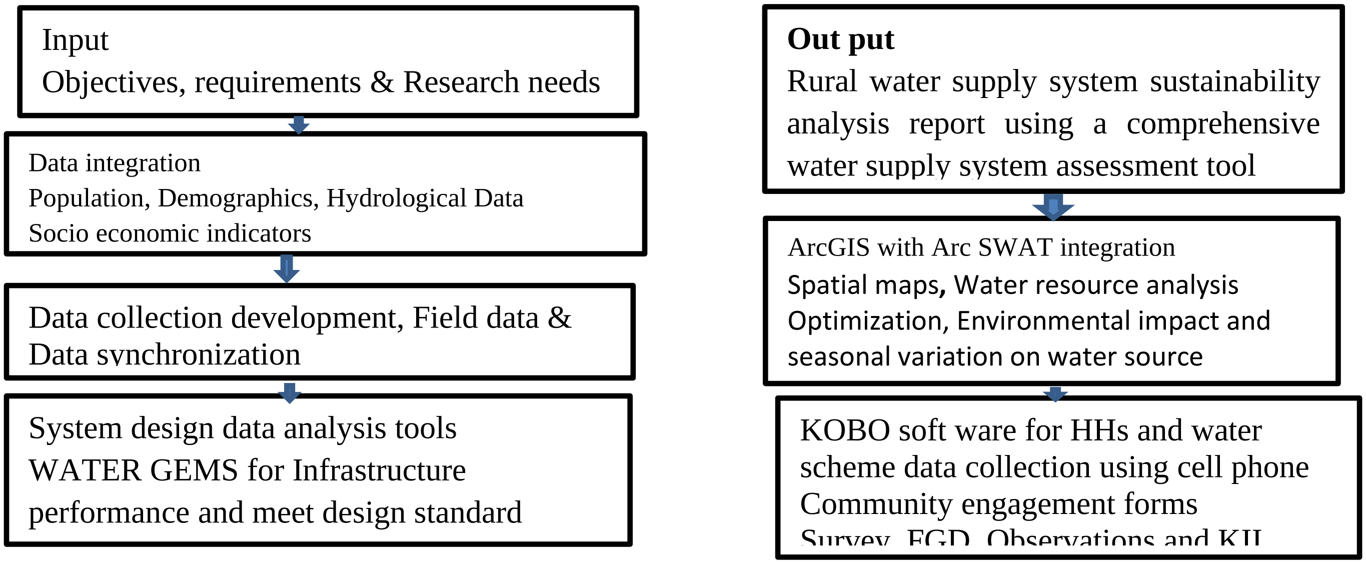


Figure 4: Study flow chart

Table 1: Determination of system sustainability of rural water supply system in Gimbichu Woreda

Components	Attributes	Indicators	Tools
Institutional	Monopolistic position of some drilling companies over a region, Biased selection of licensing or registration practice and procedure for drilling companies, Distortions in use of monitoring information for political or funding ends, Risk in shift to local-level procurement under decentralization	Days Without Repair, Spare Parts Availability, Construction Supervision Form, Water Technician Availability, Training On Operation and Maintenance, Training On Procurement Management, Asset management	FGD, Observation, Survey, interview and KII

Technical	Population distribution, water consumption patterns, peak demand periods, unaccounted for water (UFW) levels, Age and material of pipes and pumps, leak detection and repair frequency, infrastructure maintenance plans, vulnerability to natural disasters	Population density maps, water meter readings, pressure variations in the network Pipe network maps with material and age data, historical repair records, disaster risk maps, visual inspection reports	ArcGIS, Arc SWAT and Water GEMS
Financial Sustainability	User fees and tariff structure, cost recovery rate, operation and maintenance costs, potential funding sources	User fee collection data, cost-revenue analysis, O&M expenditure reports, grant applications and approvals	HH Surveys, Focus Groups and KII
Social Equity and Community Participation	Affordability of water for low-income communities, equitable access to water points, user satisfaction with service, community involvement in decision-making	Water tariff structure analysis, distance to water points for different communities, customer satisfaction surveys, participation records in community meetings	HH Surveys, Focus Groups, Observation and KII
Environmental Impact	Water source depletion potential, impact on aquatic ecosystems, water conservation practices, potential for water reuse	Groundwater level changes, environmental flow assessments, water use efficiency metrics, water reuse feasibility studies	GIS with Arc SWAT

3.9. Ethical Consideration

In this study, approval for this study was formally obtained from Addis Ababa University, College Of Technology And Built Environment.

In addition, formal consent was obtained from each participant/sampling unit before data collection was commenced. The research was undertaken to protect the rights of the respondents by ensuring that none of the respondents name were note mentioned during the research or subsequent thesis. Respondents was select to participate without compulsion. All respondents were properly informed the reason and purpose of the research and informed consent was obtained from the management of the Gimbichu rural woreda water office and selected organizations before the commencement of this research initiative.

CHAPTER FOUR

4.Results and Discussion

4.1. Analyzing the design and installation of water supply system to meet adequate daily water demand of current and future projected population.

To achieve this objective, the research is carried out using Water GEMS model which is a hydraulic modelling software application offered by Bentley Systems. Water GEMS allows for detailed modeling of a water distribution system under steady-state and extended periods. The software enables the analyst to perform a feasibility analysis of pipe networks, pumps, storage tanks and demand through system performance, deficiencies and design alternatives. The software offers evidence-based insights into system capacity and sustainability by modeling different demand scenarios and population projections. These model also aims to evaluate the hydraulic performance of water supply system by comparing with the standard criteria of the Ethiopian MoWE set for rural water supply system.

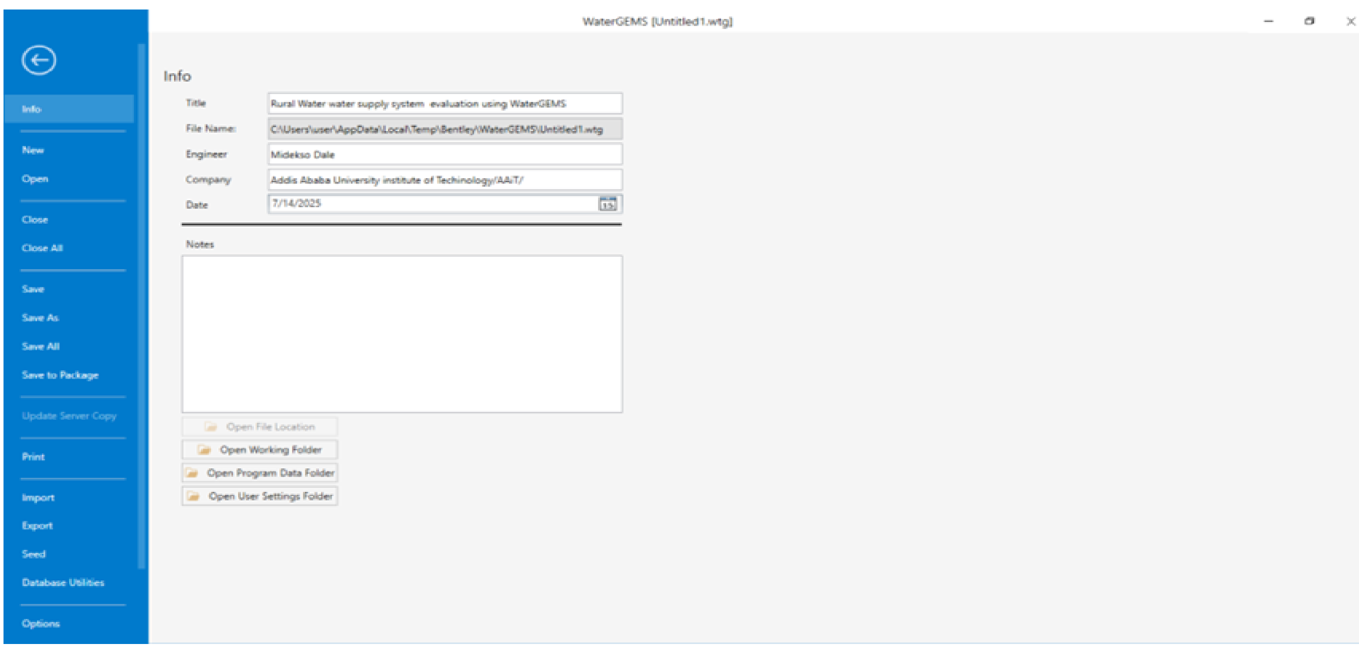


Figure 4: Water GEMS interface at which work space model file was saved.

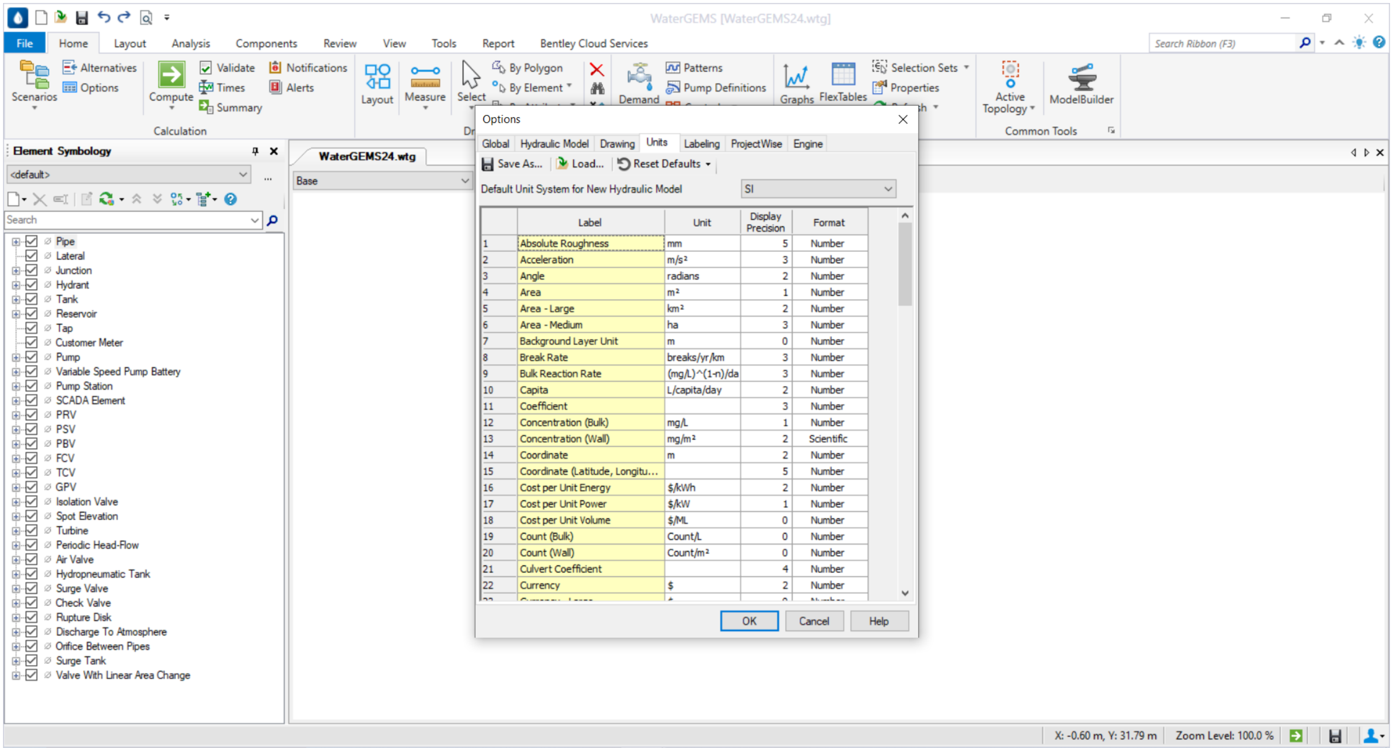


Figure 5: Water GEMS interface to adjust the SI unit before start the model calibration and validation.

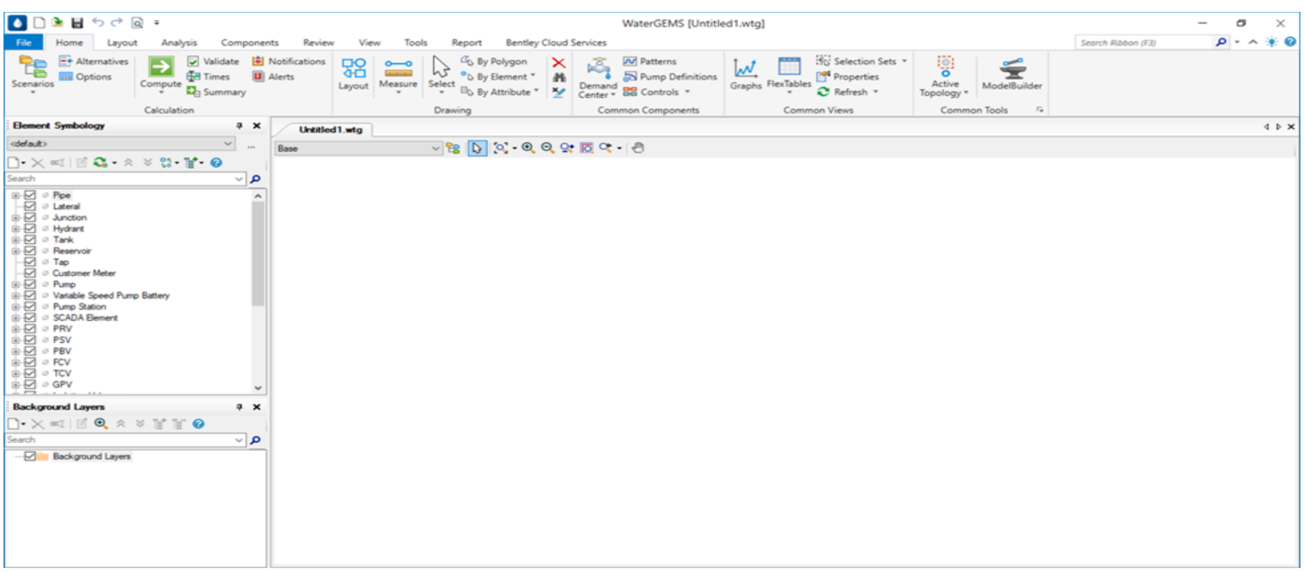


Figure 6: Water GEMS work space to draw the network and analysis of water scheme.

4.1.1. Hydraulic Performance of pipe Parameters for Haftu Seftu Water Supply System Design

The identification of hydraulic parameters particularly flow, velocity, and head loss gradient in the Haftu Seftu rural water supply system is of paramount importance to make it sustainable and operationally reliable. For this research, the outcome of the incites software output for different pipeline segments is taken into consideration to ultimately evaluate sustainability against the rural water supply systems deign standards as presented blow.

Velocity and Flow Analysis

Velocity and flow rate are basic parameters in determining the functional sustainability and energy efficiency of any water supply system. Among the outputs of incites, the maximum flow rages from 3-6 L/s and velocity ranges from 0.64 -1.92 m/s occurred in a pipe with a length of 3m to 1800m which is made of ductile iron and HDPE with the diameter of the pipe 63 mm. So when compared with the others pipes these are relatively shortest and longest of all pipes in the pipe length the distribution network respectively. So this relative high velocities are relatively within the range of acceptability for rural water supply pipes under standard conditions (usually 0.6 to 2 .5m/s) (MoWE E. , February, 2022).

But in two other sections of pipe network, the velocity is 0.32 m/s for both of these pipes, which is blow the range of acceptable velocity of rural water supply pipes standard which is 0.6 to 2.5 m/s (MoWE E. , February, 2022). This shows systematic under sizing of pumps or over sizing of pipes. This is due to design assumptions that have not fully accounted for increase sediment deposition risks if not properly flushed. The velocity performance indicates a hydraulically stable system with minimal risk of pipe bursts or excessive turbulence and demand variation. In a rural setting like Gimbichu, such design limitations translate to technical and financial unsustainability, especially where local maintenance capacity and budget provision are constrained. In General velocities vary from about 0.32 m/s in the smallest downstream branches up to 1.92 m/s in P-3 of transmission line, all of which lie within the commonly accepted range for rural water supply pipe line distribution systems which suggests low risk of both sediment deposition and excessive friction or water hammer under normal operation.

Head Loss Gradient Analysis

Head loss gradient is an important hydraulic performance and energy efficiency parameter. Based on the information, pipes with ID no 45 (P-3),33(P-1),37(P-2) and 46(P-4) registered very high head loss gradient of 54.30 m/km,26m/km,17m/km and 14m/km respectively indicating severe energy loss over its length. This shows higher range than the acceptable rural water design standard which is 5m/km. The pipe sustains high friction losses, possibly a result of the combined relatively high flow velocity, material internal roughness, and small loss coefficients through bends or fittings. Persistent energy losses at such a magnitude can cause decreased service pressure at consumer terminals, causing damage to water access and reliability key pillars of rural water supply system sustainability.

The other pipe segments, like P-5,P-6,P-7 and P-8, have better head loss slopes of 7m/km,1.956 m/km,7m/km and 1.955 respectively. This shows almost closer range to the acceptable rural water design standard 5m/km((Ethiopia, Februray 2022). These segments, built with HDPE and lower flows (1-2 L/s) and lower velocities (0.32-0.64 m/s) which are within the favorable operating ranges and show that appropriately sized materials and designs were used in these segments but pipe section of P-7 and P-8 are less than 5m/km of the network and cannot offset the more ingrained inefficiencies of the large HDPE pipes and the velocity in P-6 and P-8 are 0.32m/s which is less 0.6m/s and which is blow recommended rural water supply in Ethiopia which can cause low risk of both sediment deposition and water hammer under normal operation.

Material Choice and Small Head Losses.

The entire HDPE pipe system, while invariably popular in rural distribution systems due to corrosion resistance and economically seems to be subjected to extremely high hydraulic stress by poor velocity control and high minor loss coefficients. Except P-3 all other Pipes , have a minor loss coefficient of 0.5000 an outlier indicating the presence of several valves, tees, or bends which may add pressure losses and diminish system strength during different demand conditions.

In addition, the existence of check valves in most pipe system reflects efforts aimed at preventing backflow and the requirement to ensure water quality and system integrity. Check valves could result in energy losses, and where coupled with intrinsic high velocities, compromise the pressure conditions and make the system unreliable and more expensive to operate.

Sustainability Implications for Gimbichu rural Woreda

From a sustainability point of view, the current hydraulic operation of the Haftu Seftu water supply system is a mixed scenario. While the selection of material, use of check valves, the substantially low flow and acceptable velocity range in several pipe sections indicate a determination for long-term usability, system longevity and cost-effectiveness. However the resulting high head loss gradients in most of the pipes which is above the acceptable rage in rural water supply system in Ethiopia indicate pressure control sub optimum which can result in frequent service disruptions and low user satisfaction and undermines considerations intrinsic to rural water supply systems long-term sustainability.

Further, such inefficiencies are contrary to key sustainability principles of affordability, technical appropriateness, and dependability. For Gimbichu Woreda, whose limited financial and technical resources can hardly be mobilized, poorly optimized systems can end up being economically and technically onerous to local institutions and communities.

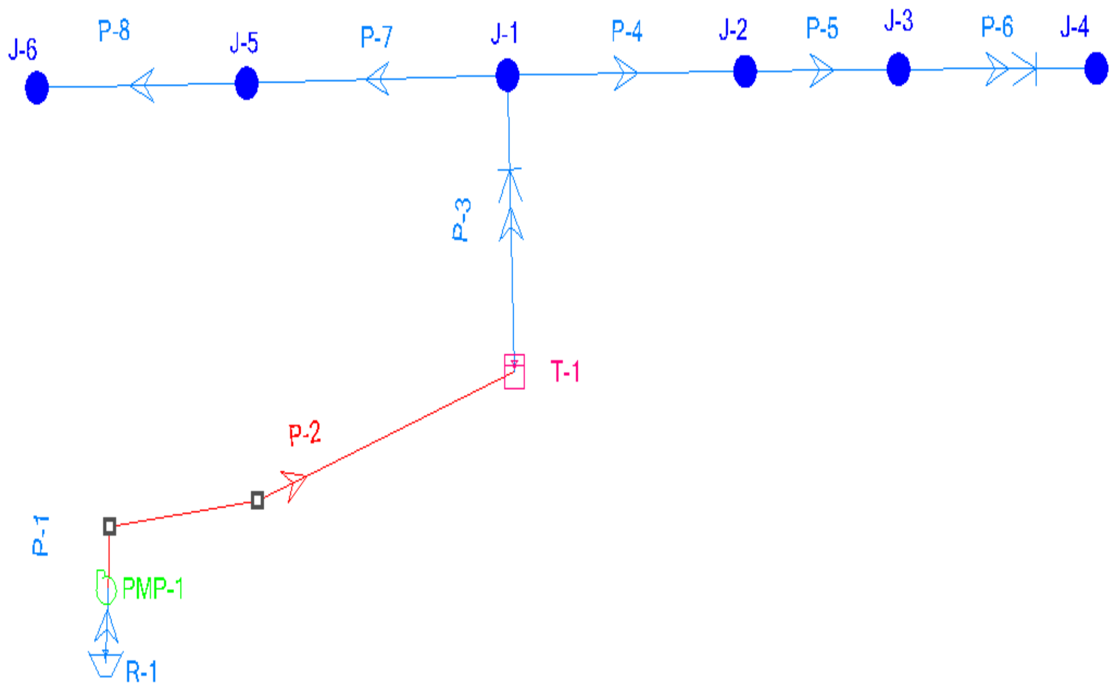


Figure 7: Haftu Seftu Borehole water supply layout network

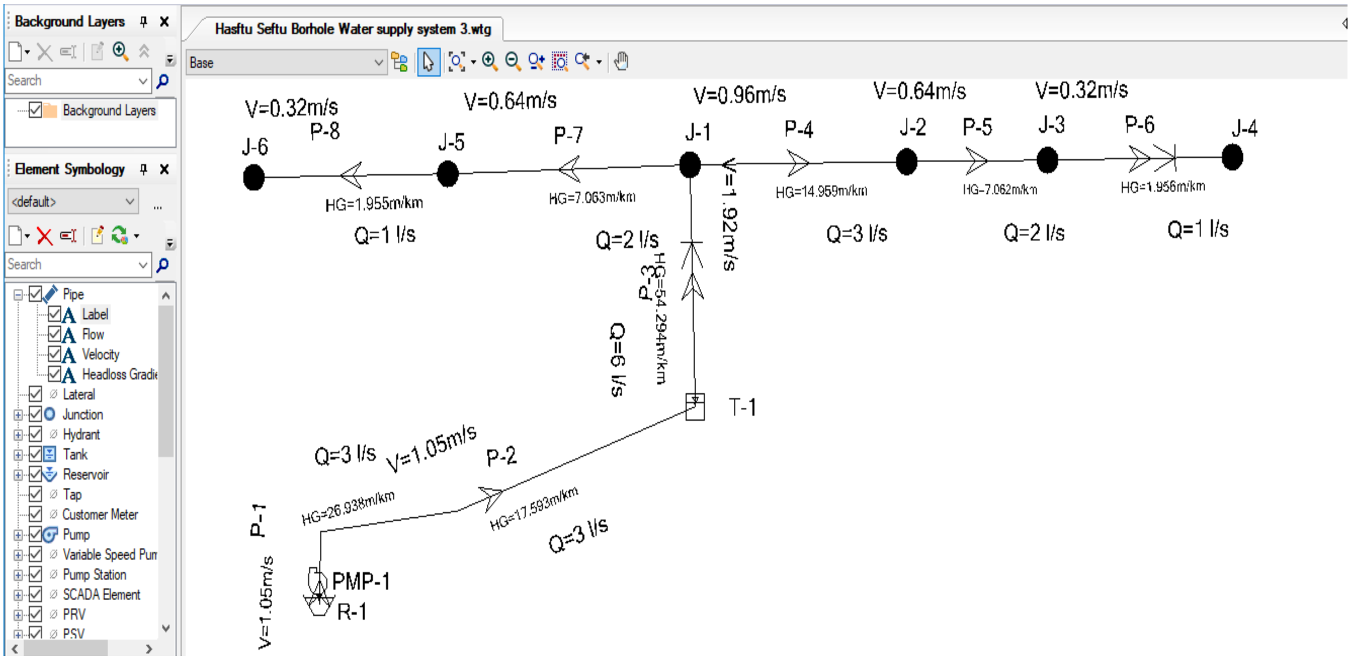


Figure 8: Pipeline network displayed with result Velocity, Hydraulic Grade and Flow rate

Table 2: The Pipeline Result of Velocity, Hydraulic Grade and Flow rate for Haftu seftu water supply

FlexTable: Pipe Table (Current Time: 0.000 hours) (Hasftu Seftu Borhole Water supply system 3.wtg)

	ID	Label	Length (Scaled) (m)	Start Node	Stop Node	Diameter (mm)	Material	Hazen-Williams C	Has Check Valve?	Minor Loss Coefficient (Local)	Flow (L/s)	Velocity (m/s)	Headloss Gradient (m/km)	Has User Defined Length?	Length (User Defined) (m)
33: P-1	33	P-1	2	R-1	PMP-1	63.0	Ductile Ir	150.0	☐	0.500	3	1.05	26.938	☑	3
37: P-2	37	P-2	38	PMP-1	T-1	63.0	HDPE	150.0	☐	0.500	3	1.05	17.593	☑	1,800
45: P-3	45	P-3	17	T-1	J-1	63.0	HDPE	150.0	☑	1.280	6	1.92	54.294	☑	590
46: P-4	46	P-4	19	J-1	J-2	63.0	HDPE	150.0	☐	0.500	3	0.96	14.959	☑	720
47: P-5	47	P-5	12	J-2	J-3	63.0	HDPE	150.0	☐	0.500	2	0.64	7.062	☑	580
48: P-6	48	P-6	16	J-3	J-4	63.0	HDPE	150.0	☑	0.500	1	0.32	1.956	☑	620
49: P-7	49	P-7	21	J-1	J-5	63.0	HDPE	150.0	☐	0.500	2	0.64	7.063	☑	570
50: P-8	50	P-8	17	J-5	J-6	63.0	HDPE	150.0	☐	0.500	1	0.32	1.955	☑	670

Table 3: Flex Pipe Table with pipeline diameter in mm, junction, reservoir and pump start and end node and material type for Haftu seftu water supply

FlexTable: Pipe Table

ID	Label	Length (Scaled) (m)	Start Node	Stop Node	Diameter (mm)	Material
33	P-1	2	R-1	PMP-1	63.0	Ductile Iron
37	P-2	38	PMP-1	T-1	63.0	HDPE
45	P-3	17	T-1	J-1	63.0	HDPE
46	P-4	19	J-1	J-2	63.0	HDPE
47	P-5	12	J-2	J-3	63.0	HDPE
48	P-6	16	J-3	J-4	63.0	HDPE
49	P-7	21	J-1	J-5	63.0	HDPE
50	P-8	17	J-5	J-6	63.0	HDPE

Table 4: Flex Table of, Hazen-Williams coefficient, check valve, Minor Loss Co Coefficient, Flow and Velocity

Hazen-Williams C	Has Check Valve?	Minor Loss Coefficient (Local)	Flow(L/s)	Velocity(m/s)
150.0	False	0.500	3	1.05
150.0	False	0.500	3	1.05
150.0	True	1.280	6	1.92
150.0	False	0.500	3	0.96
150.0	False	0.500	2	0.64
150.0	True	0.500	1	0.32
150.0	False	0.500	2	0.64
150.0	False	0.500	1	0.32

Table 5: Flex Table of Head loss Gradient(m/km) and User Defined Length for Haftu seftu water supply

Head loss Gradient(m/km)	Has User Defined Length?	Length (User Defined)(m)
26.938	True	3
17.593	True	1,800
54.294	True	590
14.959	True	720
7.062	True	580
1.956	True	620
7.063	True	570
1.955	True	670

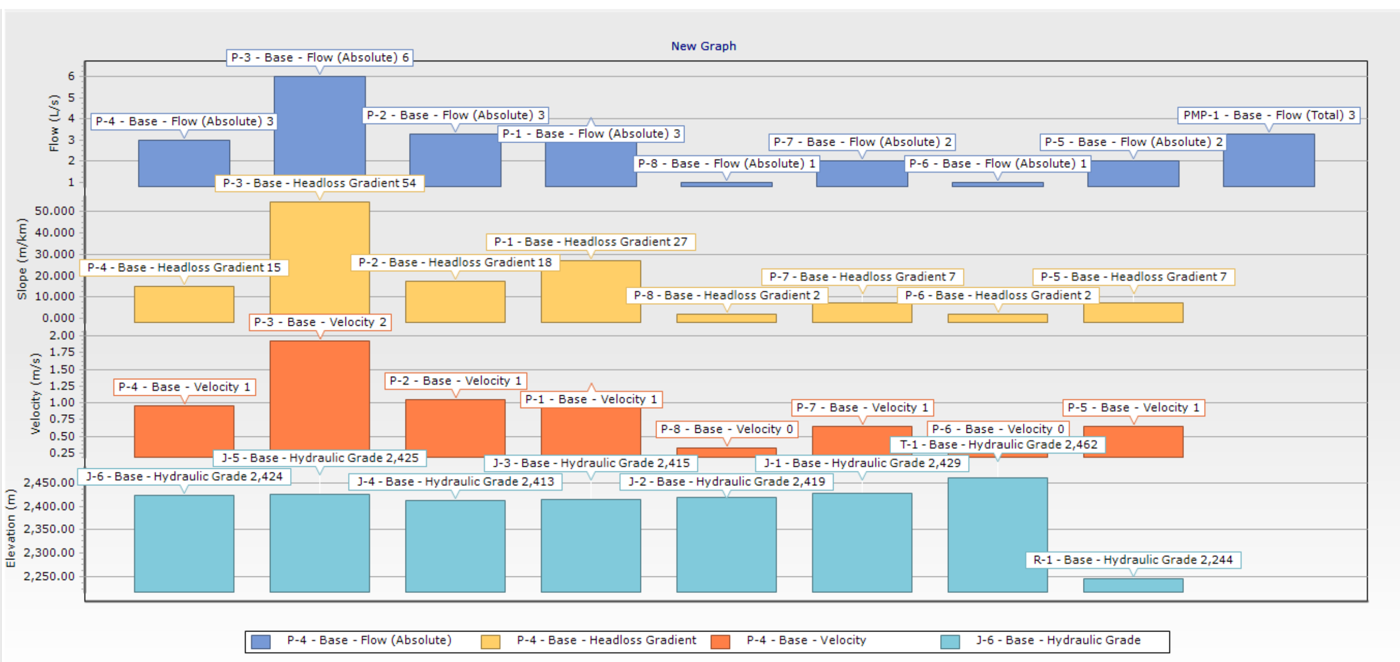


Figure 9: Pipe result, Flow, Head loss Gradient and Velocity displayed with bar chart

4.1.2. Hydraulic Performance of Junction Parameters for Haftu Seftu Water Supply System

Analysis of Water GEMS model junction-level output for the Haftu Seftu rural water supply system provides valuable information on its hydraulic performance for sustainable provision of services in Gimbichu rural Woreda. The report takes into account three vital parameters demand, hydraulic grade, and pressure to check if the system is fulfilling the technical requirements for sustainable design and operation of rural water supply.

Junction Demand Analysis

Water demands at junctions are almost similar which are 1L/s and it is thus likely to be a main distribution point it supplies an array of almost similar consumers in the downstream water point.

Hydraulic Grade Line (HGL) Analysis

Hydraulic grade elevations at every junction points are negative, reflecting major issues with system head availability at junctions as follow. These are: J-1: (2463-2429.47)=33.53m, J-2:(2463-2418.70)=44.3m, J-3: (2463-2414.6)=48.4m, J-4: (2463-24-2413.39)=49.61m, J-5: (2463-2425.44)=37.56m and J-6: (2463-2424.13)=38.87m. In every functional hydraulic system, HGL should be greater than the elevations at service points to allow gravity pressurized flow distribution of water to the consumer occur. The hydraulic grade fails within the standards of rural water supply system 10m-80((MoWE, 2022) which indicates technically well designed water supply system.

Regarding pressure analysis, the Very relevant to hydraulic grade is pressure at every junction point. Water GEMS result displayed utmost negative pressures at each junction, J-1: - 328kPa J-2: - 434kPa, J-3: - 474 kPa, J-4: - 486 kPa, J-5: - 368kPa and J-6: - 380kPa. These pressures are falls within acceptable range normal pressures of rural water supply system which is 200 to 600 kPa (Energy, RURAL WATER SUPPLY DESIGN CRITERIA AND GUIDELINE, February, 2022). This is permissible to provide constant flow velocity and also limit backflow and comply with requirements of consumers of water. Low pressures below atmospheric level (negative pressure) indicate suction conditions, which can lead to, Back-siphonage, increasing the risk of contamination, Entrance of air into the pipelines, decreasing the efficiency of flow and Structural stress in the network elements. Also Hydraulic modeling results show extremely negative pressures (–328 to –486 kPa) throughout the network, indicating insufficient head, high friction losses, and structural inadequacies. These conditions prevent effective water delivery.

Technical sustainability is very weak regarding pressure of water supply system, operational and financial sustainability are fragile, and institutional capacity is limited. Implications For Sustainability includes the outcomes from the model indicate serious sustainability issues at technical, economic, and social levels such as negative pressures suggest system failure, design integration mistakes, inefficient pump head,, all compromising infrastructure operation, under sized demand results in infrastructure and increased capital and operating expenses, making infrastructure less accessible, negative pressure indicate low water delivery which does not meet the demand, reducing user confidence and risking long-term system acceptability and negative pressures raise the risk of backflow contamination, jeopardizing water quality and public health. In rural settings like Gimbichu, institutional capacity and resources being limited, such failures could compromise the presumed advantages of the water system to result in non-use or system abandonment.

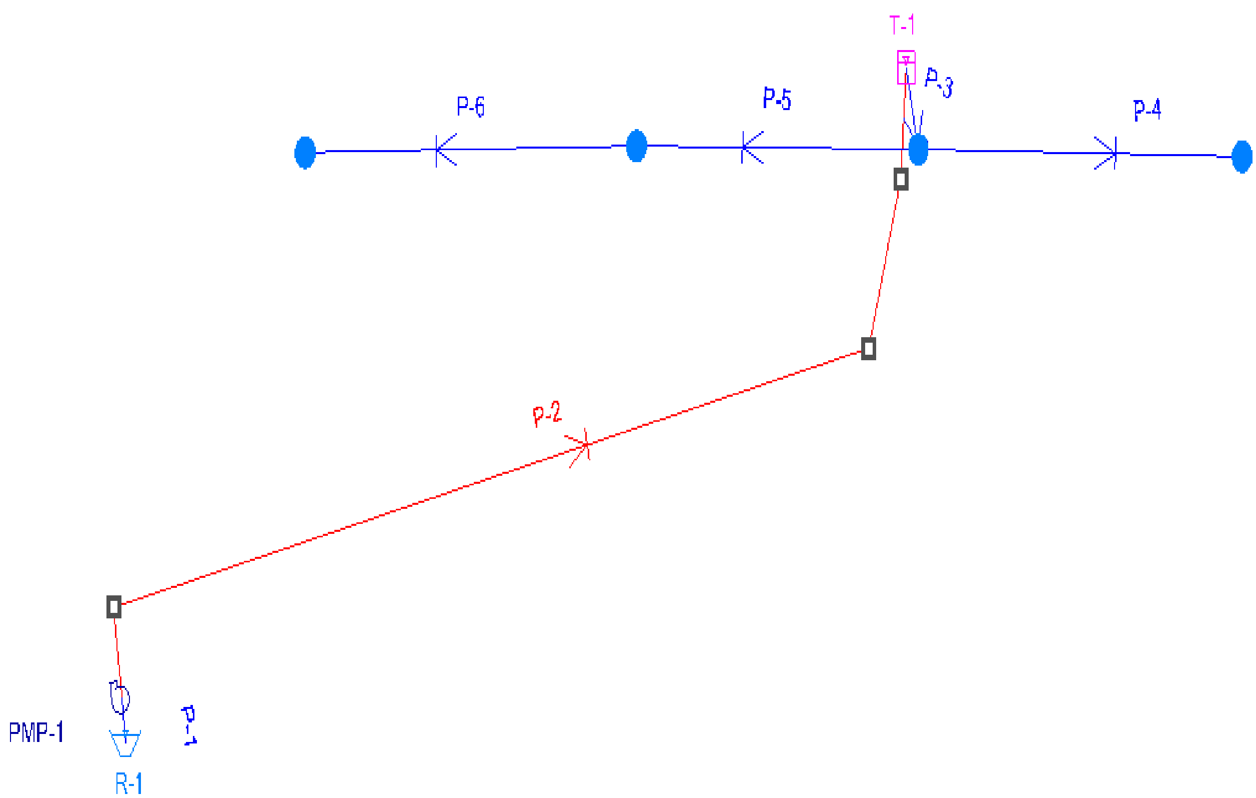


Figure 10: Haftu seftu water supply network layout.

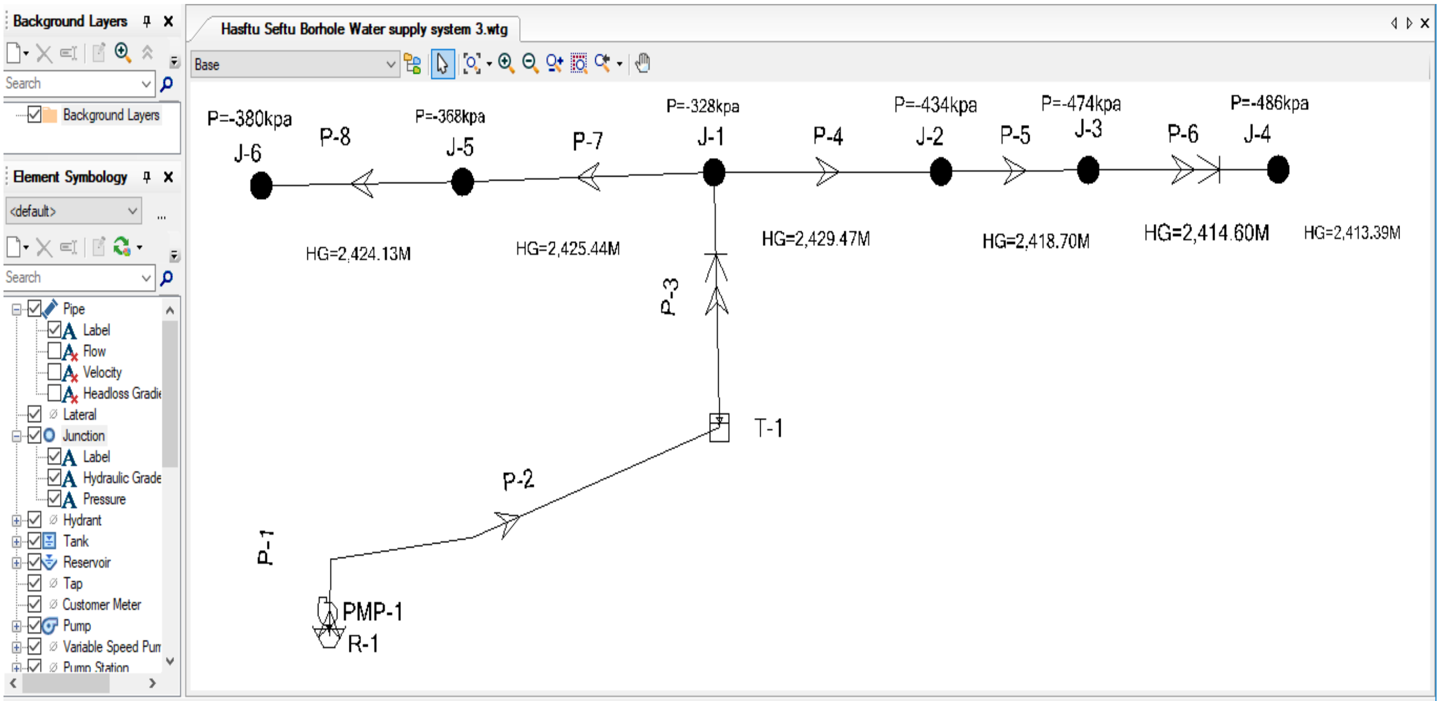


Figure 11: Junction result Hydraulics Grade(m), Pressure(kpa) and demand displayed in network

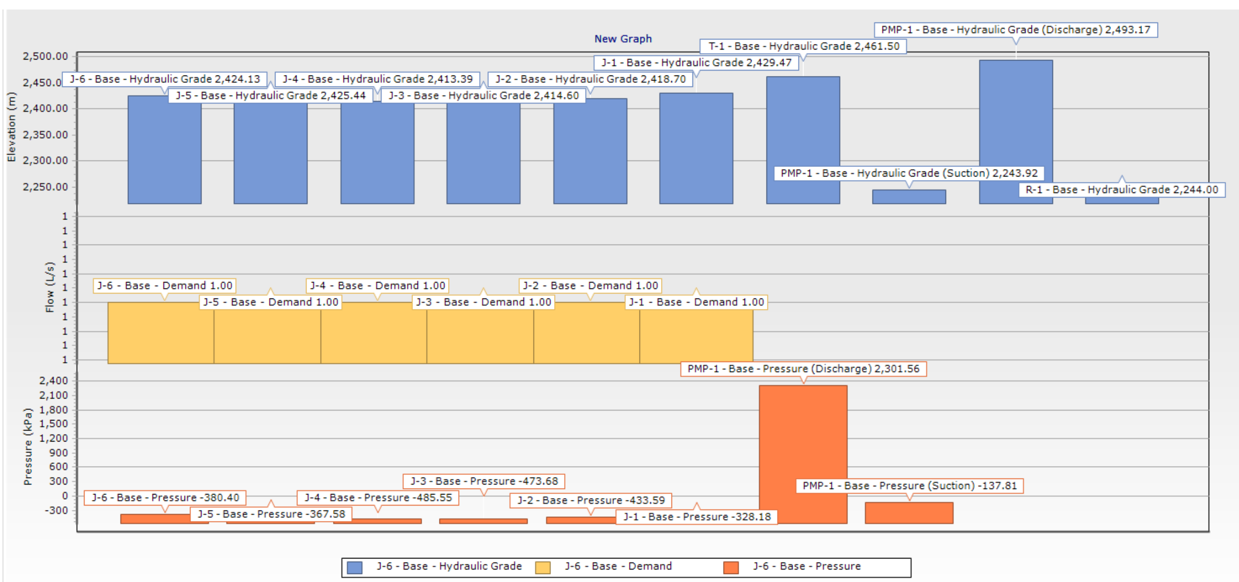


Figure 12: Junction result Hydraulics Grade(m), Pressure(kpa) and demand displayed in Bar chart.

Flex Table 6: Junction result Hydraulics Grade(m), Pressure(kp) and demand(L/s) for Haftu seftu water supply

FlexTable: Junction Table (Current Time: 0.000 hours) (Hasftu Seftu Borhole Water supply system 3.wtg)

	ID	Label	Elevation (m)	Zone	Demand Collection	Demand (L/s)	Hydraulic Grade (m)	Pressure (kPa)
39: J-1	39	J-1	2,463.00	Zone - 4	<Collection:	1	2,429.47	-328
40: J-2	40	J-2	2,463.00	Zone - 5	<Collection:	1	2,418.70	-434
41: J-3	41	J-3	2,463.00	Zone - 6	<Collection:	1	2,414.60	-474
42: J-4	42	J-4	2,463.00	Zone - 7	<Collection:	1	2,413.39	-486
43: J-5	43	J-5	2,463.00	Zone - 8	<Collection:	1	2,425.44	-368
44: J-6	44	J-6	2,463.00	Zone - 9	<Collection:	1	2,424.13	-380

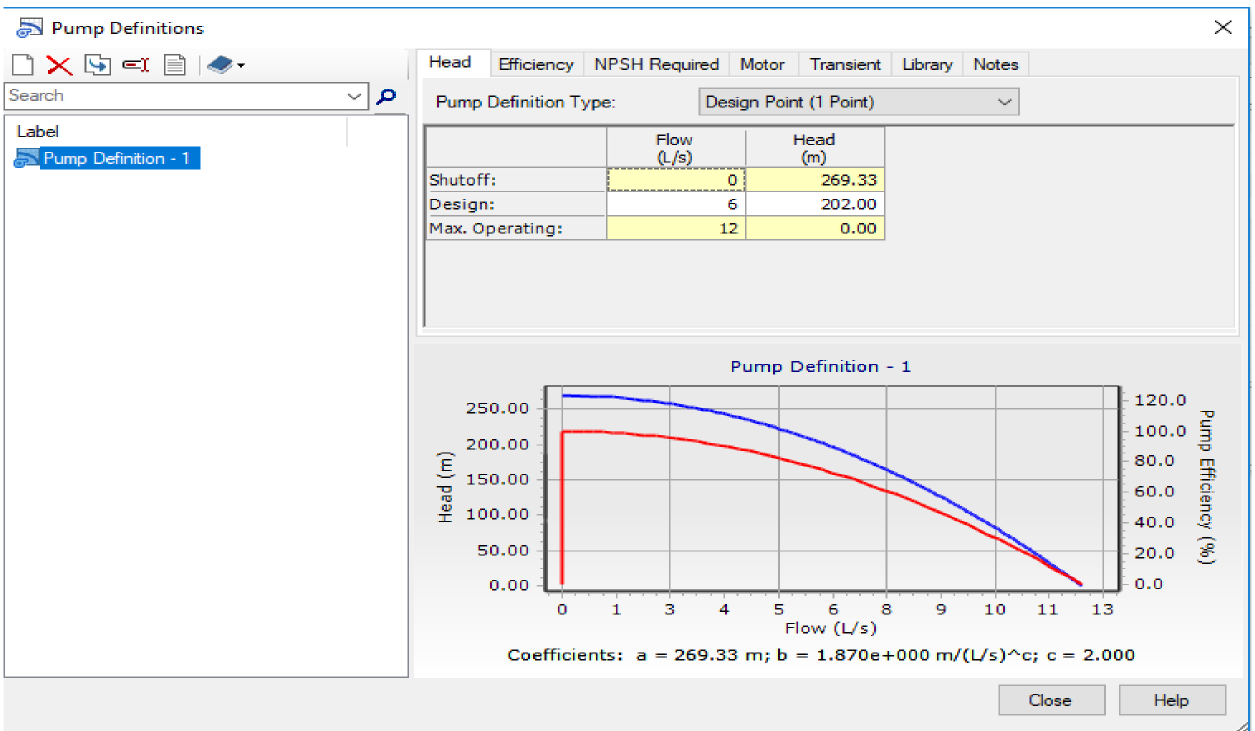


Figure 13: pump definition

Calibration and Validation for Hydraulic Grade Model Performance

Calibrated and validation for the Haftu Seiftu water supply system was done using a Darien calibration of Genetic Algorithm (GA) to optimize hydraulic grade and flow. Model calibration and validation were performed by comparing observed and simulated hydraulic grade values under demand conditions. The scatter plot shows strong agreement, with data points closely aligned along the 1:1 correlation line. The coefficient of determination (R^2) is 0.97, indicating strong correlation. This confirms high predictive accuracy, minimal error, and model reliability for hydraulic analysis, operational planning, and future demand scenario evaluation.

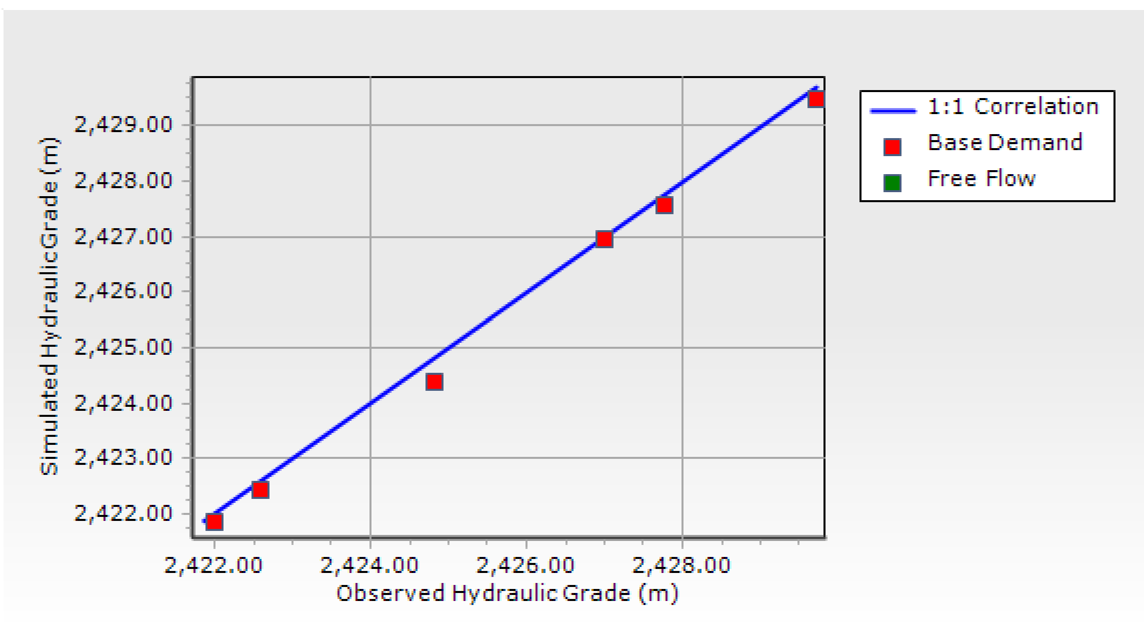


Figure 14: Calibration and Validation for Hydraulic Grade Haftu Seiftu water supply system

Calibration and Validation for Haftu Seiftu water supply system for the Flow Simulation Performance have been done using Darine model calibration using Genetic Algorism(GA)

The calibration and validation of the hydraulic model were evaluated by comparing observed and simulated flow rates under free-flow conditions. The scatter plot illustrates simulated flow (L/s) plotted against observed flow (L/s) with a 1:1 correlation line representing perfect agreement. The data points lie almost exactly on the 1:1 line, indicating excellent consistency between measured and modeled values across all observation points. Based on the near-perfect alignment of the points, the coefficient of determination R^2 values is 0.98**,** demonstrating also indicates strong linear relationship. This implies that nearly all variability in the observed flow is explained by the model simulation, with negligible error.

The minimal deviation confirms that the model parameters are well calibrated and that the validation results are highly reliable. Therefore, the hydraulic model is considered accurate and suitable for predicting system performance under similar operating conditions.

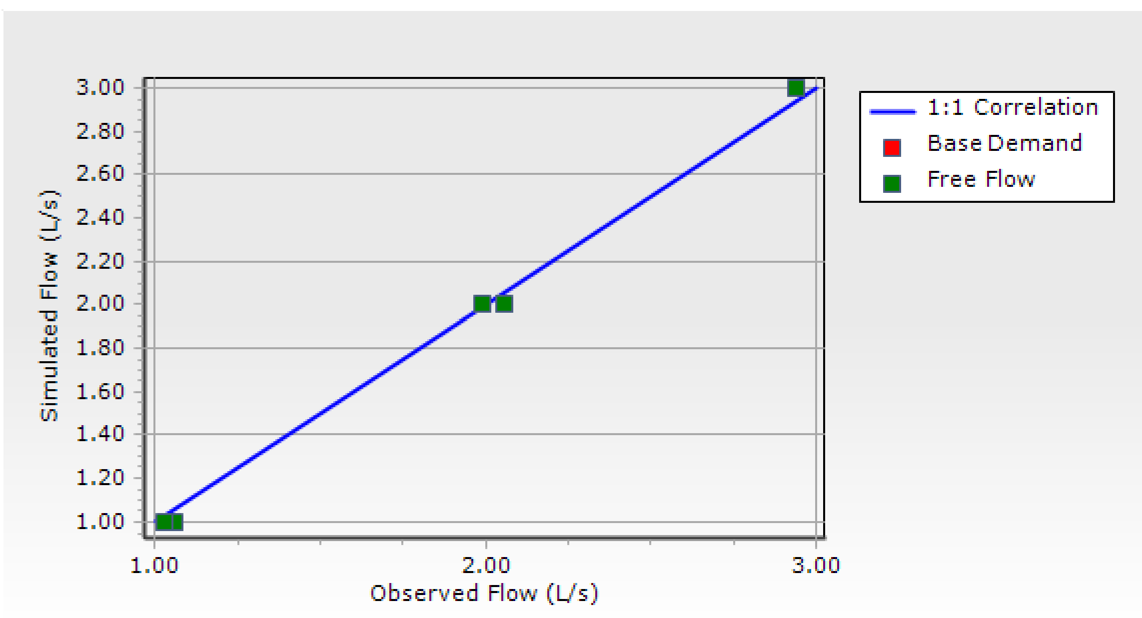


Figure 15: Calibration and Validation for Flow Haftu Seiftu water supply system

4.1.3. Hydraulic Performance of pipe Parameters for Kersa Riga Deep Well.

Technical Results Analysis

The results of blow narrative indicates important hydraulic properties of six pipes within the Kersa Riga water supply system such as flow rate, length, velocity, and head loss gradient. All these parameters are directly linked to system efficiency, reliability and sustainability.

Flow Rate (L/s)

Flow rates in pipes range from 1 to 2L/s, but the majority of pipe flow are 1L/s. The maximum flow of 2L/s in Pipe P-3 is for heavy supply and may be this is for large villages connections and primary junctions. Within the other pipes such as Pipe-1,Pipe-2,Pipe-4,Pipe-5 and Pipe-6 the flow is l L/s which is the indicative of point of discharge distribution pipe and lines supplying to small villages. This reflects uniform flow all over main pipes implies proportional planning. But top-end high flows can jeopardize supply disruptions if not balanced by pump strength and well production, particularly at drought and peak consumption. Minimum demand must still be satisfied by lower flows to small communities. In general the flow values are very low for a rural community water system that typically requires 1.2–2.5L/s per branch depending on population. This insufficient flow results in inadequate water reaching community taps, fluctuation of water delivery during peak hours and difficulty meeting daily per-capita demand. From sustainability implication**,** insufficient flow undermines the system's reliability and may cause communities to use to unsafe water sources for domestic purpose.

Velocity (m/s)

Range of variation of measured velocities varies between 0.25m/s to 1.02 m/s. Velocities in the majority of pipes range within the accepted 0.6–2.5m/s for rural water supply systems (Ethiopia, Februray 2022) This indicate that low-flowing sections of velocity in P-1, P-2, P-5 and P-6 pipes as compared to the rural water distribution of pipe line. That is, velocity needs to be kept above 0.6m/s to discourage sedimentation, whereas less than 2.5m/s decreases rough wear and cost of energy. The system design captures these compete requirements, providing sustainability in terms of minimum repair risk and cost-effective operating expenses. Over all low velocities in Pipes such as P-6, P-1, P-2 and P-5, are 0.25m/s , 0.33m/s , 0.47m/s and 0.51 m/s <0.6 m/s increase sediment deposition inside HDPE pipes which reduce water quality through stagnation and increase risk of biological regrowth. Overall velocity performance is mixed, reducing long-term sustainability of the system.

Head Loss Gradient (m/km)

Head loss gradients range from 1.668 m/km to 21.741m/km. Peak head loss in P-5: 6.028 m/km, in P-4:12m/km and in P-1: 21.741 m/km arises wherever the flow is at its maximum and more than acceptable head loss Gradient for rural water supply distribution network 5m/1000m (Energy E. M., 2022)These indicates severe energy loss and low pump head used and thus focuses much attention on pump selection and energy planning. Gradients for downstream pipes P-1 and P-6 are approximated at 2m/km and P-2 is 5.038m/km which are within acceptable limits, ensuring a long-distance supply without undue pressure drop. That is, steeper mains supply pipe gradients would be anticipated due to the increased pipe length and flow, but high head losses need to be kept to a minimum for energy conservation purposes as well as to prevent undue system component stress.

Discussion within the Sustainability Context

In such system sustainable rural water supply is characterized by Flows and velocities which are in favorable equilibrium with demand, reducing outages of service. Interims of efficiency head loss gradients are low, reducing energy requirements and operational costs, which is important for rural areas where finances are limited. Pipe material options available HDPE and ductile iron are a compromise between durability and cost, which is important for systems working in challenging physical and financial conditions.

Current data show that the design of the Kersa Riga water supply scheme follows best practice for regulation of velocity, flow control, and energy efficiency. Nevertheless, excessive head loss can undermine long-term sustainability if not restrained in specific areas, threatening in terms of increased cost of operation and wear.

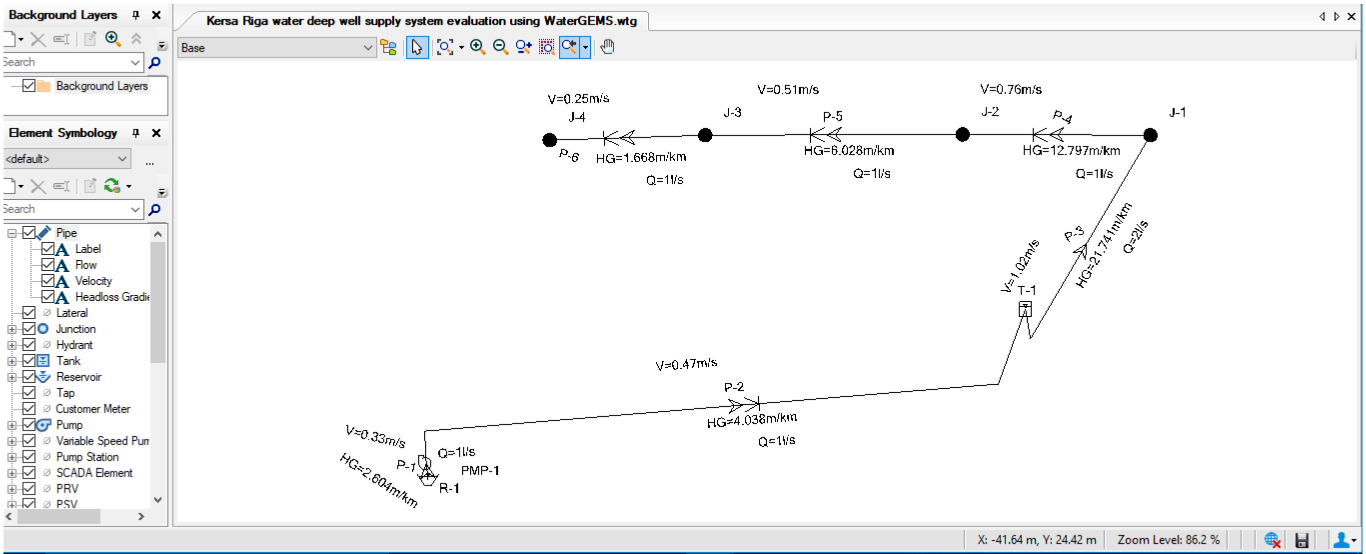


Figure 16: Pipe result for kersa riga water supply system, velocity, Head loss and Flow displayed with network.

Flex Table 7: Kersa Rega Pipe output/result Velocity, Hydraulic Grade and Flow rate for Kersa Riga water supply

FlexTable: Pipe Table (Current Time: 0.000 hours) (Kersa Riga water deep well supply system evaluation using WaterGEMS.wtg)

	ID	Label	Length (Scaled) (m)	Start Node	Stop Node	Diameter (mm)	Material	Hazen-Williams C	Has Check Valve?	Minor Loss Coefficient (Local)	Flow (L/s)	Velocity (m/s)	Headloss Gradient (m/km)	Has User Defined Length?	Length (User Defined) (m)
70: P-3	70	P-3	35	T-1	J-1	50.0	HDPE	150.0	☐	0.370	2	1.02	21.741	☑	720
71: P-4	71	P-4	25	J-1	J-2	50.0	HDPE	150.0	☑	0.780	1	0.76	12.797	☑	450
72: P-5	72	P-5	34	J-2	J-3	50.0	HDPE	150.0	☑	0.500	1	0.51	6.028	☑	520
74: P-6	74	P-6	20	J-3	J-4	50.0	HDPE	150.0	☑	0.300	1	0.25	1.668	☑	480
83: P-1	83	P-1	2	R-1	PMP-1	75.0	Ductile Ir	150.0	☐	0.300	1	0.33	2.604	☑	2
84: P-2	84	P-2	90	PMP-1	T-1	63.0	HDPE	150.0	☑	0.300	1	0.47	4.038	☑	696

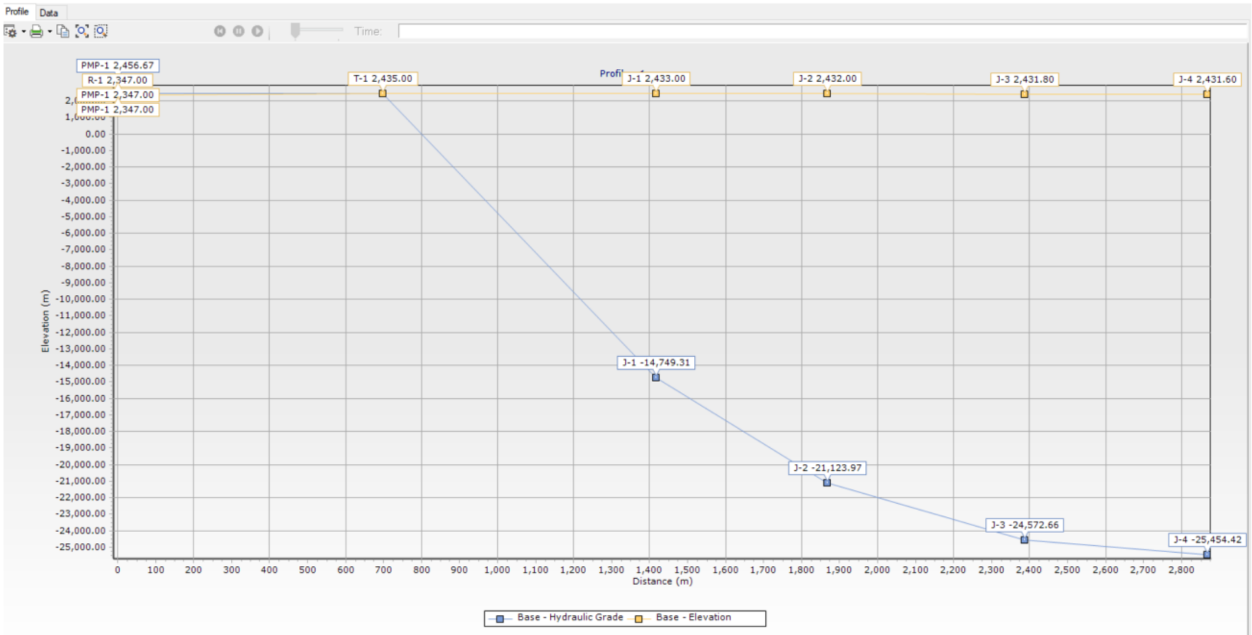


Figure 17: Line graph of Hydraulic Grade and Base Elevation

4.1.4 Hydraulic Performance of Junction Parameters for Kersa Riga Deep Well

An effective analysis of junctions in any rural water supply system is extremely crucial for effective distribution, pressure adequacy, and sustainability of service delivery. The findings in the given table provide major parameters demand, hydraulic grade, and pressure at four major junctions in the Kersa Riga deep well system. These measurements act as reference points for measurement of the effectiveness and sustainability of water supply to the Gimbichu rural Woreda communities over the long term.

Demand (L/s)

All the junctions, J-1, J-2, J-3 and J-4 are metered with an even demand of 1 L/s. This is an even distribution to each of the critical nodes, and the water supply system has been laid down on the principle of redundancy and evenness. In reality, such demand consideration is necessary to preclude short supply during peak demand periods and accounts for future anticipated population growth or group service connections.

Hydraulic Grade (m)

The hydraulic grade values for the four junctions are extremely different J-2: (2432-2415.59)=16.41m, J-3: (2431-2415.45)=15.55m, J-1: (2433-2415.35)=17.65m and J-4: (2430-2415.65)=14.35 m . All four junctions in the Kersa Riga Deep Well rural water supply system retain sufficient pressure for regular water distribution, according to the hydraulic grade analysis. The HG differences ranging from 14.35 m to 17.65 m confirm that the system can deliver water reliably under current conditions.

The four junctions' hydraulic grades at J-1=17.65 m, J-2=16.41m, J-3=15.55m, and J-4=14.35m are within the acceptable range of rural water supply design 10m-80m (Ethiopia, Februray 2022) Hence, the system is hydraulically feasible and can successfully deliver water by gravity without developing excessive pressure in the pipes. The difference in HG values does not signify a design fault, but rather, as anticipated, natural head losses occur throughout the pipeline network. This indicates that the energy dissipated is adequate and the flow is controlled through the system. When the water level at J-4 drops, less water will be available to meet future demands after taking into account the constraints of problems, degradation of pipes and limitations on the water source in the dry season. Without investment of new water sources, reliability will start to ache. In general, the system is expected to show good sustainability in the short to medium term, provided that maintenance, demand management and periodic hydraulic review are undertaken to avoid pressure deficit and equitable service delivery to all junctions.

Pressure (kPa)

Pressure readings are very low throughout, J-2: -161kPa, J-3: -182kPa, J-1: -114kPa and J-4: -180kPa. The negative pressures system in an operating of water distribution system is against the gravity but its high values indicate strongly a true serious that would lead to absolute system delivery of leakage and water loss as it more than acceptable rural water supply standard 200 to 600 kPa (Ethiopia, Februray 2022).

Discussion on Sustainability Perspective

All of the junctions negative pressures show a serious hydraulic inadequacy, which increases the risk of pollution, back-siphonage, and service interruption. The system is unable to sustain sufficient pressure even at a low demand of 1 L/s. At those points to system low performance is due to low capacity pumps, high elevation differences, or too much friction losses. The imbalance in hydraulic grade indicates uneven service distribution and threatens long-term sustainability.

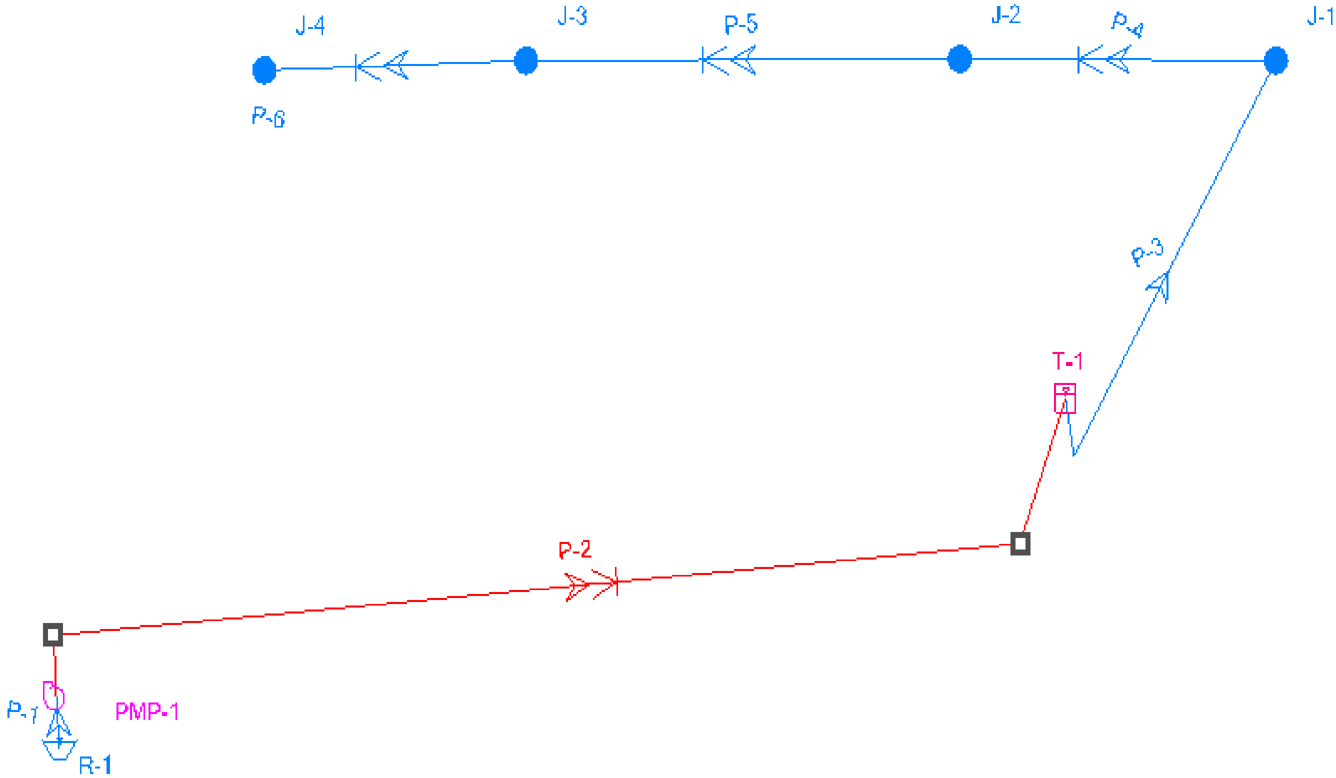


Fig 18: Kersa Riga Water supply network layout.

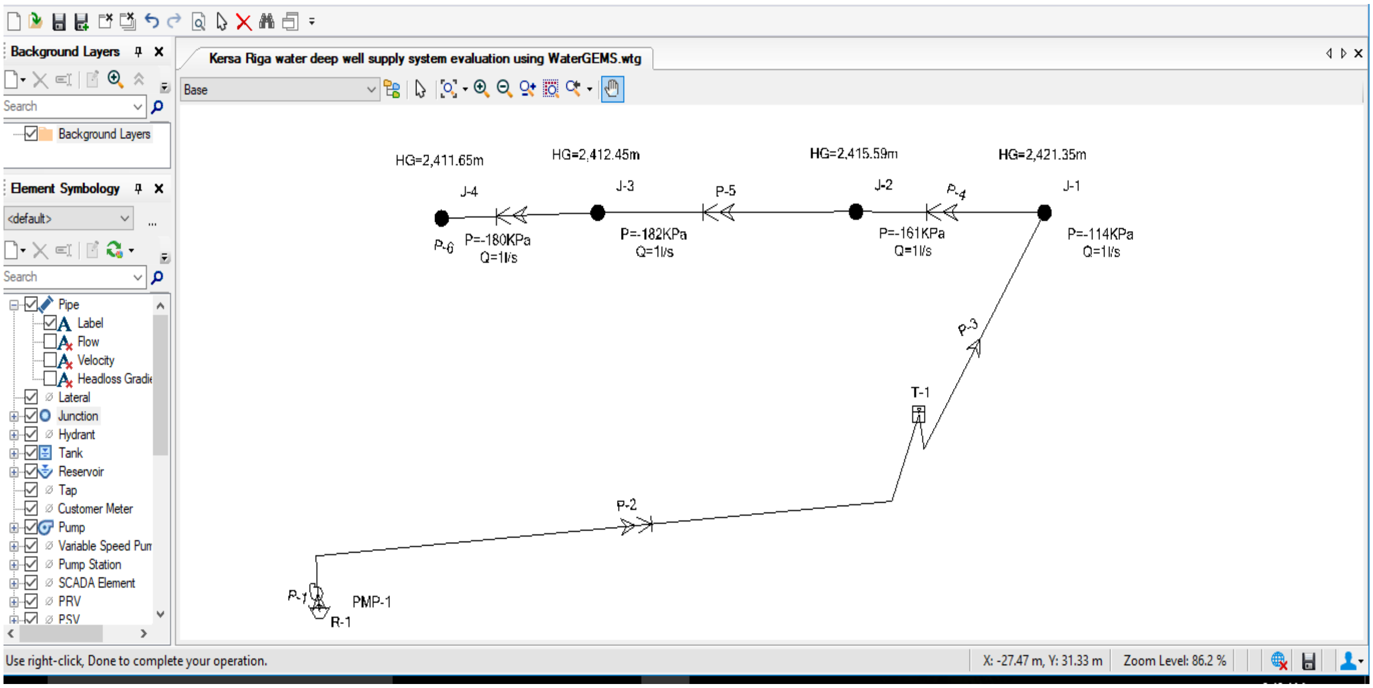


Figure 19: Kersa Riga water supply system, Pressure, Demand and Hydraulic Grade displayed Junction network.

Table 8: Kersa Riga Water supply system Junction output/result, Demand, Hydraulic Grade(m) and Pressure for Kersa Riga water supply

FlexTable: Junction Table (Current Time: 0.000 hours) (Kersa Riga water deep well supply system evaluation using ...

	ID	Label	Elevation (m)	Zone	Demand Collection	Demand (L/s)	Hydraulic Grade (m)	Pressure (kPa)
49: J-2	49	J-2	2,432.00	Zone - 5	<Collection:	1	2,415.59	-161
50: J-3	50	J-3	2,431.00	Zone - 6	<Collection:	1	2,412.45	-182
51: J-1	51	J-1	2,433.00	Zone - 4	<Collection:	1	2,421.35	-114
73: J-4	73	J-4	2,430.00	Zone - 7	<Collection:	1	2,411.65	-180

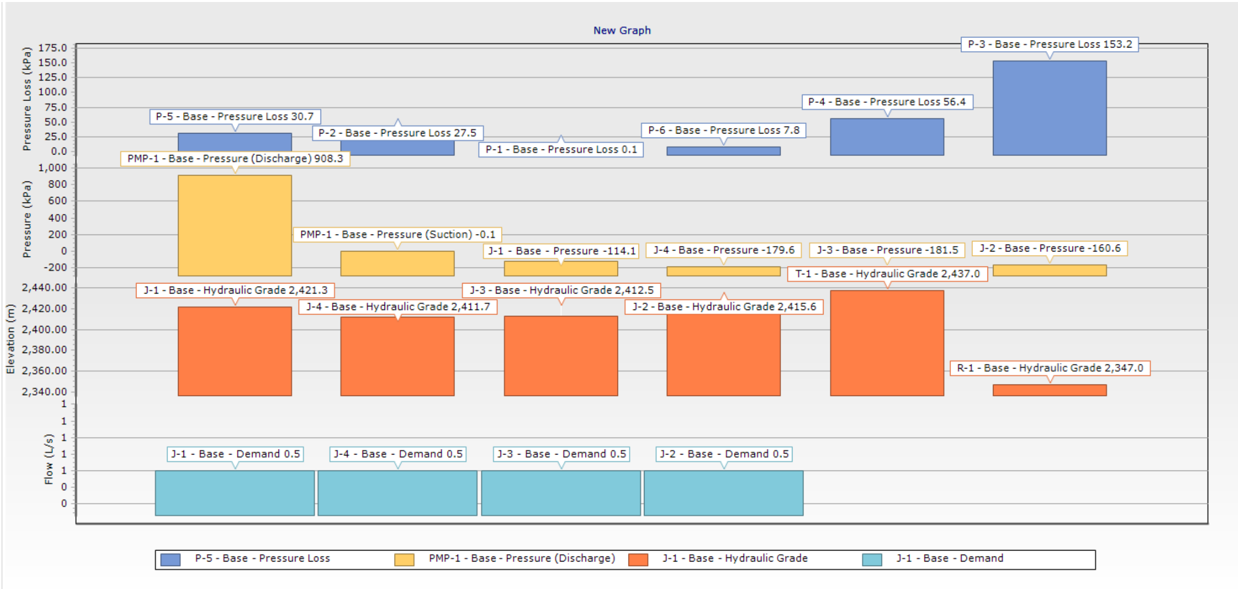


Figure 20: Bar chart of Kersa Riga Water supply system Junction output/result, Demand(l/s), Hydraulic Grade(m) and Pressure(KPa).

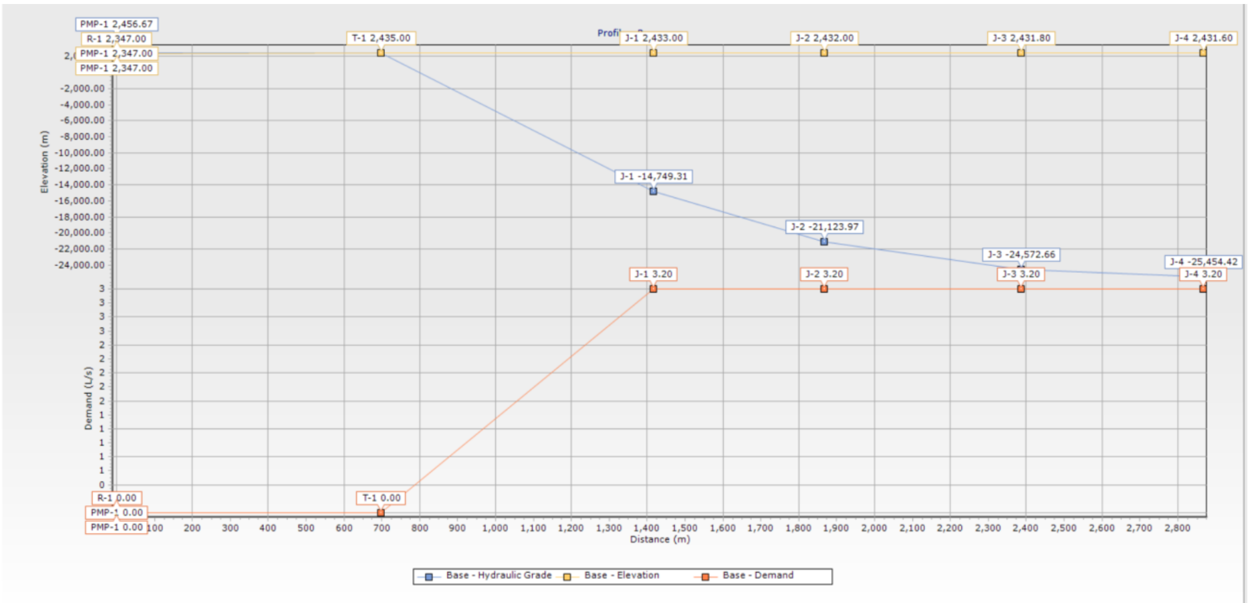


Figure 21: Graph of Kersa Riga Water supply system Junction output/result, Base Hydraulic Grade(m), Base Elevation(m) and Base Demand(l/s).

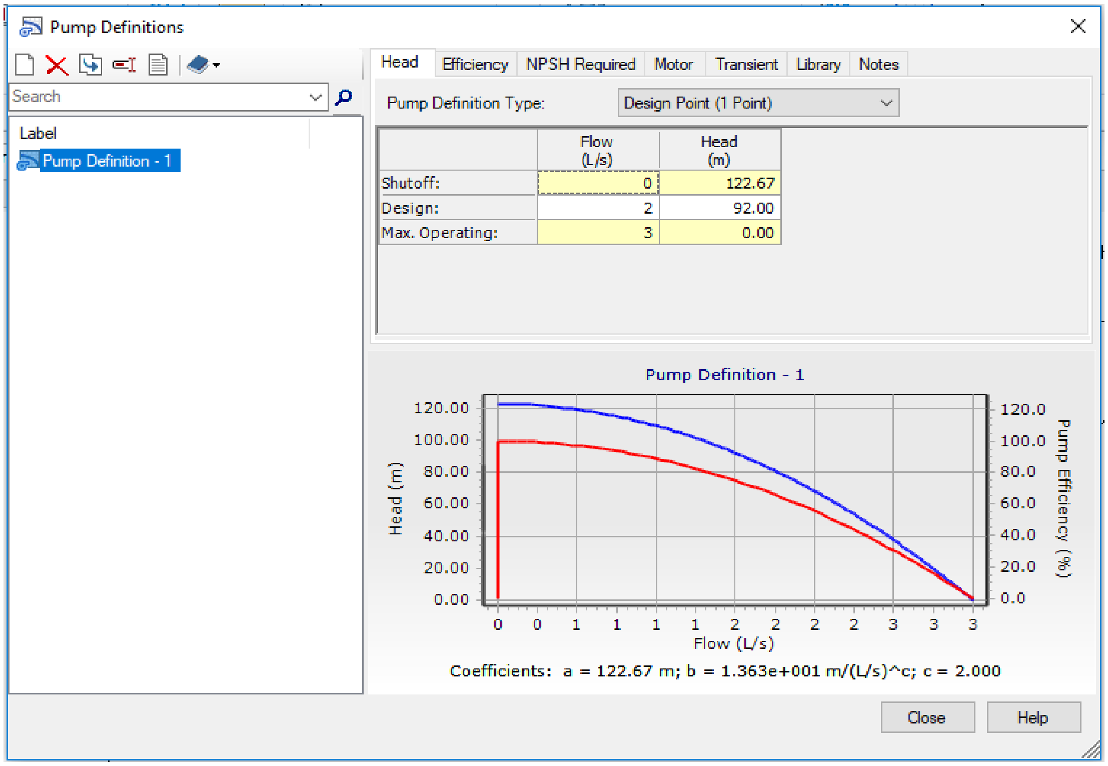


Figure 22: Pump definition Graph

Model calibration and validation performed using Darine Genetic Algorism(GA) for both hydraulic grade and Flow for Kersa Riga water supply system

Model calibration and validation pressure/hydraulic grade of Kersa Riga water supply system.

The blow graph illustrates the calibration of a rural water supply system by comparing observed and simulated hydraulic grades using Darine Genetic Algorism(GA). The data points for Base Demand align remarkably well with the 1:1 Correlation line, indicating high model accuracy.

Based on the tight clustering of data points around the identity line, the predicted R^2 value is approximately 0.98. This suggests that the model explains nearly all the variability in field observations.

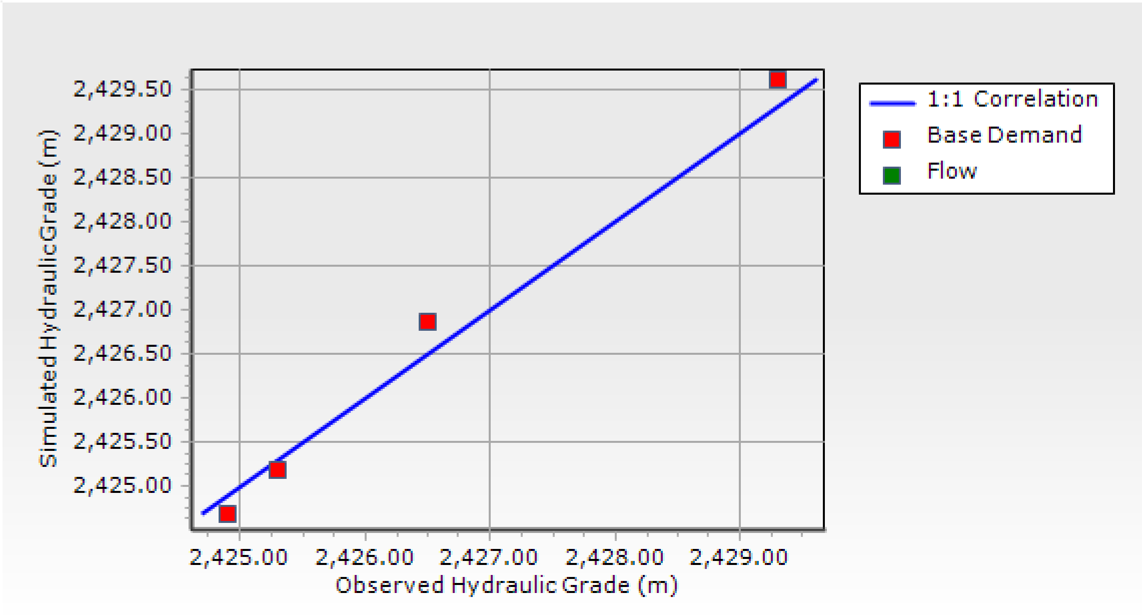


Figure 23: Calibration and Validation for Hydraulic Grade for Kersa Riga water supply system

Model and validation using Genetic Algorism(GA) for the flow Kersa Riga water supply system.

The provided graph displays the relationship between Observed Flow (L/s) and Simulated Flow (L/s) for a rural water supply system. The alignment of the Flow data points with the 1:1 Correlation line serves as a primary indicator of model reliability and predictive accuracy.

The data points show minimal deviation from the identity line across the range. Given this tight visual fit, the predicted R^2 value is approximately 0.94. This suggests that the hydraulic model captures nearly 94% of the variance in actual flow conditions.

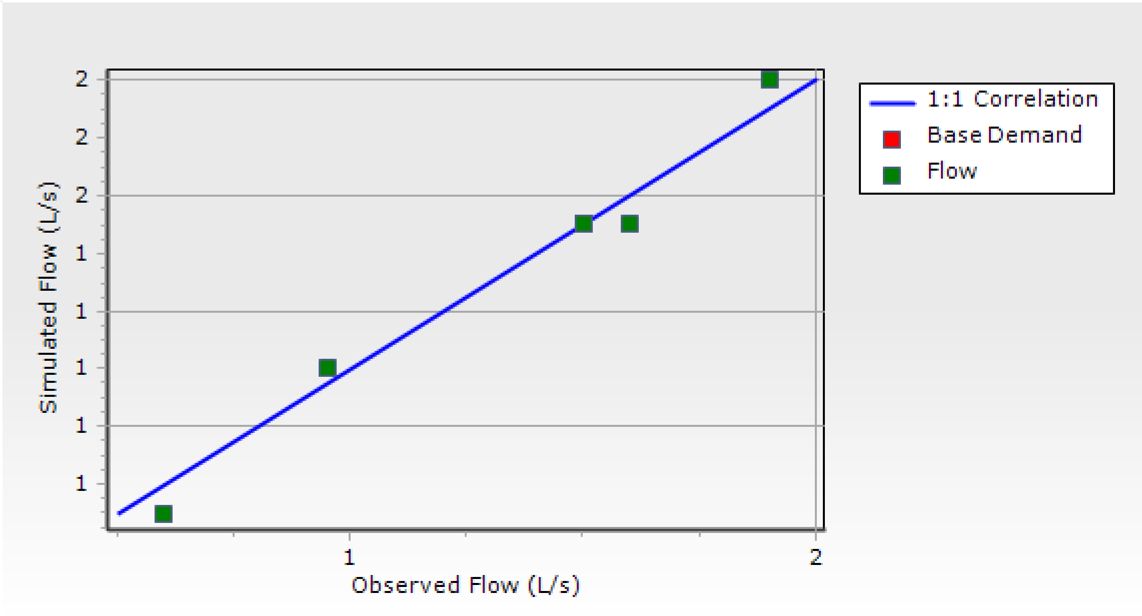


Figure 24: Calibration and Validation for Flow for Kersa Riga water supply system

4.1.5. Hydraulic Performance of pipe Parameters for Karsa Kamise Water Supply System

Pipe network under consideration in the analysis comprises 6 pipe sections (P-1 to P-6) of largely HDPE material with a constant diameter of 50.8mm. The hydraulic analysis is concerned with the following important parameters.

Flow Rate

All pipe lengths are constructed with the size to provide a flow from 1-3 L/s. This small variation of flow is an aim of balancing water supply and eliminating hydraulic shocks or imbalances across the network that reduces constant pipe wear of flow and promotes steady system behavior, a requirement for long-term operation and planning sustainability.

Velocity

Pipe velocities are from 0.34m/s to 1.01m/s. This is the ideal range for most rural water supply pipes except at P-6 & P-4 where velocities are 0.34m/s and 0.39m/s respectively and velocities lower than 0.6m/s which may lead to water quality and sedimentation problems and more than 2.5m/s may lead to pipe scratch, water hammer risk, as well as energy losses. The measured velocities indicate a good-calibrated system for self-cleaning velocity and for the prevention of stagnation or excessive head loss hazard.

Head Loss Gradient

Head loss gradients are quite different, from 2.826m/km to 16.351m/km. Almost all Headloss Gradients faill under acceptable head loss of MoWE would normally be less than 5m/km which are ideal circumstances except P-1: 11.609m/km which are more than 5m/km but this is not higher HLG since rural schemes with headroom are able to accept greater gradients.

The P-3 : 16.351m/km sizes include very steep head loss gradients, which suggest extensive energy dissipation, perhaps due to pipe roughness, fittings or local resistance. Consequently, therefore, excessive head loss gradients decrease the net available head to customers, may discourage dependability when demand is at a peak or supply is limited, and can jeopardize delivery pressure.

In terms of pipe material and loss Coefficients

Pipe material is HDPE preferred due to flexibility and corrosion resistance, for sustainability purposes through reduced maintenance. For small loss coefficients, loss coefficient variation, 0.17 to 0.5 is for different network elements or appurtenances. Excessive local losses add further head losses.

Sustainability Considerations

Gimbichu Woreda rural water supply system sustainability is closely related to the capacity of the system to supply sufficient volumes of water at required pressure for a very long duration with minimal failures or interruptions. Hence, the nearly uniform flow and appropriate velocities ensure safe operation and minimize early piping failure risk. System sections with high head loss must be checked for design optimization since prolonged high energy loss will over-stress pump operation, be expensive, and lower system life. Low-maintenance use is provided by HDPE pipes and galvanized fittings and is therefore appealing in rural applications where technical facilities and means are limited.

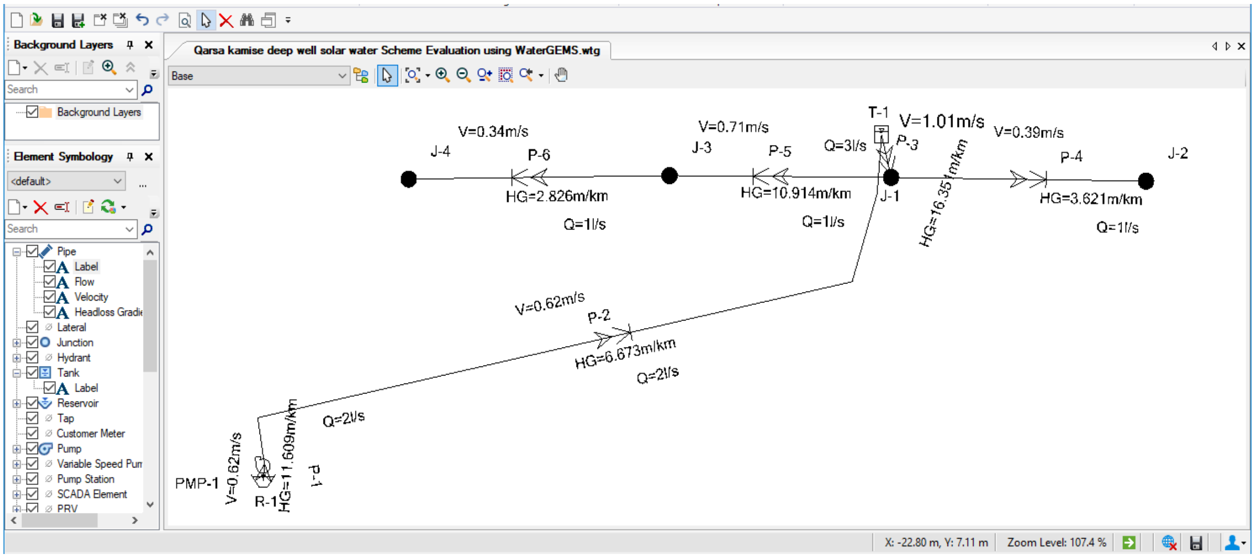


Figure 25: Pipe result for kersa Kamise water supply system, velocity, Head loss and Flow displayed with network

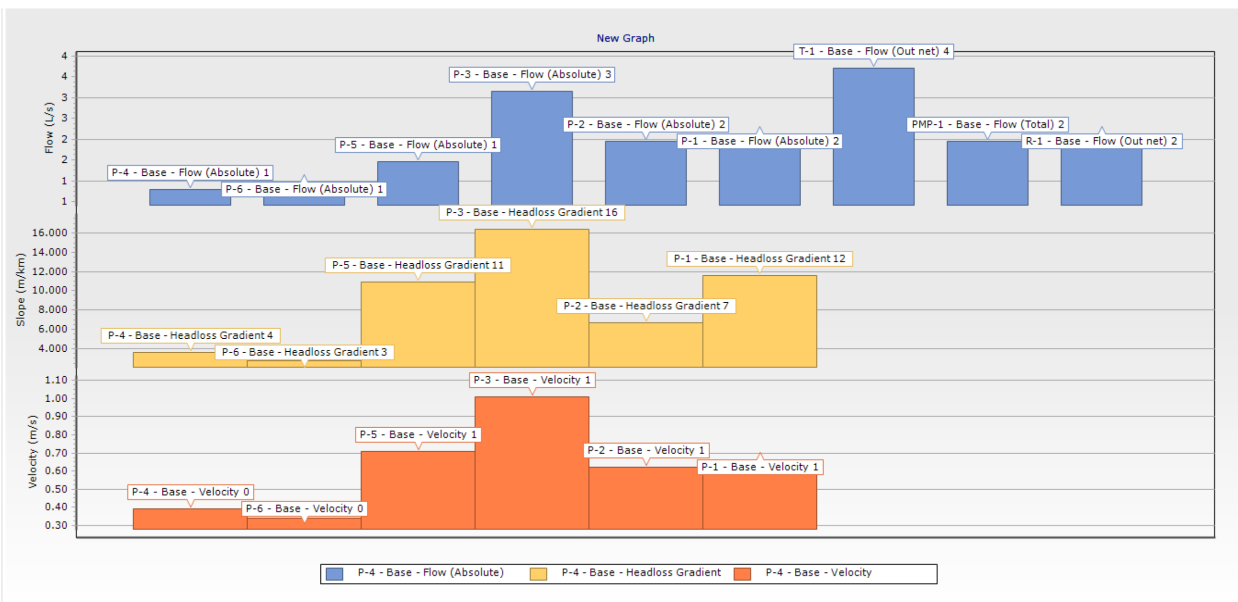


Figure 26: Chart of Kersa Kamise water supply system displayed by Base Flow, Base Head loss Gradient and Base velocity.

Table 9: Kersa Kamise Flow, velocity and Head loss Gradient for Qarsa Kemise water supply

FlexTable: Pipe Table (Current Time: 0.000 hours) (Qarsa kamise deep well solar water Scheme Evaluation using WaterGEMS.wtg)

	ID	Label	Length (Scaled) (m)	Start Node	Stop Node	Diameter (mm)	Material	Hazen-Williams C	Has Check Valve?	Minor Loss Coefficient (Local)	Flow (L/s)	Velocity (m/s)	Headloss Gradient (m/km)	Has User Defined Length?	Length (User Defined) (m)
99: P-1	99	P-1	2	R-1	PMP-1	63.0	Galvaniz	150.0	☐	0.500	2	0.62	11.609	☑	2
100: P-2	100	P-2	89	PMP-1	T-1	63.0	HDPE	150.0	☑	0.170	2	0.62	6.673	☑	696
103: P-3	103	P-3	5	T-1	J-1	63.0	HDPE	150.0	☑	0.170	3	1.01	16.351	☑	690
104: P-5	104	P-5	25	J-1	J-3	51.0	HDPE	150.0	☑	1.280	1	0.71	10.914	☑	740
105: P-6	105	P-6	29	J-3	J-4	51.0	HDPE	150.0	☑	0.500	1	0.34	2.826	☑	630
106: P-4	106	P-4	28	J-1	J-2	51.0	HDPE	150.0	☑	0.500	1	0.39	3.621	☑	520

Table 10: start and End nodes of reservoirs, Tank, Junction, Pump and pump level and diameter for Qarsa Kemise water supply.

FlexTable: Pipe Table

ID	Label	Length (Scaled) (m)	Start Node	Stop Node	Diameter (mm)	Material
99	P-1	2	R-1	PMP-1	63.0	Galvanized iron
100	P-2	89	PMP-1	T-1	63.0	HDPE
103	P-3	5	T-1	J-1	63.0	HDPE
104	P-5	25	J-1	J-3	51.0	HDPE
105	P-6	29	J-3	J-4	51.0	HDPE
106	P-4	28	J-1	J-2	51.0	HDPE

Table 11: Material type, Hazen William coefficient, check valve, Minor Loss Coefficient, Flow and Velocity for Qarsa Kemise water supply

Hazen-Williams C	Has Check Valve?	Minor Loss Coefficient (Local)	Flow (L/s)	Velocity (m/s)	Headloss Gradient (m/km)	Has User Defined Length?	Length (User Defined) (m)
150.0	False	0.500	2	0.62	11.609	True	2
150.0	True	0.170	2	0.62	6.673	True	696
150.0	True	0.170	3	1.01	16.351	True	690
150.0	True	1.280	1	0.71	10.914	True	740
150.0	True	0.500	1	0.34	2.826	True	630
150.0	True	0.500	1	0.39	3.621	True	520

4.1.6 Hydraulic Performance of Junction Parameters for Karsa Kamise Water Supply System.

The Karsa Kamise deep well solar water scheme provide an important view on rural sustainability of the design for supplying water in Gimbichu rural Woreda. Demand (L/s), hydraulic grade (m) and pressure (kPa) based analysis of the network provides a detailed context for the performance, efficiency and reliability required to ensure long-term sustainability of water supply in a rural environment.

System Parameter Evaluation

The hydraulic table estimates operational information for four junctions (IDs 69-3, 70-2 , 71-1, and 78-4. Since the three standpipes are landing region and isolated from water supply source connected to them is interrupted network at time of day, showing both engineering feasibility as well as potential problems.

Demand (L/s)

For the given demand under observation, all four junctions have same consistent demand of 1L/s which depicts that a balanced system can achieve an even distribution and reduces chances for uneven provision creating service void. The peak loading at all the connection points is indicative of strategic size capacity to ensure fairness in water delivery.

Hydraulic Grade (m)

The hydraulic grade values across the evaluated junctions span from J-3:(2474.40-2457.14)=17.26m, J-2:(2474.3-2463.34)=10.96m, J-1:(2474.5-2465.22)=9.96m and J-4:(2474.6-2455.36)=19.24m . A piezometer would display the water elevation which matches the Hydraulic Grade(HG) that combines pressure head together with elevation head measurements. The consistently elevated HG values indicate a powerful system capability to supply sufficient pressure which proves beneficial in rural areas with hills. The minor decrease in HG between upstream points such as 9.96m at 71-1 represents a controlled energy dissipation which occurs through pipeline friction and small pipeline losses.

Pressure (kPa)

The pressure range measured in the sample points falls between -91kP to -188kPa with all readings being negative. The negative pressure indicates the direction at which water flow from higher elevation to low elevation by force of gravity which points out potential areas where air ingress along with pipeline collapse and contamination can happen due to sub-atmospheric conditions. The values emerge when elevation differences become significant and head loss grows substantial and pipes remain undersized while supply head is weak against high demand. Long-term sub-atmospheric pressures can draw contaminants into drinking water supply system which results in pipe deformation, puts pressure, distribution pipe structure and the safety of water supply at risk.

Implications to sustainability

The scheme achieves greater resilience through uniform demand distribution which ensures equal water supply at all times. The system operates efficiently at reduced HG levels which remain within system loss tolerances but requires pressure control measures. Maintaining optimum safe pressures in the system functions as a fundamental barrier against external contamination which directly impacts public health metrics. When pipeline systems operate under negative pressure conditions their wear rate increases which leads to higher maintenance expenses and presents more frequent chances of system breakdowns.

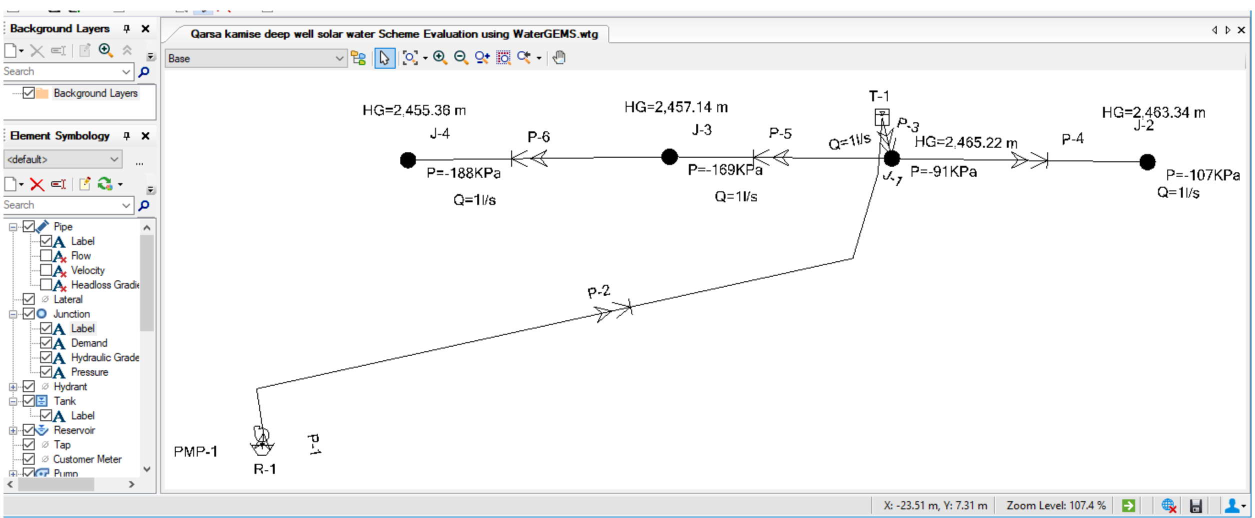


Figure 27: Kersa Kemise water supply system Junction network Hydraulics Grade, Demand and Pressure.

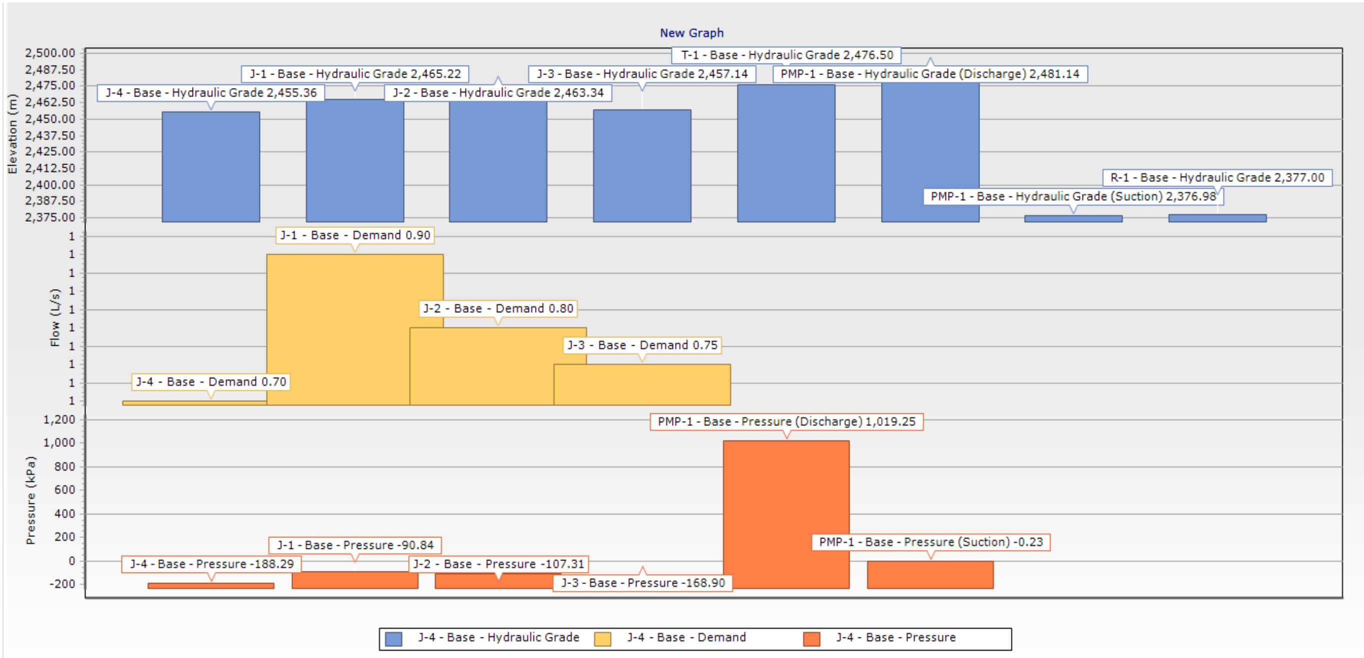


Figure 28: Bar chart of Kersa Kemise water supply system, Base Hydraulics Grade, Base

Table 12: Demand, Hydraulics Grade and Pressure of Kersa Kemise water supply system.

FlexTable: Junction Table (Current Time: 0.000 hours) (Qarsa kamise deep well solar water Scheme Evaluation using...

	ID	Label	Elevation (m)	Zone	Demand Collection	Demand (L/s)	Hydraulic Grade (m)	Pressure (kPa)
69: J-3	69	J-3	2,474.40	Zone - 6	<Collection:	1	2,457.14	-169
70: J-2	70	J-2	2,474.30	Zone - 5	<Collection:	1	2,463.34	-107
71: J-1	71	J-1	2,474.50	Zone - 4	<Collection:	1	2,465.22	-91
78: J-4	78	J-4	2,474.60	Zone - 7	<Collection:	1	2,455.36	-188

Table 13: Demand(L/s), Hydraulic Grade(m) and Pressure(kPa) for Qarsa Kemise water supply

FlexTable: Junction Table

ID	Label	Elevation (m)	Zone	Demand Collection	Demand (L/s)
69	J-3	2,474.40	Zone - 6	<Collection: 1 items>	1
70	J-2	2,474.30	Zone - 5	<Collection: 1 items>	1
71	J-1	2,474.50	Zone - 4	<Collection: 1 items>	1
78	J-4	2,474.60	Zone - 7	<Collection: 1 items>	1

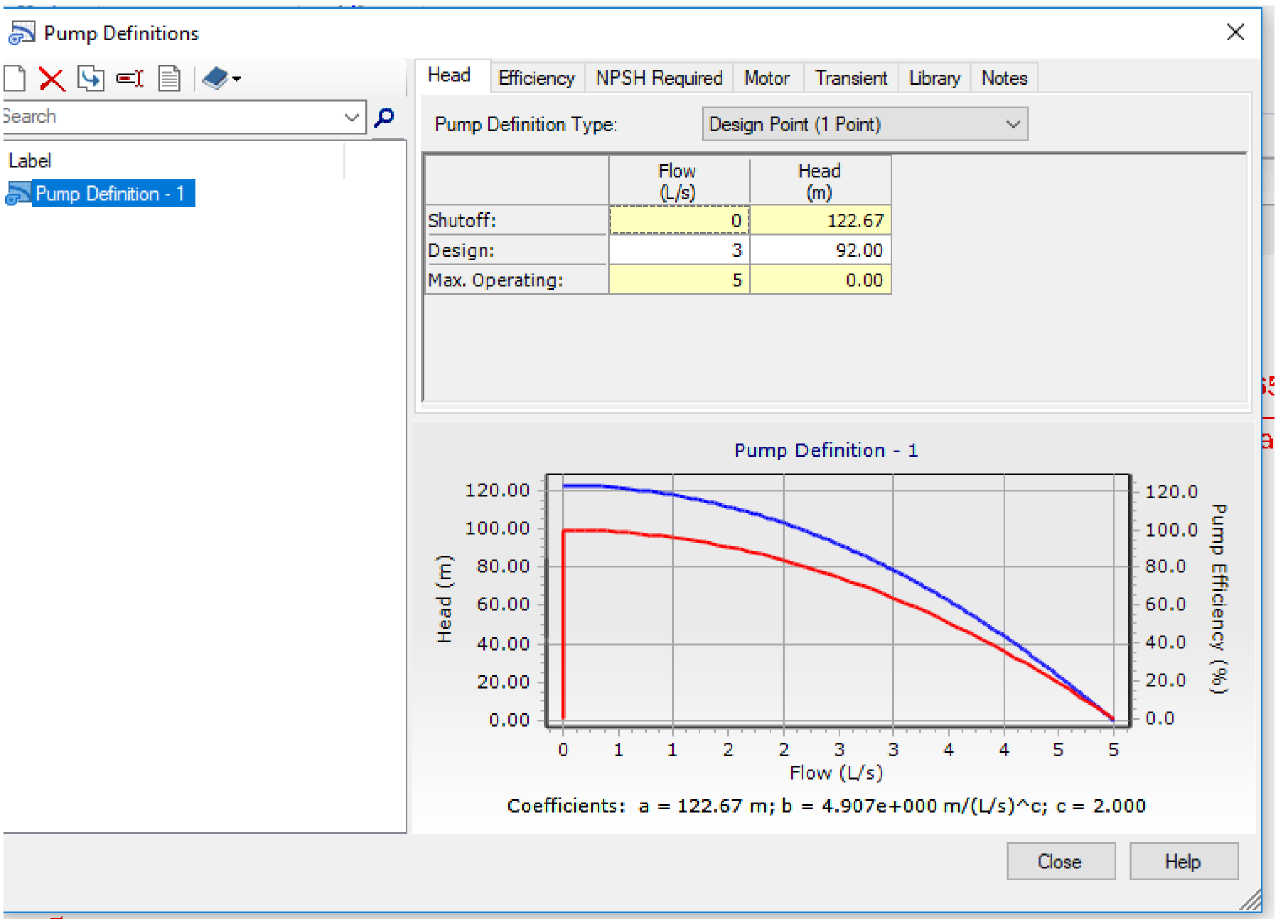


Figure 29: Pump definition

Darine model calibration conducted using Genetic Algorism(GA) for both hydraulic grade and Flow for Kersa Kemise water supply system.

The calibration and validation results demonstrate strong agreement between observed and simulated hydraulic grades, confirming the reliability of the rural water supply system model. The plotted points closely align with the 1:1 correlation line, indicating high accuracy and minimal deviation. The coefficient of determination R^2 is 0,98 reflecting excellent model performance in predicting hydraulic behavior under base and flow conditions. This strong correlation verifies that the system components pipes, nodes, and flow parameters are appropriately designed and functioning efficiently. Therefore, the validated model supports the technical sustainability, operational stability, and long-term performance of the rural water supply system.

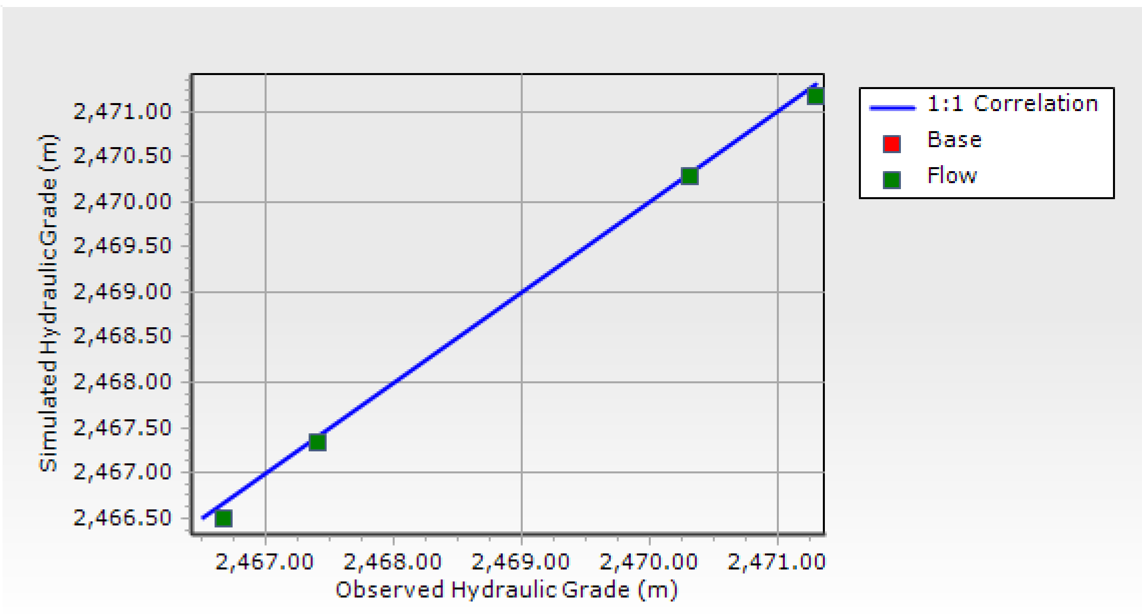


Figure 30: Calibration and Validation for Hydraulic Grade for Kersa Kemise water supply system

Blow is Darine model calibration using Genetic Algorism(GA) for hydraulic grade.

The calibration and validation of observed and simulated flow rates indicate excellent model performance for the rural water supply system. The plotted data points closely follow the 1:1 correlation line, demonstrating strong agreement between measured and simulated flows under base conditions. The coefficient of determination R^2 is 0.99, confirming high predictive accuracy and minimal deviation. This strong correlation verifies that the hydraulic parameters, pipe sizing, and demand estimations are appropriately designed. The validated model ensures reliable flow distribution, adequate service delivery, and operational efficiency, thereby supporting the long-term technical sustainability and resilience of the rural water supply system.

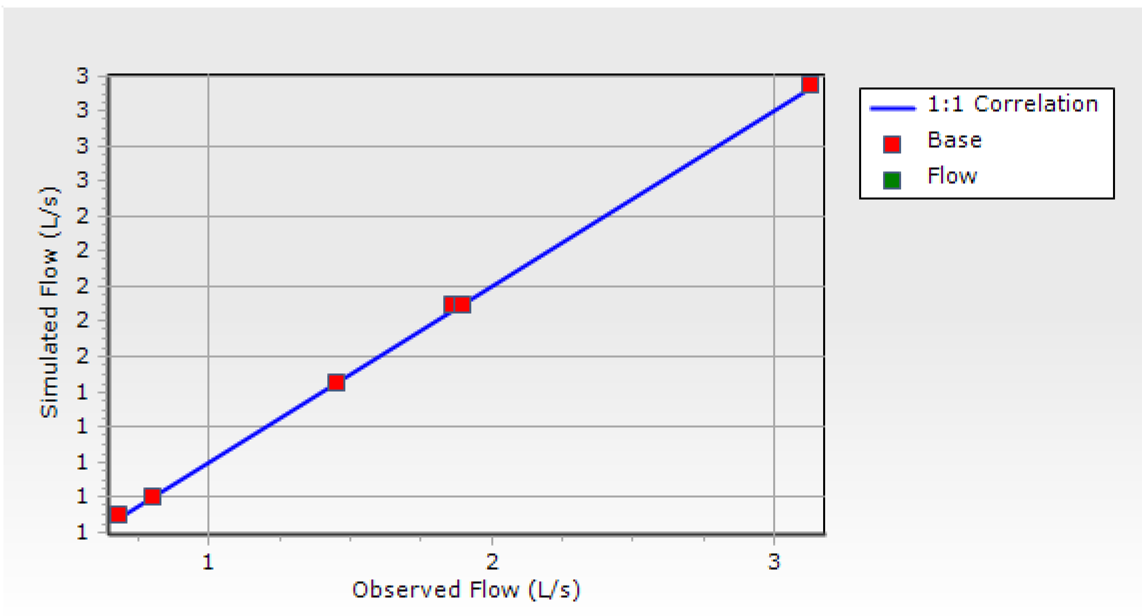


Figure 31: Calibration and Validation for Flow for Kersa Kemise water supply system

4.1.7 Installation of water supply system in Gimbichu rural woreda

Regarding the installation as it is seen from the blow photo, the structures of pipelines are in certain areas are exposed to the surface and not buried under ground which shortens the life spans of the pipe. Also from site observation at solarized water supply scheme there is no power bank or power storage and the solar scheme can supply water to the costumer only during sunny times of the day and cannot supply water before early morning 8:00am and after 4:30pm and during cloudy time.

Figure 32: Photo of pipe installation taken during field survey

4.2. Assessment of the Current Functionality Status of Gimbichu woreda Rural Water Supply Systems

The assessment of rural water supply system sustainability in Gimbichu woreda reveals a varied landscape of water scheme functionality. Out of 244 total schemes surveyed, 184 are functional, while a significant 71 schemes are non-functional, resulting in an overall non-functionality rate of 29%. This shows that providing rural dwellers access to safe and adequate water supply is the major challenge.

4.2.1 Categorization of Non-functional Water Supply Schemes based on their Types.

Non-functional water supply schemes based on their types shows that supplying safe and adequate access water supply is a major challenge. A number of factors, such as technology choice, energy dependence, O&M capability, environmental change, and community management structures, create either sustainability or non-sustainability of rural water supply systems in the study area. Analysis of functionality across scheme types reveals that systems with higher technical energy complexes are having disproportionately higher failure rates, weakening the service delivery over medium to long terms.

Wells found deeper that use fuel generators or on grid electricity having the highest non-functionality rate which is 53% seem structurally dependent on external energy sources. The high price of fuel, frequent power cuts, lack of local technical expertise and difficult access to spare parts in local market do not enable timely maintenance. These factors form the system vulnerability, which damages the sustainability and dependability of the system, causing long outages, even due to small technological failures. The non-functionality rate for shallow wells with hand pumps is high with 54%, indicating that technological simplicity does not guarantee sustainability. The existence of sites includes factors such as inadequate preventive maintenance, poor installation quality, lack of availability of spare parts locally, and poor training of community caregivers. Environmental factors aggravate these problems. Groundwater depths have gradually increased because of changing land use and land cover. Consequently, Afridev pumps are already technically unsuitable. So, more complicated and costly alternatives, like the India Mark II pumps, are necessary. Hand-dug wells, on the other hand, have a not functionality rate of 22%. The simplicity of design, ease of maintenance and strong community ownership makes them robust. But seasonal fluctuations of the water table, structural failure, and risk of contamination still limit their usefulness, provided they are not protected and monitored. The moderate non-functionality of gravity-fed spring systems is 31%, this is due to intake damage, source depletion, and lack of protective structures for transmissions. Sustainability mainly depends on catchment management and regular system maintenance, despite low operational costs. According to the latest study, the lowest rate of non-functionality, 20% is observed in solar-powered shallow wells, indicating a positive trend in sustainability.

Operational risk is greatly decreased when fuel and grid electricity are not used. To ensure long-term resilience, however, issues like limited energy storage during cloudy periods, panel theft, and high upfront investment must be resolved.

In general, Gimbichu Woreda's sustainability results from the alignment of suitable energy sources, environmental circumstances, financial fee collection, institutional capacity, and community-based O&M systems rather than just technology.

Table 14: The Current Functionality Status of Rural Water Supply Systems in Gimbichu woreda.

S/No	Water supply scheme type in Gimbichu rural woredas	Total scheme	Functional	Non functional	% of non functional scheme
1	Deep well fitted with fuel generator and electric power	15	10	8	53
2	Hand dug well	158	124	34	22
3	Shallow well fitted with hand pump	35	24	19	54
4	Shallow well fitted with solar system	10	8	2	20
5	On spot springs with gravity system	26	18	8	31
6	Total	244	184	71	29

Figure 33: Photo During functional spring observation & reservoir elevation point taking

4.2.2 Population Projection for the period 2024 to 2044, (20 years) for water demand

Assumptions:

Base Year: 2024

Projection Year: 2044

Base Population (P_0): 80,572

Projection years(t): 20 yrs

Growth Rate (r): 2.6% (as World Bank population growth rate for rural Ethiopia)

2. Geometric Method

This is compound population growth, in which each year's increase depends on the population of the preceding year.

Formula:

$P_t=P0*(1+r)^t$

Population Numbers

$P2035=80,572*(1+0.026)^{20}=80,572\times1.6616=134,555$

Table 15: Gimbichu Rural Woreda Population Projection from 2024-2044

Year	Geometric
2024	80572
2029	91708
2034	104468
2039	118974
2044	134555

Summary:
Geometric method suits biological or population growth better more than the other and best closes to the average.

Gimbichu Woreda population has been estimated from 80,572 in 2024 to 134555 in 2044, a growth of 67%. With the average water supply of 35 liters per capita per day (l/p/d), the demand will increase from around 2.82 million liters/day in 2015 to 4.71 million liters/day in 2044. This increase is a serious threat to rural water supply sustainability unless the current water supply system is upgraded to meet the growing. The Geometric method display steady trend increases, which indicate to the urgency of upgrading the current water supply system with the population growth rate.

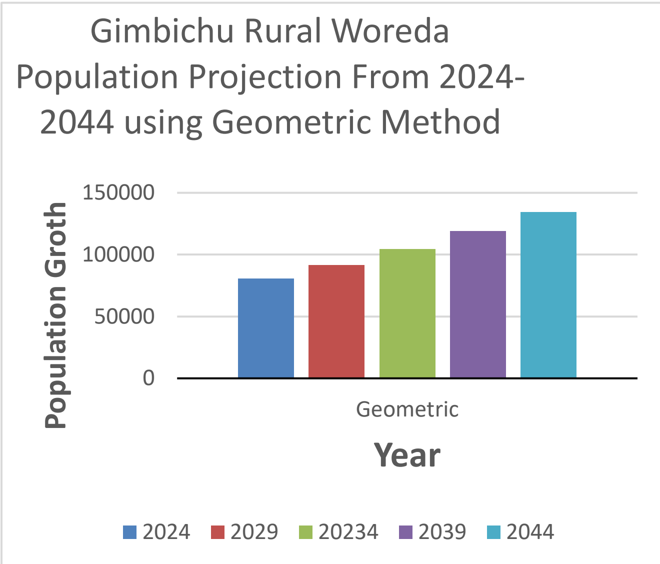


Figure 34: Population projection for water demand for Gimbichu rural Woreda

4.3 Technical and Socioeconomic Factors Influencing the Sustainability of Rural Water Supply Systems in Gimbichu Woreda

4.3.1 Demographic Characteristics of Respondents

While collecting data, the respondents were classified based on whether they belong to WASHCOs or not, whether they have water-fetching responsibility and their age, gender, number of people in a household and water-fetching responsibility. Structured questionnaires were administered and respondents were interviewed while collecting data. Out of the respondents, 29.2% were males and 70.8% were females. For the purpose of getting the correct data the respondents that have good information the age of respondents to be interviewed was determined to be is 18 years and older. Similarly, the respondents' age was between 18-60 years. The majority of the respondents were between the ages of 20-60. These age groups were chosen since individuals in this age bracket were indeed involved in community work for the pre-construction, construction, post-construction phases and operation and maintenance of water supply schemes. In addition, at the time when the study was being conducted respondents' household sizes were considered and therefore results show that household size less than ranges from 1-8+. The respondents explained that they require a big household size because of cultural reason and family planning lack.

The education status of the interviewed households reveals that a majority (44.0%) can read and understand, while 37.7% have attended formal education from Grade 6 to 12. This indicates that most community members have the basic literacy skills necessary to follow instructions, attend trainings, and participate in managing their local water supply systems. However, the 18.3% who are illiterate may face challenges in understanding technical guidelines or participating in written reporting, which can impact system sustainability. Community education in combination with targeted assistance group with lower educational levels can improve the sustainability and ownership of rural water supply services. Based on a descriptive analysis of the data, it is clear that most community members actively participate in the daily collection of water, as 90.57 percent of the households analyzed are involved in obtaining water directly. Given the high level of involvement, in addition to being major clients, the families are essential shareholders of the rural water supply system's sustainability. Only 15.1% of respondents are members of Water User Committee (WAC) while the rest 84.9% are not. Thus, a very low share of respondents is officially involved in water governance frameworks.

A gap between committee members and users may indicate some form of neglect in representation and decision-making. Accordingly, this gap may inhibit the responsiveness and ownership of water supply systems. The results highlight the significance of enhancing community-based management structures by promoting increased involvement and raising understanding of the roles and duties within the WUC. From the standpoint of water supply engineering, sustainability is best attained when users are empowered to participate in system operation, maintenance, and governance in addition to being consumers. Therefore, to improve system resilience and long-term functionality, focused capacity-building initiatives and inclusive engagement tactics are essential.

Table 16: Respondents' Demographic Characteristics at Gimbichu Rural Woreda

Age categories of HH respondents	Frequency	Percent
18-24	8	2.5
25-34	44	13.8
35-44	207	65.1
45-60	59	18.6
Total	318	100
Gender of respondents	Frequency	Percent
Female	225	70.8
Male	93	29.2
Total	318	100
Family size of the HH respondents	Frequency	Percent
1-2	2	0.6
2-3	167	52.5
3-4	1	0.3
4-5	139	43.7
5-6	2	0.6
6-7	3	0.9
7-8	1	0.3
8+	3	0.9
Total	318	100
Education status of respondents		
Illiterates	58	18.3
Can read and understand	140	44.0
From Grade 6-12	120	37.7
Number respondents who are also responsible for Fetching Water	Frequency	Percent
No	30	9.43
Yes	288	90.57
Total	318	100
Number of household respondents who are member Water User Committee	Frequency	Percent
No	270	84.9
Yes	48	15.1
Total	318	100

4.3.2. Existing problems to sustainability of rural water supply Schemes

4.3.2.1 Local community participation in during planning, site selection, construction, maintenance, operation and Fee collection.

4.3.2.2 Membership in Water User Committees (WUCs) in Gimbichu rural Woredas

One important indication of rural water supply sustainability and local control of rural water supply systems is community participation such as Water User Committees (WUCs). The following was shown by data collected from 318 home respondents in Gimbichu Woreda. Only 15.09% (n = 48) of all respondents said they actively participated in WUCs, while a sizable majority (84.91%; n = 270) said they did not. This pattern is further supported by the cumulative data, which shows low grassroots participation in committee structures with full saturation (100%) obtained by the inclusion of the Yes category. The sustainability of rural water delivery schemes is directly threatened by the startlingly low membership percentage (15.09%) in WUCs, which represents a substantial institutional and participative gap. Ethiopian rural WASH implementation guidelines and water governance principles state that community involvement, particularly in decision-making and operational management, is crucial for: ensuring timely maintenance and repair; mobilizing local financial resources; improving transparency and accountability; and promoting equitable water distribution. According to the data, the great majority of water users do not actively participate in the management and supervision of their own water systems, which may result in system neglect, a delay in reporting faults, financial mismanagement, and user discontent. Low WUC participation's effects on sustainability aspects
Institutions, governance, and community ownership are all weak. Technically possible delays in system breakdown responses and repairs. Financially inadequate oversight of fund utilization and revenue collection Socially Low user engagement, risk of conflict and inequality.

Table 17: Water User Committee (WUC) membership in rural Gimbichu Woredas, July 2025.

Response	Frequency	Percent (%)	Cumulative Frequency	Cumulative Percent (%)
No	270	84.91%	270	84.91%
Yes	48	15.09%	318	100.00%
Total	318	100.00%		

4.3.2.3 Community Participation for Water Supply System during Operation and Maintenance and Site Selection.

The long-term sustainability and performance of rural water delivery systems are significantly influenced by community involvement in operation and maintenance (O&M). Strong community involvement is evident in the data gathered from 318 homes in Gimbichu Woreda, while the distribution of contribution types is skewed: Most families (51.6%) provided local materials, which suggests a considerable degree of in-kind contribution (wood, gravel, sand) for the upkeep of infrastructure. The fact that 28% of households reported providing labor suggests that the community is willing to assist with physical work, such as digging trenches, repairing pumps, and moving materials. There may be some scope for financial sustainability through some cost-sharing mechanisms, as evident from a small but curated cash contribution of 19.8%. One area in which institutions do appear to be somewhat deficient in sustainability is idea generation, which is identified as having an incredibly low level (0.6%).

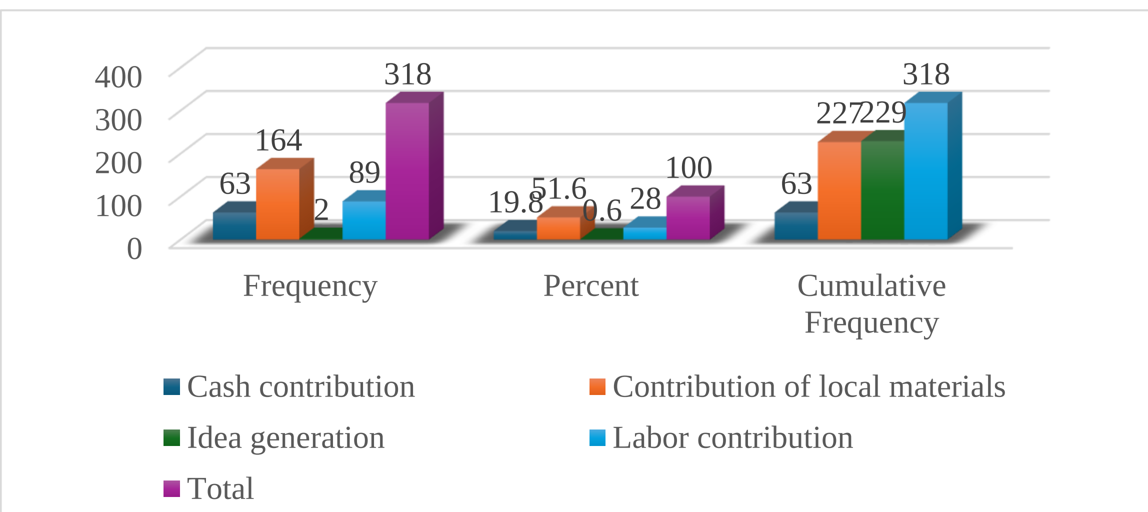


Figure 35: Community participation during operation and follow up the rural water supply system in Gimbichu rural woreda in July 2025.

The majority of respondents chose the survey and open discussions, with 38.1% opting for it in site selection. This shows a relatively wide, participatory process that strengthens long-term community commitment to system maintenance and enhances the credibility of the project. It is noteworthy that 23% of respondents were notified of decisions after they occurred. This approach that comes from higher levels of power restricts what the community can suggest for location, which might not cater to local needs or environmental hazards but is better than being left out entirely. In above one-fifth (19.2 percent) cases, only local leader's contacted. There are hazards to sustainability since this tokenistic style of involvement might not represent the requirements of the larger population and could erode community accountability.

It is encouraging that historic water-sourcing methods are acknowledged. Finding dependable, seasonally adaptable water sources can be greatly aided by local ecological knowledge. The ratio of 19.8%, however, suggests that there is more space for methodically integrating indigenous methods. However, limited participation is reflected in exclusionary practices (42.2%), where groups were either narrowly consulted or only informed after choices were made. This may lead to dissatisfaction, reduced ownership, and possible system abandonment over time.

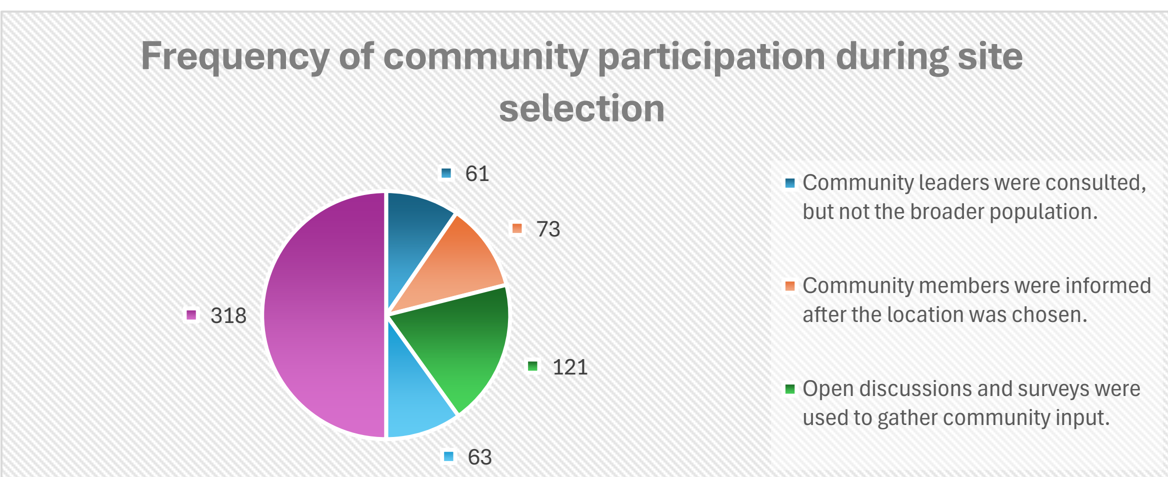


Figure 36: Community Participation for during site selection of rural water supply system in Gimbichu rural woredas, July 2025.

4.3.2.4. Community awerness on maintainace & opration of rural water supply system

A survey as conducted in Gimbichu rural woreda to assess the sustainability of its rural water supply system. A primary area of investigation was whether the public was aware who is responsible for maintaining the water supply. The results reveal a lack of understanding from the surveyed population. Out of 318 respondents, 299 people or 94% of them said that they did not know who maintains the water supply system. On the contrary, only 19 respondents or merely 6% showed that they were conscious of this important task. The relative cumulative frequency further illustrates this, as it shows that 94% did not have any knowledge of this.

A low level of awareness about the rural water supply system in Gimmick worked threatens its sustainability in the long run. From the perspective of environmental engineering and water supply engineering, community ownership and participation are essential for sustainable water resources. When the community does not know who is responsible for maintenance it can lead to: delayed Reporting of Issues – minor issues can become serious problems, lack of Proactive Maintenance, lack of accountability, limited Community Participation that contributes with financial and in-kind labor for maintenance and extra burden on external Entities.

The community does not know enough about the maintenance, as per the findings.
The responsibilities of the rural water supply system in Gimmick worked. The usefulness of the water structure.This prevalent ignorance greatly hampers their effectiveness.

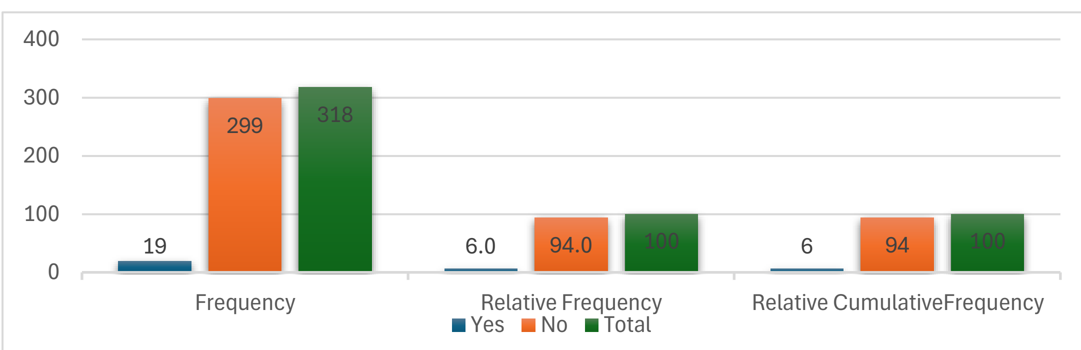


Figure 37: Awareness of responsibility for rural water supply system maintenance at Gimbichu rural woreda, July 2025.

According to 318 respondents, a severe lack of local technical capability exists in the region. An alarming 97.2% of responders (309 people) stated that there was no staff assigned for O&M (operation and maintenance). It indicates that there are hardly any formal or informal organizations and or people responsible for the water infrastructure. Only 7 respondents or 2.2% of total respondents said they have an idea about maintenance. The idea is perhaps only the basic chores. Even more interestingly, just two respondents (0.6% of the sample) were O&M trained skilled members of the community. The cumulative frequencies reveals that 99.4% of the community, are either without O&M personnel or have only basic understanding, with only a negligible number being trained formally.

Due to this extreme shortage of community technical capacity, the rural water supply system in Gimbichu woreda is threatened for its sustainability. Survey sources revealed the following: Though ownership is an issue, water quality and quantity suffers. Operations increases costs, and deteriorates faster.

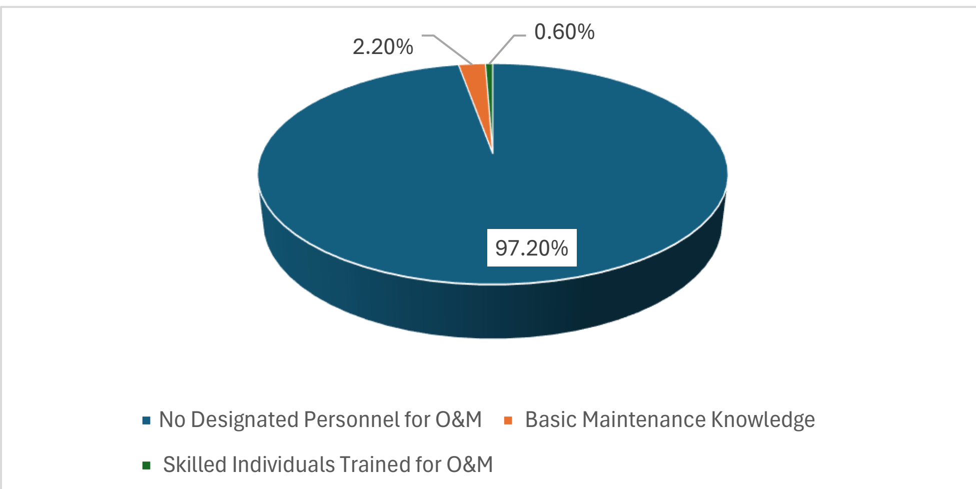


Figure 38: Community Technical Capacity for Water System Maintenance in Gimbichu rural Woreda, July 2025.

On the other hand, a whopping 93.1 percent (296 of 318) of respondents were not aware of the scheduled repairs in the local water supply systems. In stark contrast, only 22 people (6.9%) said they knew. The data indicates that community and system operators do not communicate effectively, which can jeopardize the sustainability of water systems in the longer term.

Misinformation often leads to poor community ownership, delayed reporting of defects, and rapid deterioration of infrastructure due to neglect.
Due to this serious ignorance, the very sustainability that rural water systems require, including routine maintenance, preventive maintenance, and user participation, is threatened. If the community is not informed or engaged, these systems face an increased risk of malfunctions, inefficient resource consumption, and a deterioration of trust in public infrastructure.

Dependability of water supply system, follow-up and fee payment. The dependable provision of services is one of the most important indicators of the sustainability of O&M in rural water supply systems. Based on survey results conducted on the frequency of water supply disruptions in Gimmick Worked, a greater percentage of the population encounters outages occasionally. Out of 318 respondents, 215 or 67.6% stated that there is “occasionally” an interruption in water supply. 9.4% or 30 reply that they never run out of service. 21.4%, or 68, were responses to the water supply is running out "rarely." Five respondents or 1.6% were disrupted frequently, which is troubling.

The reliability and sustainability of the water systems are at risk because of this trend, wherein more than two-thirds of the community feels inconvenienced at some times. Despite only a small percentage facing interruptions frequently, the majority of irregular ones indicate capacity failures, inadequate maintenance, or technical limitations within the water system. While most interruptions aren't serious, the regularity points to some malfunctioning processes. Power issues, equipment failure, or lack of spare parts may all result in intermittent breakdowns, which pose a serious sustainability risk in rural areas.

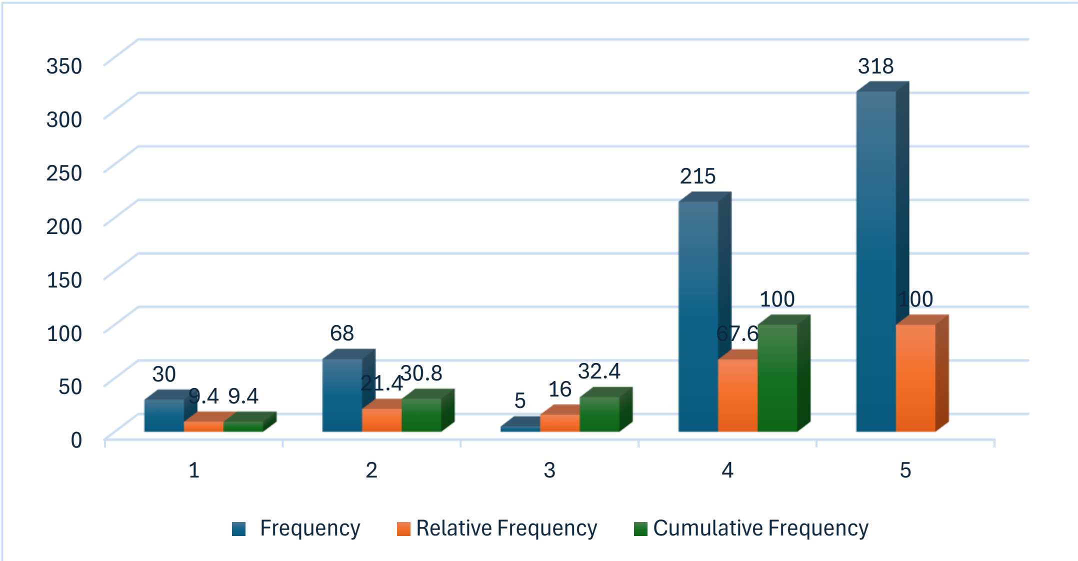


Figure 38: Community attitude regarding the break of the rural water supply system in Gimbichu rural woreda, July 2025.

The survey conducted on the rural work of Gimmick measured the community's view and willingness to maintain the rural water delivery system. The table below summarizes the replies received by the survey, with 318 replies. As per the survey, the majority of people (39.3%) remain neutral regarding the advantages of the rural water supply system, pointing out that they are not aware of it. A sizable share (28%) of the sample was not willing or interested in that. Only 13.21% of respondents were willing, while 19.5% of respondents were very strongly willing; thus, a smaller but significant number participated in sustainability. A total of 46.7 percent of the respondents exhibited a certain degree of willingness. Thus, they can be engaged if initiated in the right manner. However, a complete 67.3% is neutral or unwilling, which may jeopardize long-term system sustainability if not effectively controlled.

The high level of neutrality (39.3%) indicates a serious lack of knowledge and understanding of the rural water system impacts. Insufficient communication from the a nearby service provider or a lack of member involvement with the community creates this problem. Furthermore, a lack of trust in water governance systems or earlier service failures may account for 27.99% of the unwillingness.

Still, the 32.71% of respondents indicating willingness or great willingness provide a useful starting point for the development of community-based management methods. They could affect other people through advocacy and peer learning if they get the support.

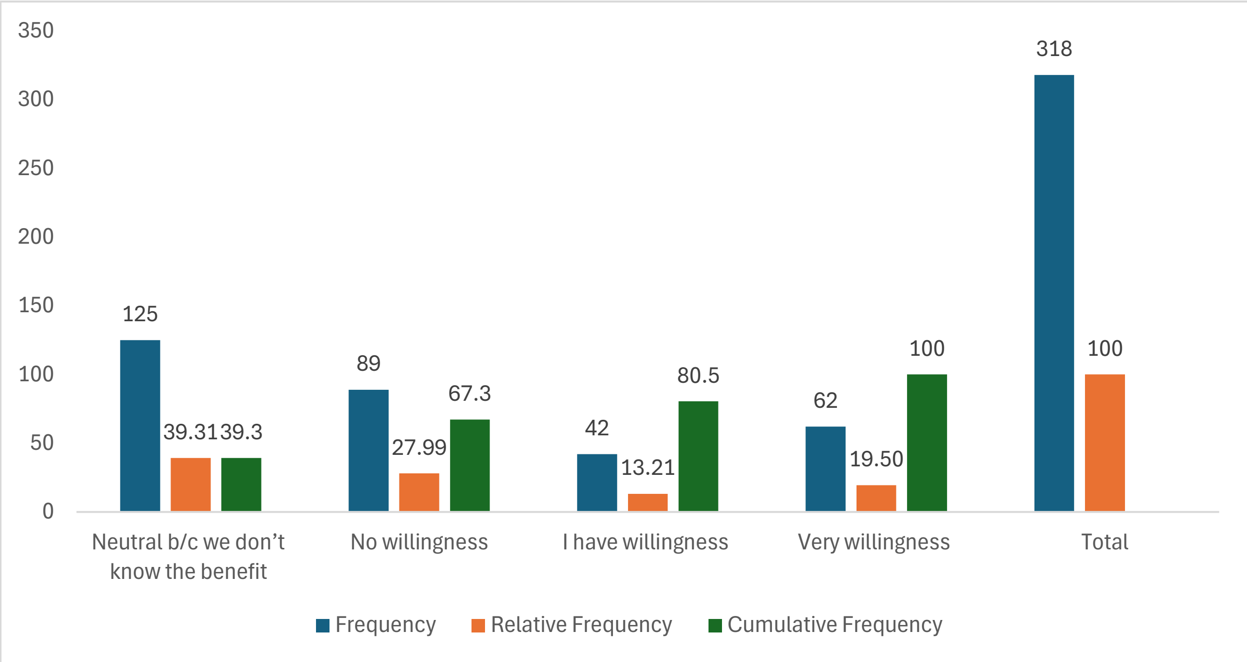


Figure 39: Willingness of the customer for financial contribution to the upkeep of the in Gimbichu rural water supply system, July 2025.

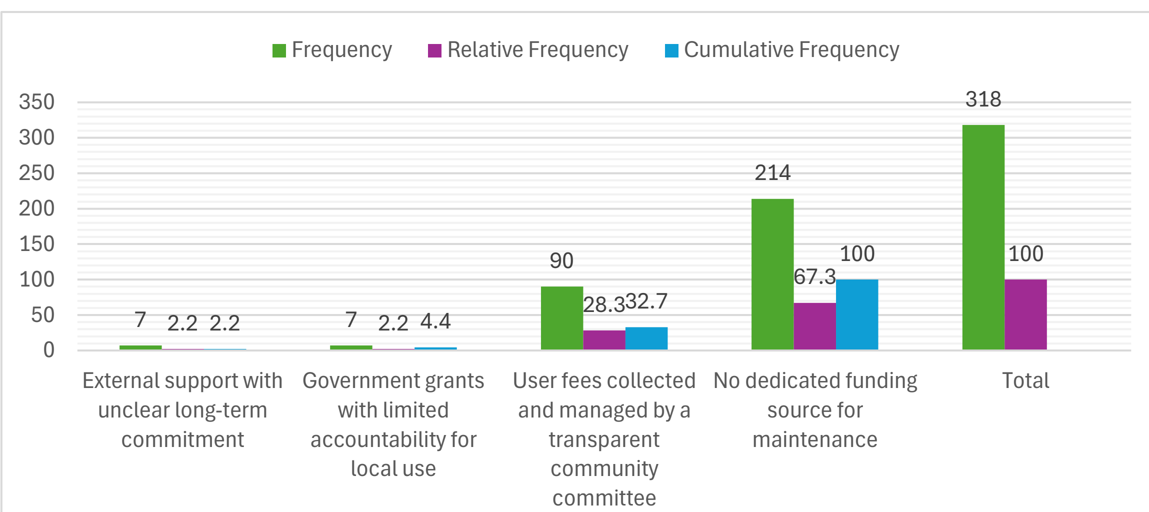
This question was asked in the survey to check the readiness of the families to make payments for the maintenance and operation of water supply systems in Gimmick Worked. Of the 318 respondents, 66.7% indicated that they would be willing to pay, which shows a considerable community commitment for the maintenance of water services. Around 33.3% of the respondents were not on board with any such option, which is something to take note of as it could be due to budgetary constraints, distrust on management's part, and discontent with current services. The results suggest that many people are very conscious of how important cost-sharing is to sustain rural water. This willingness may be due to an increasing understanding of the importance of maintenance in preventing more frequent system failures. Yet, with 33.3% of respondents having indicated that they would not pay, especially in poor households or where community trust is at the low end, the financial sustainability may be in jeopardy. The findings suggest that cost-recovery strategies can be sound as long as constraints for the 33.3% are removed as appropriate.

Table 18: Indicates the commitment of customers to contribute financial support for O&M of Gimbichu Woreda rural water supply system.

S/no	Response	Frequency	Relative Frequency	Cumulative frequency
1	No	106	33.3	33.3
2	Yes	212	66.7	100
3	Total	318	100	

According to an assessment of the policies on which the long-term financial sustainability of rural water delivery systems depends, there are large maintenance budget gaps in Gimmick Worked. The survey of 318 respondents shows a clear gap between the methods used to fund system maintenance and repairs. According to most respondents, there is no particular financial source for maintenance (67.3%). This important recognition exposes a fundamental flaw that threatens the long-term sustainability of the woreda water system. If there is no organized financial planning, infrastructure could deteriorate and service could fail.

Only 28.3% of respondents claimed that community committees collect/manage user fees in an open manner. Though critiqued for not working elsewhere, that model is shown to work in strengthening local ownership and operational sustainability of many rural water systems. 2.2% of the responses are linked to government funds with minimal local control and outside involvement



with unclear long-term commitment. While they may serve well in the short run, they are all unlikely to provide a mechanism for continuity and local involvement. As such, their reliability for long-term service delivery is questionable.

Figure 39: The financial plan for water supply maintenance in Gimbichu rural Woreda.

The study revealed a worrying lack of community readiness and technical empowerment in relation to user capacity building for sustainability of rural water supply systems implemented in Gimmick Worked. Among 318 respondents, 256 people (80.5 percent) said that the community hasn't received any official training. The shocking figure reflects a severe absence of local skills, therefore now jeopardizing the water systems' long-term sustainability. Merely 17% of the respondents said they sporadically attended training, which is not useful. This means there is training activity, even where it is shallow and has little impact. Further, 2.5% of the respondents state that material for training is available but is not used, which indicate our problems related to implementation gaps, accessibility, and awareness.

Table 19: User Capacity Building and Its Role in Sustainability of Rural Water Supply in Gimbichu Woreda July 2025.

Response	Frequency	Relative Frequency	Cumulative Frequency
No formal training provided to the community	256	80.5	80.5
Occasional training sessions with limited practical application	54	17	97.5
Training materials available but not utilized	8	2.5	100
Total	318	100	

4.3.2.6. Local availability of construction materials and their impact on the sustainable rural water supply system in rural Gimbichu Woreda.

An assessment of the viability of technologies used in Rural Water Supply Systems of Gimbichu Woreda is important for systemic sustainability issues. Out of the 318 respondents, 61.3% (195 persons) of respondents reported that the installed systems are based on complicated technologies, the repair of which requires specialists from outside. Rural communities' resilience and autonomy are gravely threatened due to their dependence on technical solutions beyond local capacities. Only 2.5% (8 respondents) of the respondent stated that the best way to ensure long-term sustainability of the system is to ensure simple technology, easy maintenance and spare parts availability. In addition, no assessment was made regarding the feasibility of this technology prior to installation, said 17% (54 respondents). This lack of oversight and teamwork went into the decisions for the technology used.

In addition, 19.2% (61 respondents) state the technology in use is not suited for the environmental and hydrological parameters of the local water supply and that the system may break down often or not work.

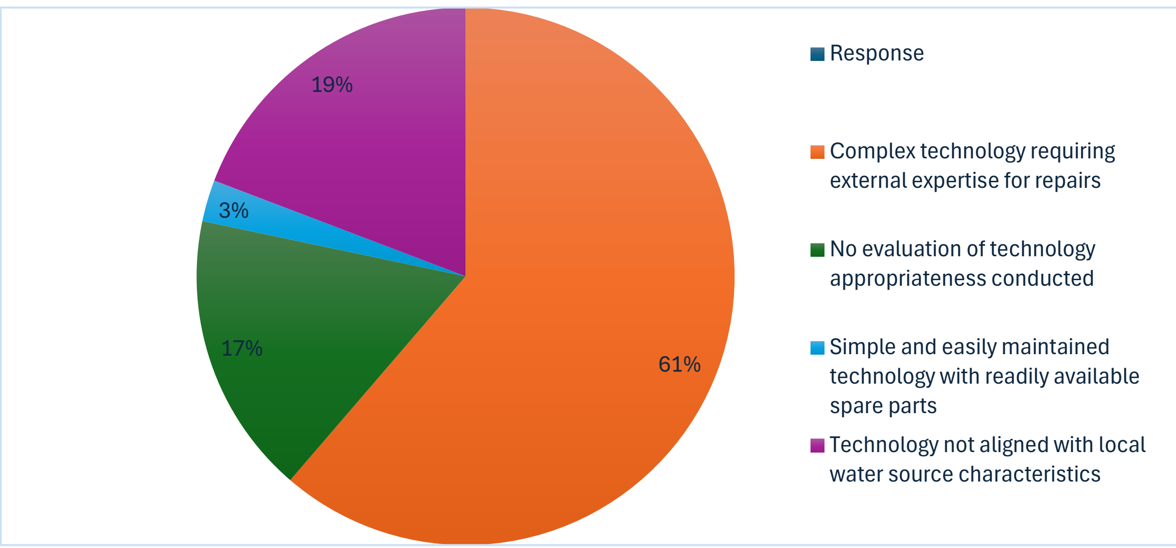


Figure 40: The appropriate technology usage for rural water supply system in Gimbichu rural woreda in July 2025.

4.3.2.7. Availability spare parts in local markets in Gimbichu rural Woreda.

Constant access to spare parts is an important requirement of sustainable rural water supply systems. The data from the survey in Gimmick Worked shows that

problem is still existing. 241 (75.8%) of the 318 respondents surprisingly stated that there was no process in place for the purchase of new parts. Water infrastructure maintenance and repair is impeded as a result of this issue.

Moreover, 18.6% (59 respondents) indicated that long lead times or external sourcing are necessary for obtaining replacement parts, which increases maintenance costs and delays. Only 5 respondents

(1.6%) said the local stores stock them. This reveals a very poor local supply chain. Thirteen respondents, constituting 4.1% of the sample, reported limited success in carrying out improvised repairs. This demonstrates the community's adaptability and resilience, but rather highlights systematic failure in the availability of standard parts and technical assistance.

4.3.2.8 The rural water supply system which managed by the Gimbichu rural woreda water management committee.

The water distribution system was said not to be under WAC by the majority of respondents (57.8%), while 14.7% said it is. The information gap in the community is evident in their response, where 27.4% did not know the management structure. Below is a visualization of responses to help in the understanding of the data. Most of the negative responses suggest that WAC has no power over the rural water supply systems of Gimmick worked. This is important, as the creation of WAC is often viewed as a key step towards sustainability, community engagement, and effective WRM. A high number of respondents do not know the management structure, which also marks a refusal to engage with the community.

Without or with hardly any WAC present, sustainability problems may arise from poor maintenance, lose functionality, and be little accountable or not at all. Rural water supply systems could face long-term threats due to these aspects. According to the study, 57.8% of the respondents claimed that WAC is not in charge of the current rural water distribution system. Shockingly, WAC's involvement in monitoring the system was in doubt by 27.4% of respondents, while only 14.7% of respondents acknowledged it. The distribution illustrates there is a considerable deal of institutional confusion or absence. Greater community awareness of governance obligations and a clearer definition of such roles are urgently needed. Lack of effective WAC control makes the system susceptible to bad management and uncoordinated maintenance.

Table 20: Gimbichu Rural Woreda's WUC-led water supply system, July 2025

Response	Frequency	Relative Frequency (%)	Cumulative Frequency (%)
I don't know	87	27.4	27.4
No	184	57.8	85.2
Yes	47	14.7	100
Total	318	100	

Frequent meetings show operational discipline and responsiveness. The results show that although 67% of WUCs hold monthly meetings, a significant 21.1% never do. The other frequencies were comparatively modest (weekly: 1.9%, biannually: 0.3%, and annually: 9.7%). These numbers show a sizable portion of active committees as well as gaps when committees are essentially dormant. To synchronize operations throughout the woreda, institutional rejuvenation is required.

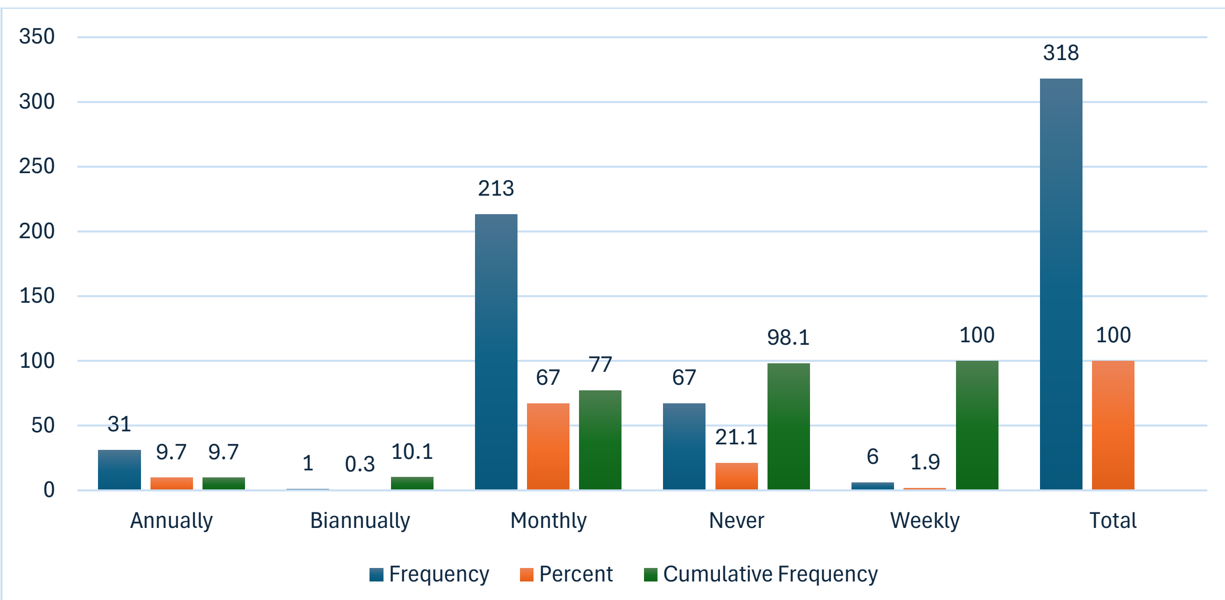


Figure 41: The frequency of WUC meetings in July 2025 to maintain and operate the Gimbichu rural woreda water delivery system.

According to the survey, 23.3% of respondents thought WUC communication was poor and 59.7% thought it was insufficient. Just 16.4% of respondents thought it was decent, and just 0.6% thought it was fantastic. These results point to a communication gap that can erode users' and service management's confidence and openness. Notice boards, village meetings, and better information-sharing tools could all help close this important gap.

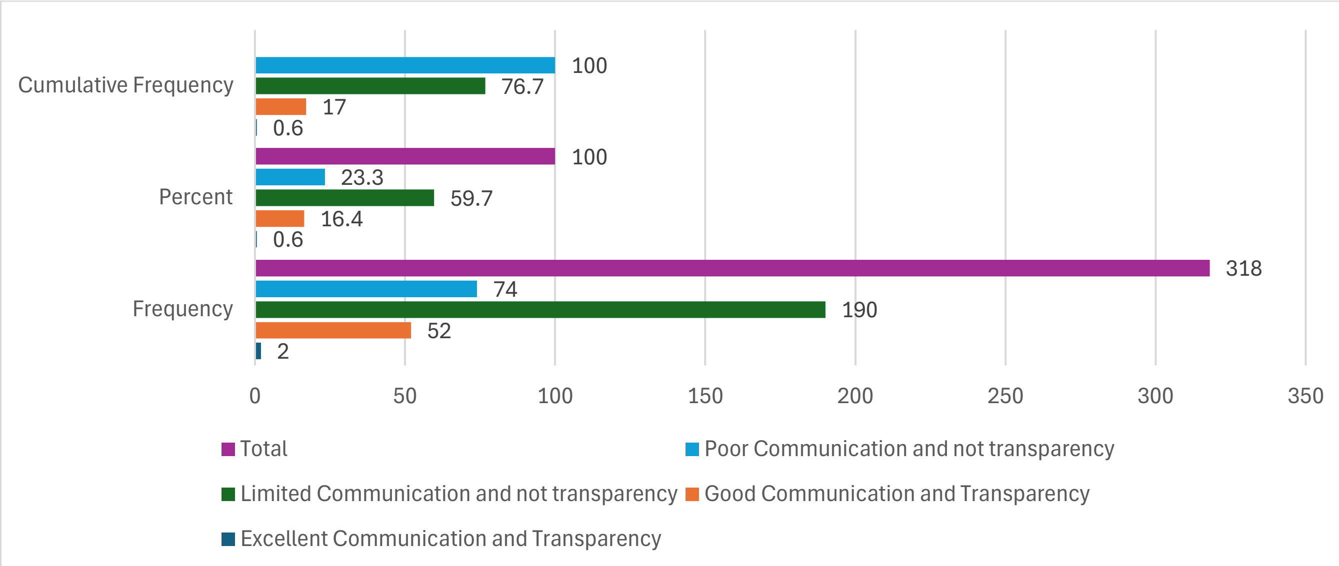


Figure 42: Shows how WUCs affect the Community when water schemes are administered in Gimbichu rural Woreda, July 2025.

4.3.2.9 The rural water system in Gimbichu woreda's capacity building and dispute resolution process for customers and WUCs.

Water disputes are common in resource-poor rural areas. In this instance, 60.7% of respondents claim that there aren't many conflict resolution processes in WUC institutions. A further 19.5% confirmed no mechanism at all, while 19.5% reported described but problematic structures. Only 0.3% of respondents claimed that the process was effective. This calls for quick institutional changes, including the development of rules, mediation training, and accountability frameworks, in order to support equitable access to water.

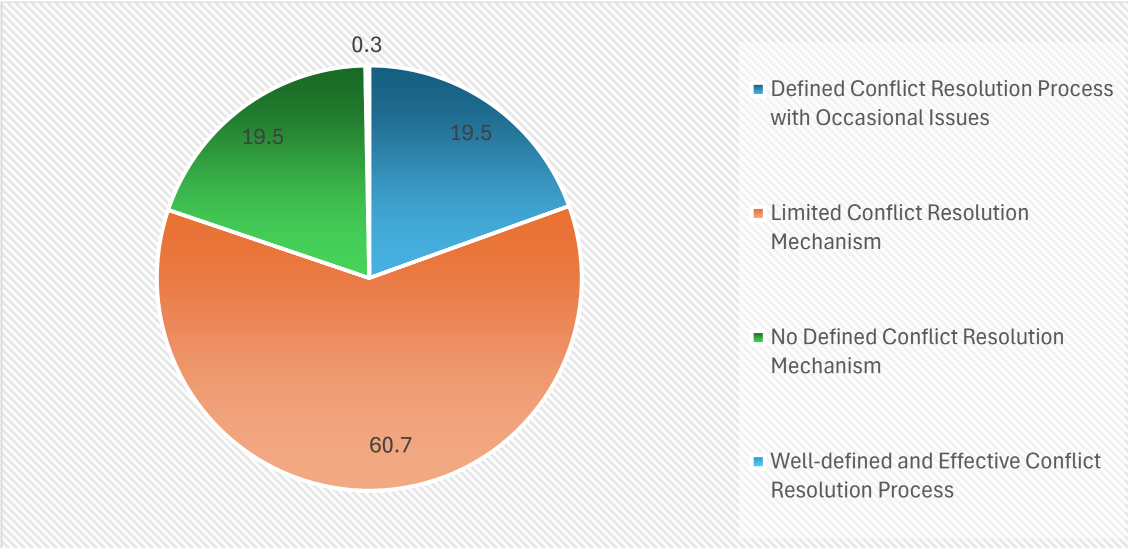


Figure 43: Conflict settlement procedures for the rural water delivery system in Gimbichu woreda, July 2025.

Capacity development ensures long-term operability. The majority (51.9%) agreed that there are little opportunities for training, however 26.1% claimed there is occasionally training. Regretfully, 22% reported receiving no instruction at all. This training gap hinders long-term sustainability and technical performance. When it comes to capacity building, government-led technical assistance programs and NGO partnerships should be given top emphasis.

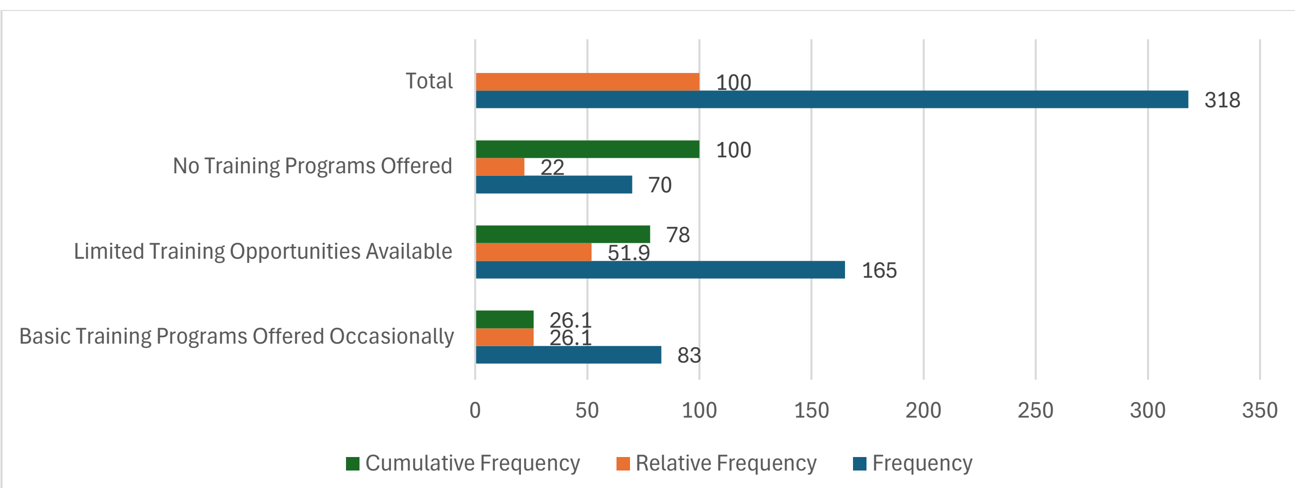


Figure 44: Training to improve WUCs' ability to sustain for Gimbichu woreda rural water schemes, July 2025.

4.3.2.10 Management of rural water schemes

The physical robustness of the water delivery system is reflected in the state of the infrastructure. According to the research, 32.4% of respondents define the system as poor, while 67.3% think it is in acceptable shape and needs regular maintenance. The infrastructure is only rated as good by 0.3%. This enormous demand for repairs draws attention to inadequate funding, logistical hold-ups, and subpar building techniques. There is an urgent need to invest in infrastructure renewal and preventative maintenance.

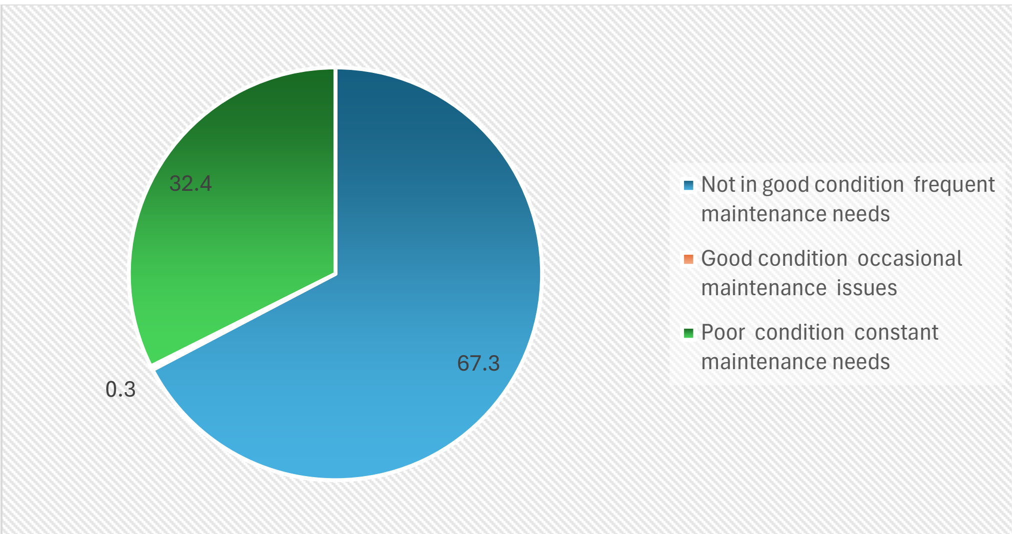


Figure 45: The Gimbichu rural water supply system requires maintenance, July 2025.

Water conservation and system efficiency depend on leakage control. According to this study, 72.3% of respondents said the system had few leak detection and repair capabilities, while 13.2% said it had none at all. Just 13.5% of respondents thought the current mechanisms were effective, and 0.9% said they were extremely effective. Water loss and resource waste are directly caused by this inefficiency. It is advised to implement leak detection technologies, map pipes, and provide local plumbers with training.

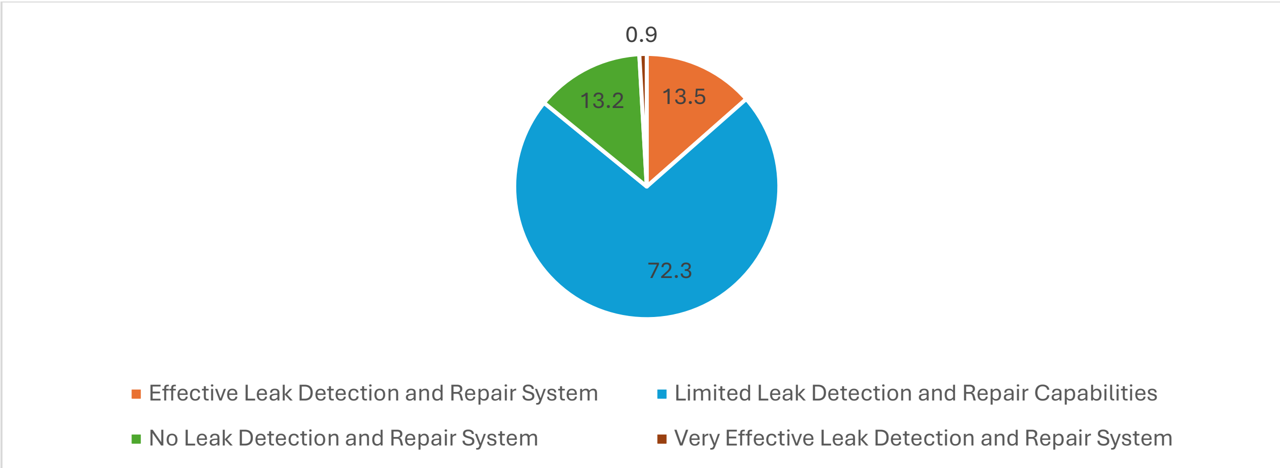


Figure 46: Leakage management effectiveness in Gimbichu rural woreda July 2025.

Strategic foresight is necessary for sustainability under population growth and climate variability. Here, 89% of respondents reported that no formal expansion plan exists. Only 3.1% acknowledged a preliminary plan, and a mere 1.3% confirmed the presence of a well-funded strategy. This shortage recommends a responsive rather than active planning culture. Long-term planning frameworks, inclusive budgeting, and donor collaboration are key to system longevity.

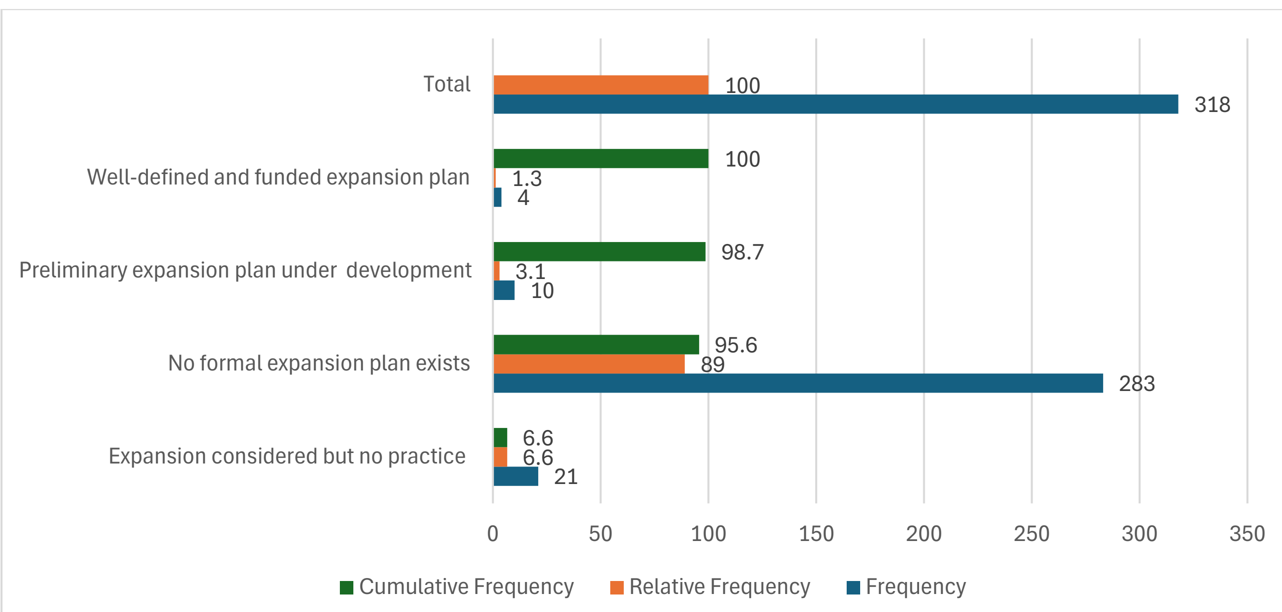


Figure 47: Future expansion plan by woreda water office in Gimbichu Rural Woreda, July 2025.

4.4. Sources of ground water balance estimation and determination of environmental impacts on its sustainability of water supply system.

4.4.1 Hydrological Modelling with ArcGIS with SWAT Modelling

The Arc SWAT model version 2012.10_5_24 released 8/19/20 was downloaded from SWAT website. Then its toolbar was added to Arc GIS 10.5 for hydrological modeling process. The modeling procedure started from SWAT project setup, Watershed delineation, and HRU Analysis, Write Input Tables, Edit SWAT Input, SWAT simulation, sensitivity analysis, Calibration, Validation and Edit and Rerun SWAT Model.

4.4.2. Watershed characteristics

4.4.2.1. Watershed Delineation

The first step in generating SWAT model is watershed delineation. The soil map, LU/LC map and the DEM were projected to UTM using ArcGIS 10.5 to the same projection prior to watershed delineation. This was done to overlap DEM, LULC and Soil maps during SWAT modeling. The watershed and sub watershed delineation was performed using 20m by 20m resolution of Awash Basin DEM data and clipped by mask for this sub catchment. The DEM was loaded and its projection was defined. Since the location of gauging station was known the outlet generated by model was modified at the gauging location for later calibration purposes. The location of the stream flow gauging station of Madjo River was manually added during the model set up process. Once the DEM set up was completed and the location of outlet was specified on the DEM, the model automatically calculates the flow direction and flow accumulation. Finally stream networks, sub watersheds and topographic parameters were calculated using the respective tools.

The watershed was delineated into 29 sub basins having an estimated total area of 120628.4 hectares. During the watershed delineation process the topographic parameters such as elevation and slopes of watershed and its sub watershed were generated from the DEM data. The elevation of the watershed ranges from1718m to 3084m above mean sea level.

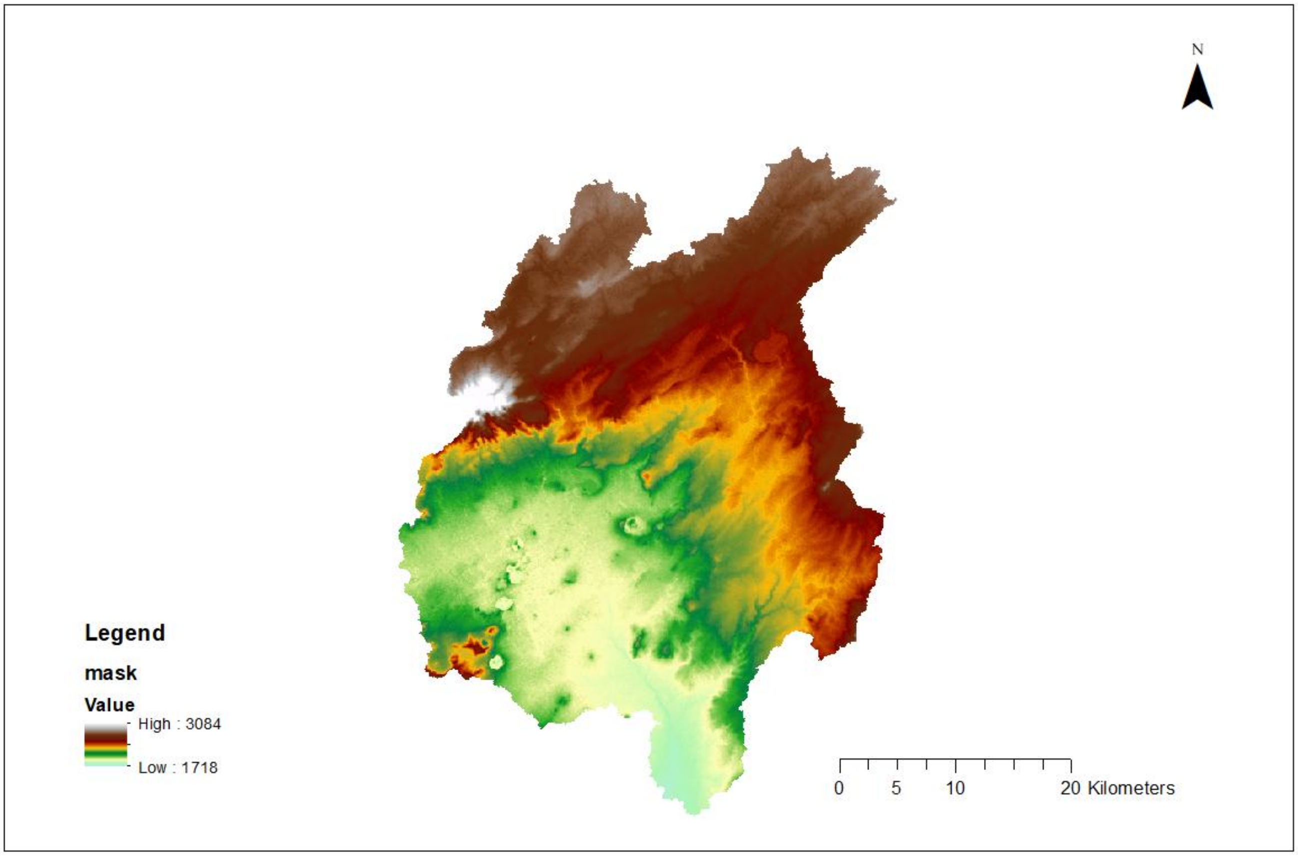


Figure 48: Digital Elevation Model

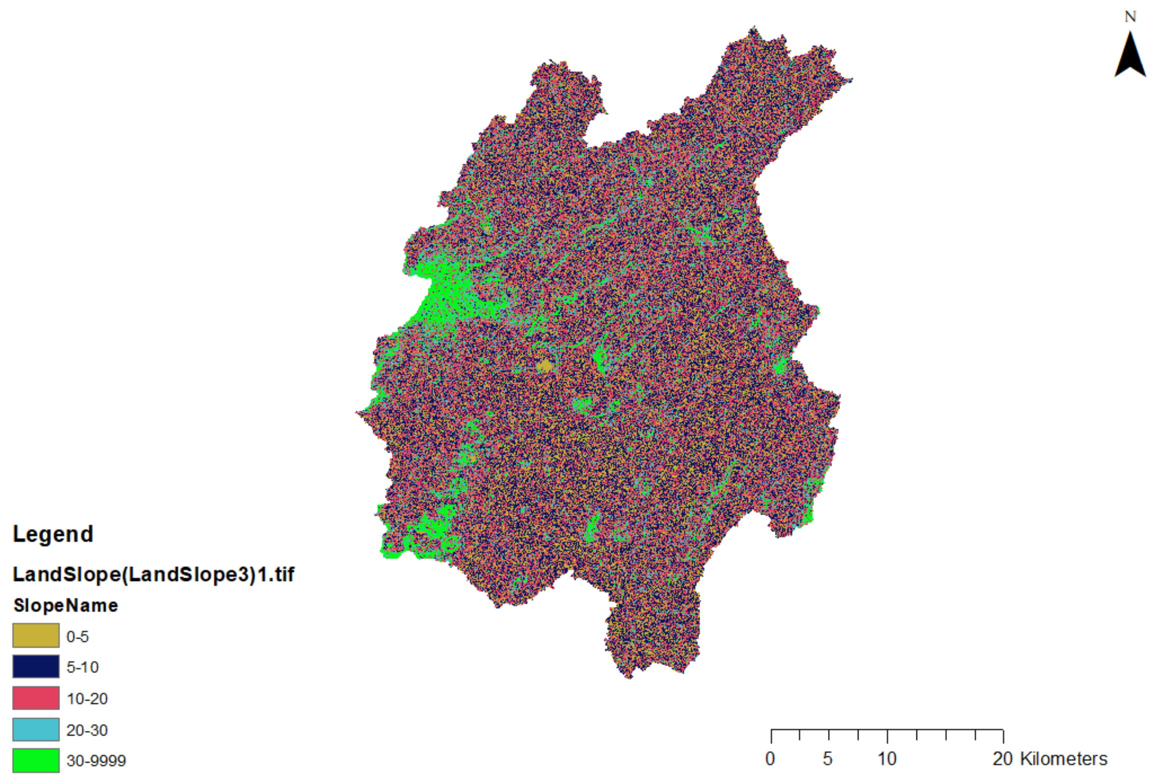


Figure 49: Slope in degree for Gimbichu Woreda

4.4.2.2. Land Use and Land Cover

One of the most important factor affecting watershed process such as Surface runoff, ground water recharge and evapotranspiration is land use and land cover management (LULC). Therefore the updated land use land cover data for this research was obtained from woreda agricultural office in a shapefile in a raster format. Then the Look up Table LULC map were prepared as per Arc SWAT 2012 requirement.

From the table blow the SWAT output highlights how land use-land cover (LULC) patterns in Gimbichu rural woreda strongly influence groundwater sources vital for rural drinking water supply. The watershed is overwhelmingly dominated by agricultural land under row crops, which is 84.8% and places significant stress on groundwater. Intensive cultivation often leads to reduced infiltration rate due to soil compaction, higher evapotranspiration during summer season. This threatens both the quantity of groundwater available for sustainable drinking water supply. The demand for extraction is further propelled by a medium density residential area (10.85%), which in turn reduces recharge through impervious surfaces and alters the ground water source for domestic use leading to localized depletion. On the other hand, although forest cover 1.54%, wetlands 0.02%, grasslands 0.18% and brush ranges 1.75% are not very extensive they help maintain infiltration, baseflow and ground water recharge by increasing retention of soil moisture and water filtration. Water bodies 0.83% and wetlands give natural buffering, but much natural buffering is not effective. The barren land with a marginal share of 0.02% has no significant contribution. Overall, the domination of agriculture and settlement reduces the sustainability of groundwater supply, while the poor presence of natural land covers undermine resilience.

Table 21: LULC Type, Name, SWAT code Areas in Hector and areas percent for Gimbich Rural Woreda.

LANDUSE	SWAT Code	Area [ha]	%Wat. Area
Water	WATR	1005.3613	0.83
Forest-Mixed	FRST	1855.8825	1.54
Range-Grasses	RNGE	217.9603	0.18
Wetlands-Mixed	WETL	26.36	0.02
Agricultural Land-Row Crops	AGRR	102296.2557	84.8
Range-Brush	RNGB	2110.1628	1.75
Residential-Medium Density	URMD	13093.4574	10.85
Barren	BARR	23	0.02

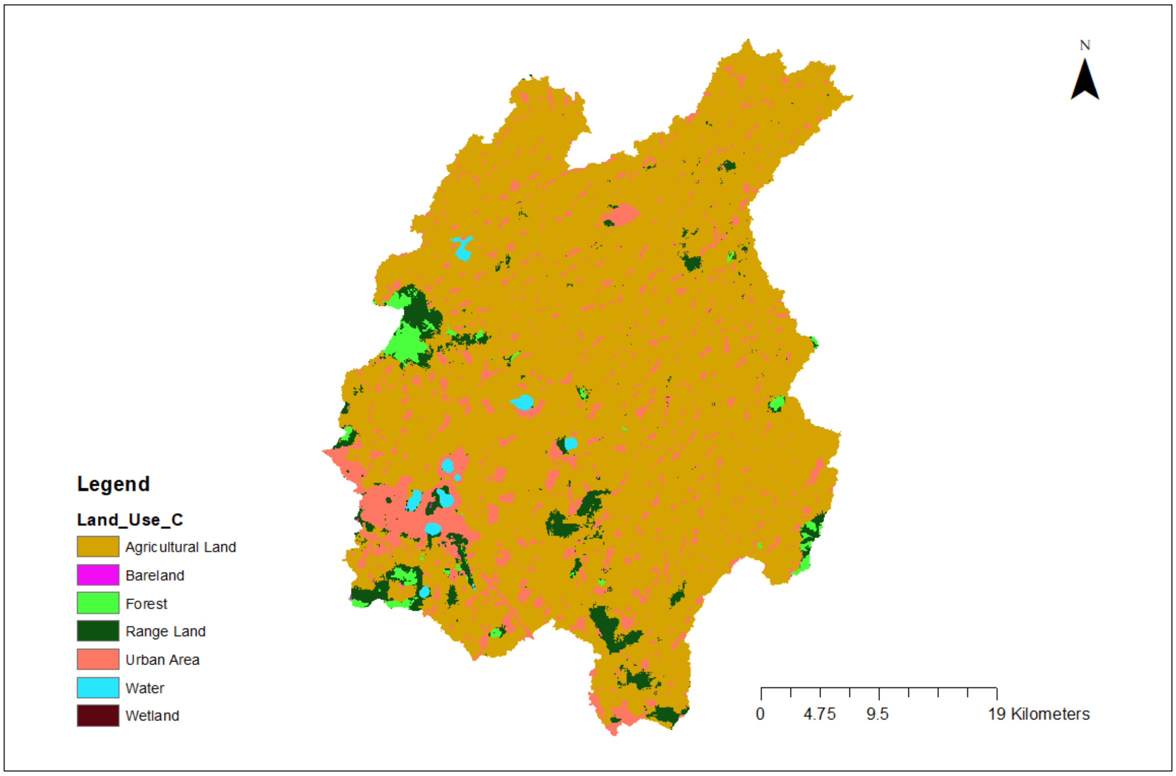


Figure 50: Land Use Land Map for Gimbichu woreda watershed

4.4.2.3. Soil Map

Runoff is a function of river basin rainfall event and conditions of underlying soils. Soil data were obtained from Ethiopian Ministry of Water and Energy. The spatial distribution of major soil type of study area is shown in Figure below.

The SWAT output indicates from the blow table that soil type strongly influences groundwater sustainability in Gimbichu. Vertisols and Cambisols dominate the watershed (>92%), with high water retention but low permeability, restricting infiltration and reducing groundwater recharge despite storing soil moisture. Luvisols (6.1%) provide moderate infiltration, aiding recharge, while shallow Leptosols (1.41%) favor runoff over storage. Andosols and Phaeozems, though negligible in area, are more permeable and recharge-friendly. Overall, the dominance of clay-rich soils limits recharge potential, posing challenges for sustainable rural drinking water supply.

Table 22 : Soil Type, Areas covered and percent of areas covered in Gimbichu rural woreda.

SOILS	Area [ha]	%Wat.Area
CHLUVISOLS	6949.96	4.81
EUVERTISOLS	66382.68	45.99
HPLUVISOLS	1916.72	1.33
LTLEPTOSOLS	2033.56	1.41
VTCAMBISOLS	67023.80	46.43
LUPHAEOZEMS	8.76	0.01
MOANDOSOLS	32.04	0.02

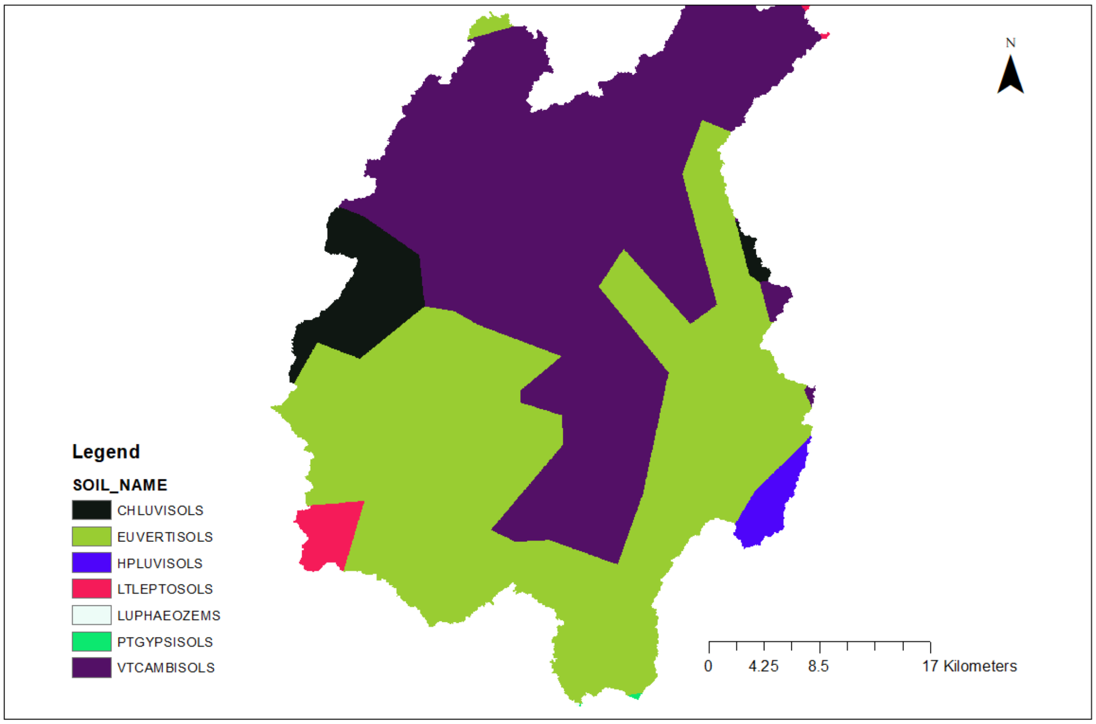


Figure 51: Soil Map of Study Area of Gimbichu Woreda watershed

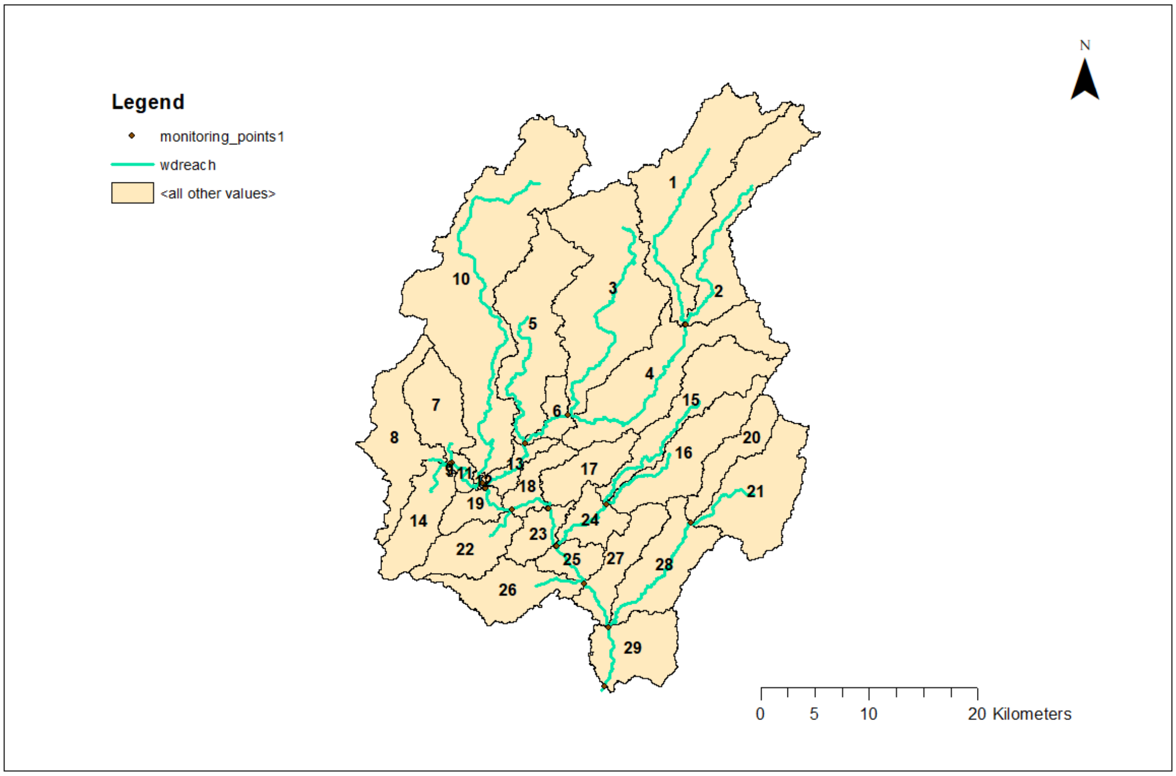


Figure 52: Sub Basins for the study area of Gimbichu woreda watershed

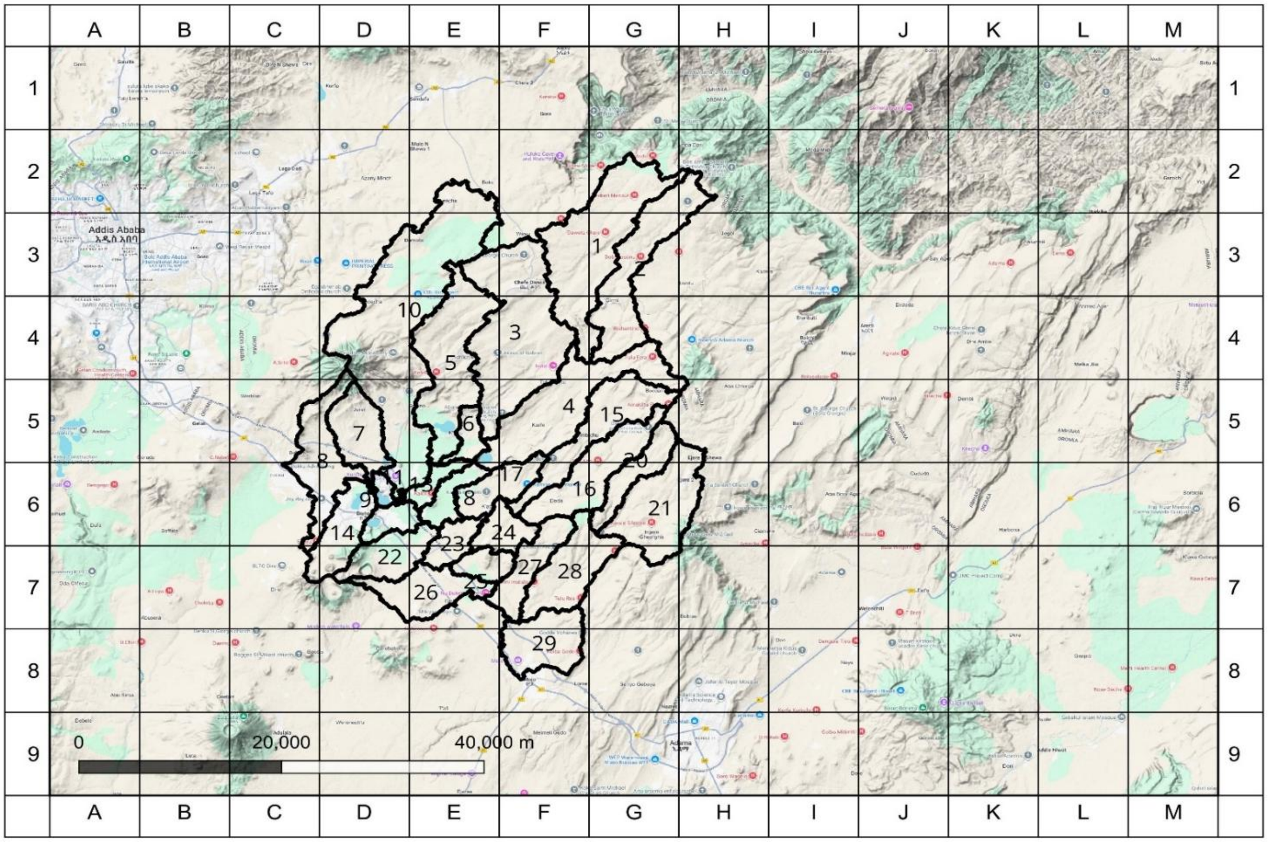


Figure 53: Sub Basin for the study area of Gimbichu woreda watershed with DEM.

4.4.2.4 Total runoff

4.4.5 Water balance components

SWAT (Soil and Water Assessment Tool) model gives monthly water balance components output reports and presented in table below.

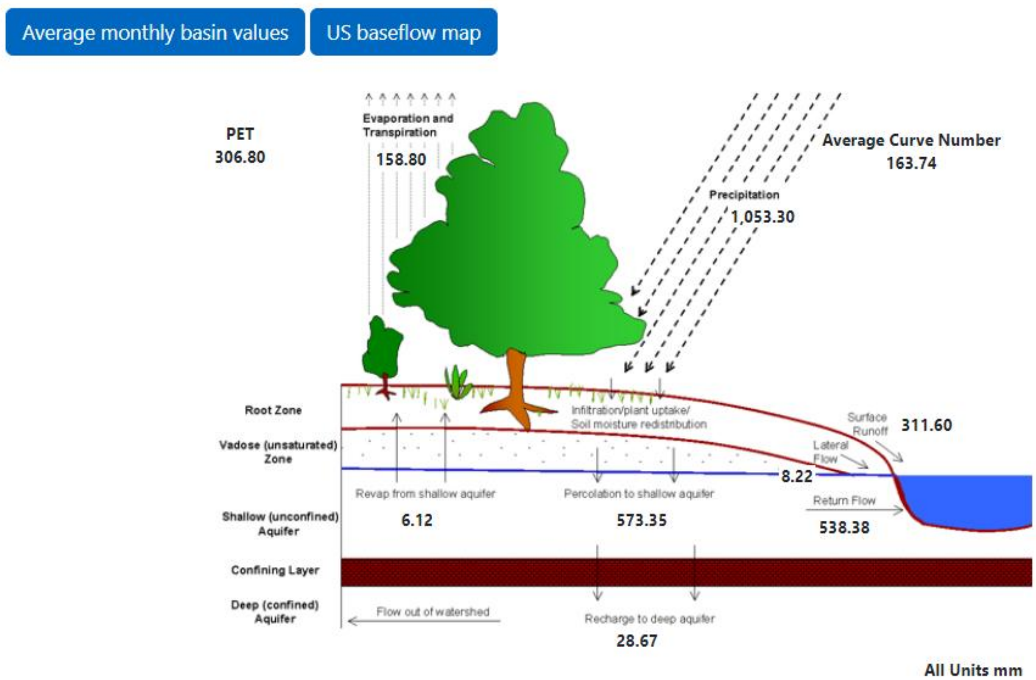


Figure 54: The average monthly basin values for Gimbichu Woreda watershed.

The SWAT output shows from the table blow shows that rainfall is the primary driver of groundwater recharge and availability for rural drinking water supply sources in Gimbichu woreda, with significant seasonal variability. From the SWAT rainfall peaks during July, with 312 mm and August, with 296 mm, generating high surface runoff, 108.89 mm and 102.72 mm and substantial water yield, 167.09 mm and 220.89 mm respectively. However, the lateral flow (representing subsurface contribution to groundwater) remains low, peaking only at 1.94 mm, indicating limited infiltration due to dominant clay soils and high runoff. In a heavy rain, the groundwater recharge is restricted as most of the rainwater.

The average river yield due to moderate rainfall in May (45.25 mm), June (111.99 mm), and September (105.69 mm) is 34.36–172.05 mm. These months are important for groundwater recharge. On the dry months (November–February), rainfall being below 15 mm and water yield being drastically less (4.39–50.96 mm), the potential evapotranspiration (22–26 mm) is higher than rainfall. This imbalance depletes soil moisture and reduces recharge, stressing rural drinking water supplies sources.

The data suggest that groundwater sustainability in Gimbichu is highly rainfall-dependent, with recharge concentrated in a few peak months, while long dry periods reduce availability.

Table 23 : Average rain fall, surface run off, LAT Q, water yield, evapotranspiration and PET

S.N	Average of Rain (MM)	Average of SURF Q (MM)	Average of LAT Q (MM)	Average of Water Yield (MM)	Average of ET (MM)	Average of PET (MM)
Jan	12.85	0.32	0.23	9.33	6.67	22.89
Feb	14.08	0.52	0.2	4.39	8.56	25.89
Mar	60.46	12.67	0.39	20.04	14.02	29
Apr	60.67	9.07	0.48	26.45	19.45	28.84
May	45.25	7.11	0.45	34.36	21.24	31.19
Jun	111.99	26.92	0.58	52.18	17.99	27.12
Jul	312	108.89	1.66	167.09	19.52	23.23
Aug	295.6	102.72	1.94	220.89	16.94	22.95
Sep	105.69	37.13	1.18	172.05	12.56	25.16
Oct	26.81	6.09	0.54	104.09	9.82	24.91
Nov	4.81	0.12	0.32	50.96	6.97	23.25
Dec	2.99	0.03	0.24	24.99	5.04	22.18

4.4.6 AVERAGE ANNUAL BASIN VALUES

PRECIP = 1053.3 MM(positive)

SURFACE RUN OFF Q = 311.60 MM(negative)

LATERAL SOIL Q = 8.22 MM(negative)

GROUNDWATER (SHAL AQ) Q = 538.38 MM(Negative)

GROUNDWATER (DEEP AQ) Q = 28.64 MM(positive)

REVAP (SHAL AQ => SOIL/PLANTS) = 6.12 MM(négative)

DEEP AQ RECHARGE = 28.67 MM(positive)

TOTAL AQ RECHARGE = 573.35 MM(positive)

TOTAL WATER YLD = 886.84 MM

ET = 158.8 MM(negative]

PET = 306.8MM(negative

4.4.7 Spatial and Temporal Distribution

To visualize spatial and temporal distribution of Average Annual Surface runoff from Each Sub basin, Average Annual lateral flow and Ground Water Contribution to Main Channel at the sub basin and Hydrologic Response Unit (HRU) levels were prepared and presented on Figure 7 and Figure 8.

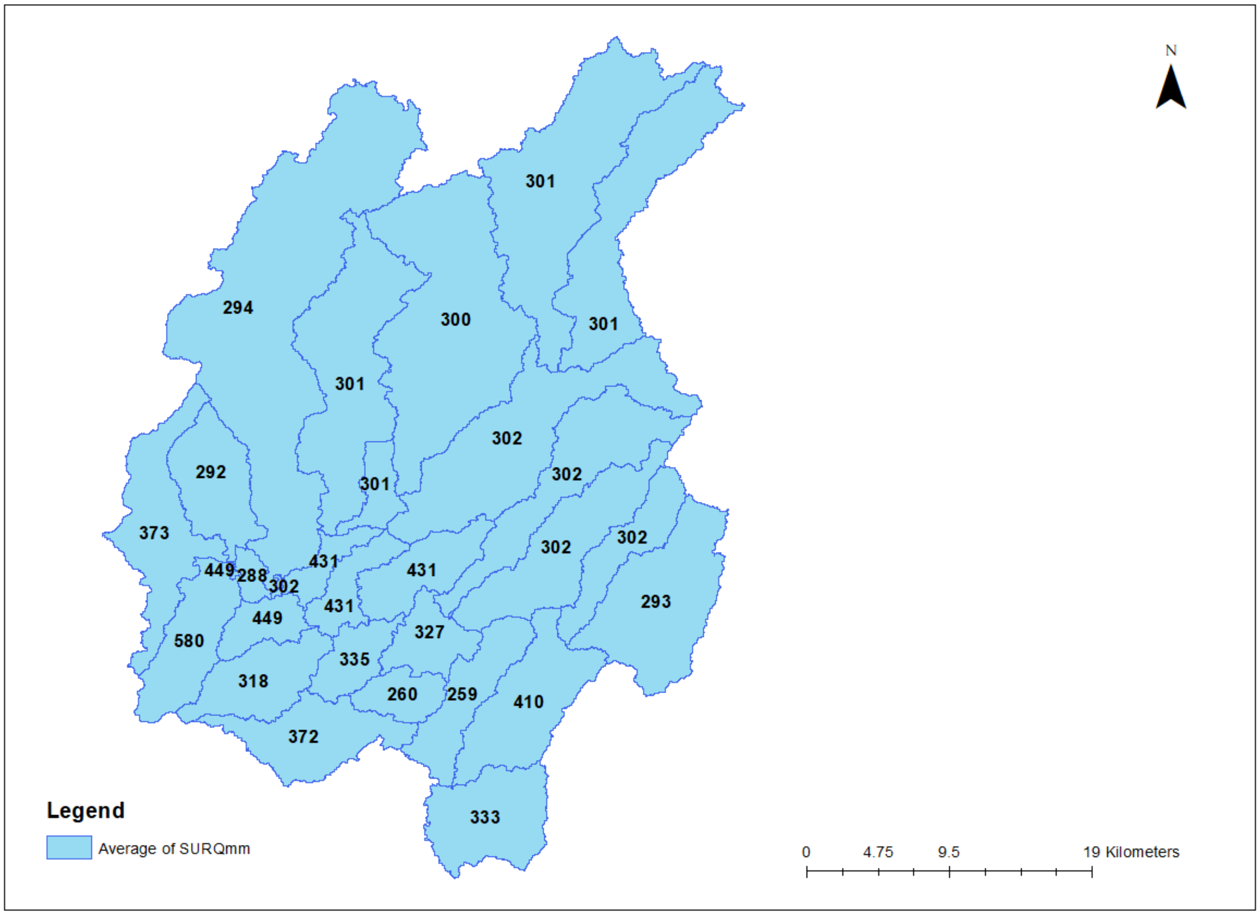


Figure 55: Average Annual Surface runoff from Each Sub basin of Gimbichu Watershed

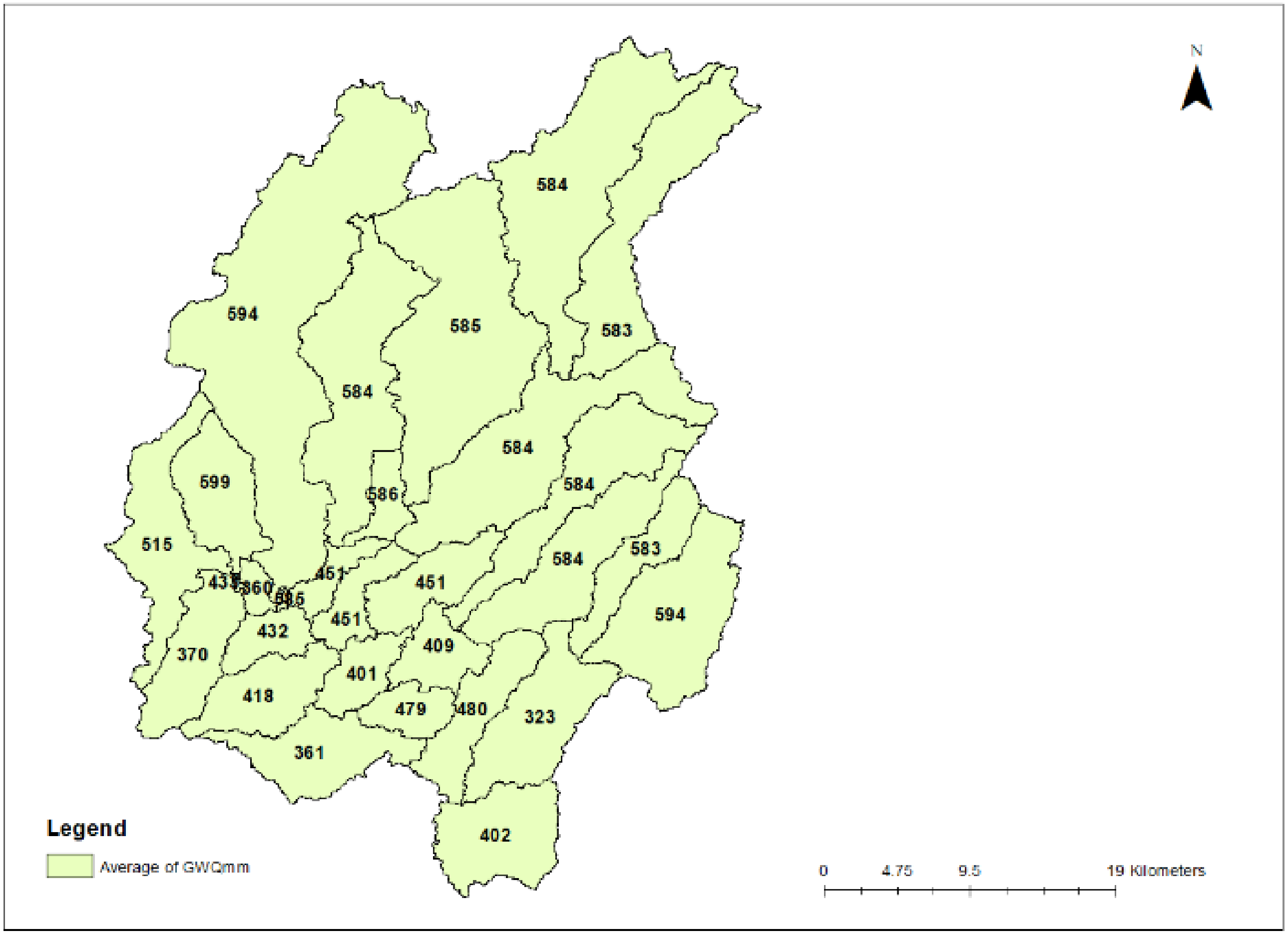


Figure 56: Average Annual lateral flow and Ground Water Contribution to Main Channel from Each Sub basin in Gimbichu Woreda Watershed

4.4.8 Model Performance Evaluation

Model calibration was be performed by adjusting model sensitive parameters to match the simulated result with the observed data as much as possible within the accepted range of deviation. In this study calibration, process was carried out for Madjo River flow. Calibration was done based on monthly time step at the outlet of the basin. Madjo station was selected due to the availability of measured flow and near to catchment outlet. The results of the calibration is presented as indicated in the Figure 9 and Figure 10.

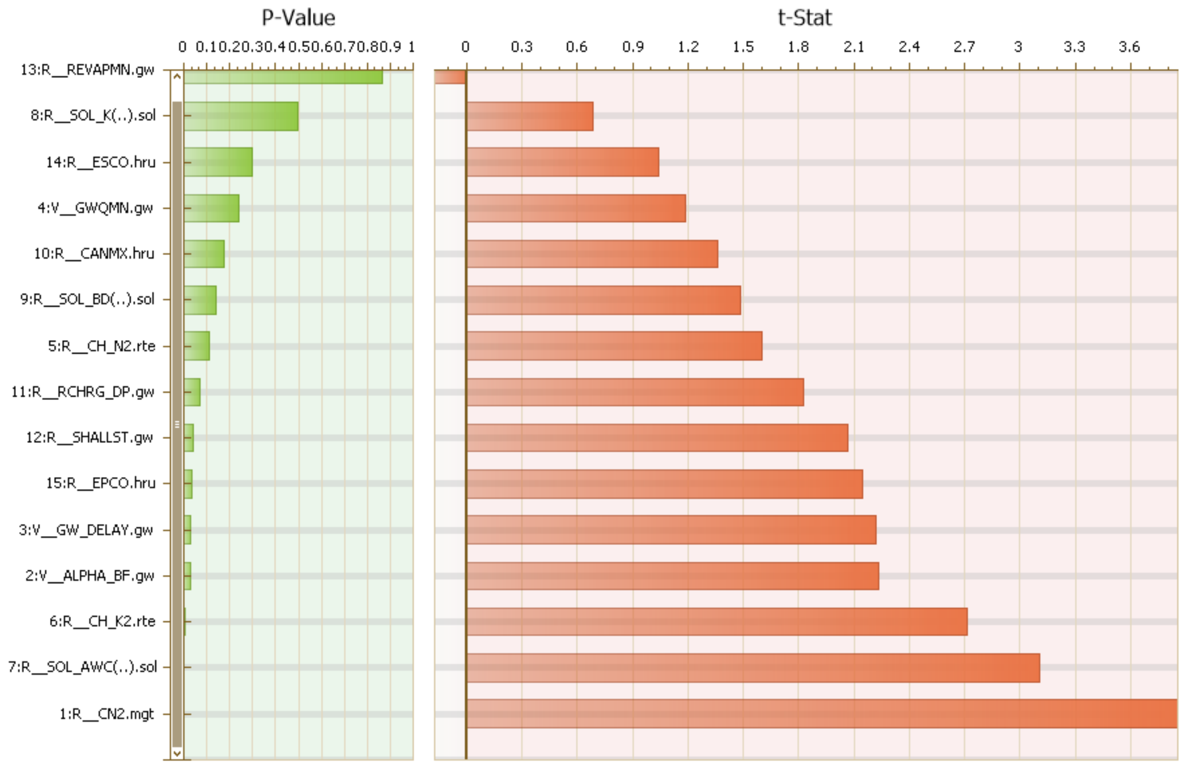


Figure 57: Parameters Used for Model Calibration

From the blow graph, the water source trends shows the decrease, that mean underground water supply source for watershed for domestic supply for Gimbichu rural woredas is in the decreasing trend due to land use and landcover negatively affects the source.

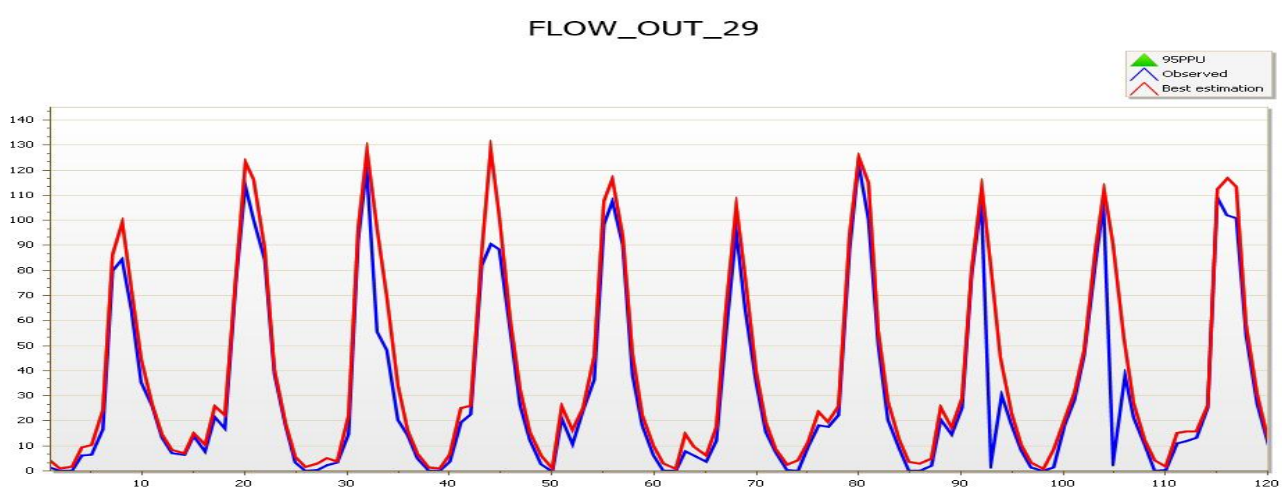


Figure 58: 95 confidence interval ppu plot During Sensitivity Analysis

Table 24: Model Performance Indicators

Performance Indicators	*Calibration*	*Validation*	*Status*
NSE	*0.87*	*0.85*	*Very good*
R^2	*0.92*	*0.91*	*Very good*
PBIAS	*19.8*	*22.3*	*Acceptable*

The model performed well when the SUFI-2 algorithm in SWAT-CUP was applied to calibrate streamflow at FLOW_OUT_29. The objective function, Nash–Sutcliffe Efficiency (NSE), produced a maximum value of 0.87 during calibration and 0.85 during validation, signifying an excellent conformity between simulated and observed streamflow. The strong linear correlation is additionally substantiated by the coefficient of determination (R^2 = 0.92 for calibration and 0.91 for validation), indicating that the model effectively represents the temporal variability of discharge.

However, the percent bias (PBIAS = -19.8% for calibration and 22.3% for validation) indicates that the model has a slight tendency to overestimate streamflow, while the degree of bias is still within the acceptable limits for watershed-scale simulations. On the other hand, the uncertainty analysis showed a low p-factor of 0.22, indicating that just 22% of the observed data fell within the bounds of the 95% prediction uncertainty (95PPU) band. With the r-factor nearing zero, this suggested the uncertainty band was extremely narrow.

In summary, the calibration outcomes indicate a strong predictive capability regarding efficiency and correlation statistics. Nonetheless, it is advisable to enhance uncertainty quantification by broadening parameter ranges and raising the number of simulations in future iterations.

5. Conclusion and Recommendations

5.1. Conclusion

The assessment of rural water supply systems in Gimbichu Woreda reveals a mixed picture of technical strengths and critical sustainability gaps. The Haftu Seftu water supply system demonstrates promising structural features, including durable construction materials and the installation of backflow check valves intended to protect water quality. However, hydraulic modeling results expose serious inefficiencies that undermine long-term sustainability such as low flow velocities in certain pipe sections, minimal head loss gradients, and irregular flow rates indicate intrinsic design weaknesses. Such conditions increase the risk of sediment deposition, stagnation, and potential contamination. In addition, simulated outputs show critical junctions experiencing excessively high hydraulic grade lines and negative pressures clear indicators of system instability. If these design gaps remain unaddressed, the physical system risks rapid deterioration, threatening public health and service continuity.

In contrast, the Keirsey Riga deep well system more effectively supports the sustainability objectives of the woreda. Its hydraulic structure reflects sound technical design principles, particularly in maintaining steady flows and appropriate velocity ranges consistent with rural water supply standards. Nevertheless, localized head loss gradients exceeding recommended guidelines in certain pipes and occasional negative pressure events present risks to energy efficiency, service quality, and system safety. As the scheme ages or expands to meet increasing demand, these weaknesses could compromise performance if not corrected. Energy-efficient operation cannot be assumed without continuous monitoring, optimization, and preventive maintenance, especially where hydraulic irregularities already exist.

Beyond technical performance, system functionality data highlight broader sustainability challenges. The overall non-functionality rate of 29% in Gimbichu Woreda is alarming. Particularly concerning are shallow well hand pumps and generator- or grid-powered deep wells, where non-functionality exceeds 50%. Although all technologies face operational challenges, solar-powered shallow wells demonstrate comparatively better performance. These findings emphasize that no technology is inherently sustainable without effective management, regular maintenance, reliable fee collection for operation and maintenance (O&M), ongoing monitoring, and strong community engagement. Strengthening existing schemes must go hand in hand with institutional reform. Community participation is not optional but essential. Active involvement of Water User Committees (WUCs) provides the institutional backbone for equitable and consistent service delivery. True sustainability extends beyond infrastructure provision; it demands that communities contribute labor and financial resources, participate in decision-making, and assume ownership from planning through maintenance.

However, limited technical knowledge remains a major barrier. Many users lack the skills required to operate and repair systems, leading to frequent breakdowns and dependence on external technicians. Combined with inadequate awareness about preventive maintenance, this skills gap threatens reliability and erodes user confidence. Financial sustainability is equally fragile. Nearly two-thirds of projects lack secure funding mechanisms, leaving them vulnerable to failure. While most households express willingness to pay user fees, collection systems are inconsistently implemented, undermining steady revenue for repairs and spare parts.

Technological complexity further complicates sustainability. Over sixty percent of schemes rely on systems requiring professional expertise, causing repair delays and increasing reliance on outside support. Simpler, more manageable technologies often recommended by international organizations are underutilized, suggesting a top-down planning approach disconnected from local realities. Supply chain weaknesses exacerbate the problem, with nearly 95% of communities reporting delays due to lack of locally available spare parts. Hydraulic design weaknesses such as low velocities, high head loss, negative pressure reduce energy efficiency, destabilize flows, and impend long-term sustainability. Unavalability of spare-parts in local market create challenge for maintenance of water supply scheme. 29% non-functional water supply system indicate low sustainability especially for generator and electric grid deep well. Solarized water supply systems lacks power bank even solar technologies show better performance. Weak customer participation and governance leads to frequent breakdowns, delayed maintenance, low-cost recovery, and create dependence on external support. Poor financial management undermines customer ownership. Land use land cover negatively affected ground water source.

5.2. Recommendations

- Improve hydraulics design pipes, pumps, pressure zones, increase monitoring and leak detection, preventive maintenance, and promote resilient technologies like solar systems,
- Empower Water User Committees in planning and monitoring,
- Train woreda staff, operators, WUCS and community technicians in O & M,
- Decentralize spare-part supply, improve transparent financing and diversify funding with fair user contributions,
- Protect recharge areas/water shade, include rainwater harvesting and implement climatic resilience water supply.
- Modify demand nodes to reflect actual service requirements and adjust system components to align with realistic current and projected water demand,
- Increase pump capacities and add or upgrade booster pumps, high-lift pumps, and storage reservoirs to ensure adequate hydraulic energy and equitable water distribution throughout the network,
- Apply pressure zoning in areas with elevation differences and install pressure-reducing valves to prevent excessive or insufficient pressure,
- Correct negative pressure zones by adjusting pump schedules, elevations, and pipeline configurations,
- Install vacuum and air-release valves in persistent problem areas and position pressure loggers at strategic locations for real-time monitoring and rapid response,
- Modify pipe diameters where necessary to prevent low flow velocities, stagnation, and contamination,
- Plan timely pipe upgrades to accommodate population growth and avoid overburdening the system,
- Combine digital early leak detection technologies with routine manual inspections and establish tracking systems for functionality and service outages,
- Conduct periodic technical assessments to prioritize maintenance needs and clean pipelines regularly to prevent sediment accumulation and water quality deterioration,
- Strengthen the capacity of local water office staff in hydraulic modeling, diagnostics, and performance monitoring,

- Train technicians and operators in preventive maintenance and minor repairs,
- Equip maintenance teams with adequate tools, spare parts, decentralized procurement mechanisms, and develop reliable local supply chains,
- Provide legal mandates, strengthen inclusive leadership, empower marginalized groups, and grant committees management authority,
- Establish regular performance and user satisfaction monitoring systems,
- Encourage transparent financial management, diversified funding sources, and community contributions based on capacity to reduce dependency on temporary grants and build trust in tariff systems,
- Strengthen stakeholder collaboration, communication, and shared responsibility,
- Develop woreda-level water master plans aligned with demographic and climate trends, institutionalize community participation, and use participatory planning tools,
- Implement integrated water resource management, protect recharge zones, conserve ecosystems, promote rainwater harvesting, and support sustainable land-use practices to safeguard water sources and ensure long-term reliability in Gimbichu.
- Water quality part is not covered/addressed in this research so, it is betted to conduct research on water quality part in the future.

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