Application of Supervisory Control and Data Acquisition System (SCADA) for Ethiopian Water Supply Projects in Case of Adama Town Water Supply Project.

Mesfin Arega Zepro

A Thesis Submitted to the Department of Civil Engineering

School Of Civil Engineering and Architecture

Presented in Partial Fulfillment of the Requirement for the Degree of Master's in Construction Engineering and Management

Office of Graduate Studies

Adama Science and Technology University

October, 2024

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Declaration

I hereby declare that this Master Thesis entitled “Application of Supervisory Control and Data Acquisition System (SCADA) for Ethiopian Water Supply Projects in Case of Adama Town Water Supply Project” is my original work. That is, it has not been submitted for the award of any academic degree, diploma or certificate in any other university. All sources of materials that are used for this thesis have been duly acknowledged through citation.

Mesfin Arega	________________	October, 2024
Name of student	Signature	Date

Recommendation

I/we, the advisor(s) of this thesis, hereby certify that I/we have read and the revised version of the thesis entitled “Application of Supervisory Control and Data Acquisition System (SCADA) for Ethiopian Water Supply Projects in Case of Adama Town Water Supply Project” prepared under my/our guidance by Mesfin Arega submitted in partial fulfillment of the requirements for degree of Master of science in Construction Engineering and Management. Therefore, I/we recommend the submission of the revised version of the thesis to the department following the applicable procedures.

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Co-advisor/Co-supervisor	Signature	Date

Approval Page of M.Sc. Thesis

I/we, the advisors of the entitled "Application of Supervisory Control and Data Acquisition System (SCADA) for Ethiopian Water Supply Projects in Case of Adama Town Water Supply Project" by Mesfin Arega, hereby certify that the recommendation and suggestion made by the board of examiners are appropriately incorporated into the final version of the thesis.

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We, the undersigned, members of the Board of Reviewers of the thesis by Mesfin Arega have read and evaluated the thesis entitled "Application of Supervisory Control and Data Acquisition System (SCADA) for Ethiopian Water Supply Projects in Case of Adama Town Water Supply Project" and examined the candidate during open defense. This is, therefore, to certify that the thesis is accepted for partial fulfillment of the requirement of the degree of Master of Science in Construction Engineering and Management.

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Abstract

Modern resource management techniques for water supply projects involve the integration of digital technologies to improve sustainability and efficiency. Thus, the aim of this study focused on exploring the application of Supervisory Control and Data Acquisition System for Ethiopian water supply projects. The study used qualitative approach through open and closed ended questionnaires as data collection tools which had been distributed to the sample population to achieve the objectives of the study. The target populations are managers and professional staffs those who are currently working on water supply projects of Adama and Addis Ababa, engineers from consultants, contractors and Chinese experts on the automated system. Data sources used on this study is composed of questionnaire and site visit on selected water supply projects as a primary data source and literature review as secondary data source. According to the findings from the analysis on current resource management techniques on water supply projects it shows poor performance with reference of key performance indicators from International Water Association manual on sustainability and efficiency, preventive maintenance and consistency related techniques, therefore it needs improvement on the resource management system by advancing automated systems. Based on analysis on the nature of Supervisory Control and Data Acquisition system it had its own constraints and challenges those prevent implementation of the system with full capacity, especially integrating the automated system with the existing technology, data management requirements, complexity of the system, changes on regulatory policy and financial related factors. As a final output detail key factors are developed to address best practices for successful implementation of the automated system on developing countries by including modular and scalable design, proper feasibility study, cyber security and data protection, proper equipment selection and capacity building and routine training. Finally, it is recommended that water supply sector should focus on implementation of automated system to get benefited from the system including adopting preventive measures, guarantee reliable and consistent productivity, shortening recovery period of initial investment cost.

Key words: Supervisory Control and Data Acquisition system, Water supply, Resource management, Performance indicators

List of Acronyms

SCADA	Supervisory Control and Data Acquisition
AWSSIP	Adama Water Supply and Sanitation Improvement Project
PLC	Programmable Logic Control
RTU	Remote Terminal Unit
HMI	Human Machine Interface
UDWS	Urban Drinking Water System
AAWSSA	Addis Ababa Water Supply and Sewerage Authority
AWSSE	Adama Water Supply and Sewerage Enterprise
MTU	Master Terminal Unit
WAN	Wide Area Network
LAN	Local Area Network
GSM	Global System for Mobile Communications
OWWDSE	Oromia Water Works Design and Supervision Enterprise
WHO	World Health Organization
WSS	Water Supply System
M/R/R	Maintenance Rehabilitation and Renewal
S-WSS	Small sized Water Supply Systems
PI	Performance Indicators
L-WSS	Large-sized Water Supply Systems
IWA	International Water Association
OFWAT	Office of Water Services United Kingdom
GHG	Green House Gas
PA	Performance Assessment

AUWSSSE	Ambo Urban Water Supply and Sewerage Service Enterprise
NRW	Non-Revenue Water
TDS	Total Dissolved Solid
WQI	Water Quality Indicator
USD	United States Dollar
ADB	African Development Bank
HH	House Hold
ISO	International Organization for Standardization

CHAPTER ONE   INTRODUCTION

1.1 Back ground

A construction project is basically a temporary endeavor with specified time and cost, initiated to create a unique product, service, or result, tend to be limited edition. According to several participants and the complex dynamic relations between them, water supply is a complex system. In the previous period, for sake of quality of life and balanced regional development, some aspects mostly relating to reliability, capacity, quality of water, development of the network, are analyzed(Collins, Parrish, & Gibson Jr, 2017).

Water supply programs in developing countries aim to address the urgent need for clean, accessible, and affordable water, often focusing on rural and semi-urban areas where infrastructure is lacking. These programs are critical for improving public health, as contaminated water sources can lead to diseases like cholera, diarrhea, and typhoid, which disproportionately affect children. Key components include developing physical infrastructure (wells, pumps, reservoirs, and pipelines), ensuring water purification and treatment, and integrating sustainable management practices. In many cases, community participation is central, with local governments, Non-Governmental Organizations, and international donors providing training and resources to ensure long-term maintenance and management. These initiatives also link to broader goals, such as poverty reduction, gender equality (since women are often responsible for water collection), and economic development, by reducing the time spent fetching water and improving agricultural productivity. However, challenges such as population growth, financial limitations, and environmental factors like droughts, water pollution, and climate change make it essential for these programs to be adaptive, innovative, and resilient (Carter, 1999).

Supervisory Control and Data Acquisition (SCADA) system is used for controlling, monitoring, and analyzing industrial devices and processes. The system consists of both software and hardware components and enables remote and on-site gathering of data from the industrial equipment. SCADA systems provide valuable information to key stakeholders. They can use the system to improve the performance of the industrial plants, keep track of the plants’ efficiency and mitigate errors and downtime through messages received from the system (Daneels & Salter, 1999).

SCADA systems are used for real-time acquisition of sensor data, monitoring equipment, and controlling processes in water distribution and wastewater collection systems, oil and gas pipelines, electrical power grid, the connecting links in the SCADA architecture are the Programmable Logic Controllers (PLCs) or Remote Terminal Units (RTUs). These are microcomputers that interact with both the equipment (also called field devices) on the one hand and HMI (which are Human Machine Interfaces) on the other hand. HMIs are also referred to as graphical user interfaces. Some SCADA systems also include options for automatic control actions and an automatic reporting engine for easy-made reports (McDonald, 1993).

SCADA (Supervisory Control and Data Acquisition) system refers to the combination of data acquisition and telemetry. It consists of collecting information, transferring it back to a central site, carrying out necessary analysis and control, and then displaying this data on several operator screens. Total modular construction and programmability of device enable its adaptation to monitoring, control and management of plants for special purpose, power stations in electric distribution, water supply, rails, medicine, sections in industry, like in other branches where remote monitoring of plants is necessary (McDonald, 1993).

Water resource systems planning and management issues are rarely simple. Demands for reliable supplies of clean water to satisfy the energy, food, and industrial demands of an increasing population and to maintain viable natural ecosystems are growing. This is happening at the same time changes in our climate are increasing the risks of having to deal with too little or too much water in many river basins, watersheds, and urban areas. Societies are becoming increasingly aware of the importance of water and its management and use; their governing institutions are becoming increasingly involved in water resources development and management decision-making processes. To gain a better understanding of the complex interactions among all the hydrologic, ecologic, economic, engineering, and social components of water resource systems, analyses based on systems perspectives are useful. While analyses of such complex systems can be challenging, integrated systems approaches are fundamental for identifying and evaluating options for improving system performance and security for the benefit of all of us (Giordano & Shah, 2017).

1.2 Statement of the problem

Rapid urbanization in developing countries has imposed threats and challenges to basic urban infrastructures like drinking water, transportation, and energy systems. The existing urban drinking water systems (UDWS) are highly stressed and unsustainable, particularly under changing hydro climatic conditions, population growth, changing socioeconomic conditions, government decisions, and various policies. To assess the gap between water supply and demand, water loss/non-revenue water, environmental, technical, institutional, and governance, etc. and propose sustainable interventions to deal with such issues so as to improve it is recommended to adopt certain sustainable interventions for controlling and monitoring through supervisory control and data acquisition (SCADA) and Internet of Things, effective and long-term planning and policy, etc. implementation of SCADA will help the decision-makers and the operators of the utilities to run the water supply schemes in a sustainable manner (Beker & Kansal, 2023).

The existing water supply system for Ethiopia has its own drawbacks and limitations on the process of proper water resource management starting from controlling water losses up to defining and adjusting on the damaged water lines therefore, enhancing application of SCADA is particularly useful for processes that can be monitored and controlled remotely, especially in cases where it is possible to reduce waste and improve efficiency (Fekrudin, 2019).

1.3 Objectives of the Research

The main objective of this research is to explore application of Supervisory Control and Data Acquisition System for Ethiopian water supply projects in case of Adama Town Water Supply Project.

1.3.1 Specific objectives

1. To assess the current performances of Ethiopian water supply projects resource management techniques in case of Adama town.
2. To evaluate constraints, challenges and application of Supervisory Control and Data Acquisition (SCADA) system for water supply projects.

3. To develop a best practice for successful implementation of the Supervisory Control and Data Acquisition (SCADA) System for Ethiopian water supply projects on resource management aspect.

1.4 Questions of the Research

- What are the existing resource management techniques and performances of Ethiopia water supply projects especially on Adama town?
- What are the constraints, challenges and applications of SCADA system for water supply projects?
- What are the best practices for successful implementation of the SCADA system on water supply projects Ethiopia for their resource management?

1.5 Scope of the Research

The research had a defined scope to assess the performance of existing water supply resource management techniques which is available in Ethiopia for the case of Adama town, besides this research evaluates the challenges, constraints and application of Supervisory Control and Data Acquisition System for water supply projects. Also, the thesis paper had a scope to develop a frame work for successful implementation of Supervisory Control and Data Acquisition System for water supply projects; finally, it had a case study for application of Supervisory Control and Data Acquisition System on Adama town water supply project.

1.6 Significance of the Study

The worldwide water supply represents a significant portion of the global resource consumption and it is related to the collection, treatment, and transportation of water, entails a large amount of costs. This research paper had its own significance on providing a review about measures and methods to achieve water supply delivery systems efficiency. The research summarizes and compares current water supply controlling mechanisms with the automated water supply system (SCADA) by allocating proper monitoring on each resource during and after completion of construction projects.

In addition, the research paper sets a frame work on the successful implementation of system for water supply projects to consider automation system as one part of the project during its initiation phase up to completion of the construction, to achieve their objective on short period of time and to provide sustainable and consistent service for water supply utilities.

1.7 Structure of the study

The study is composed of 4 different chapters

CHAPTER ONE: INTRODUCTION

The introduction part includes: Background, Significance of the Research, Statement of the Problem, Objective of the Study, Questions and Scope of the study.

CHAPTER TWO: LITERATURE REVIEW

This chapter encompasses of relevant related literature on current performances of selected Ethiopian water supply projects with aspect of resource management, automated water supply SCADA controlling techniques, and its contribution on prevention/minimization of wastage on resources, previous experiences on water supply sectors and utilities for resource management aspect and further published journals on Adama town water supply existing system.

CHAPTER THREE: MATERIALS AND METHODOS

This chapter covers how the research is carried out and covers the research methodology, case study, target population, instruments of data collection, data collection techniques and procedures and data analysis.

CHAPTER FOUR: RESULTS AND DISCUSSIONS

This chapter interprets and presents the finding of the study with proper data presentation by including limitations and implications for future researches.

Finally, Conclusion and recommendations are the presented based on the findings of the study depending on reflective aspect of the researcher.

CHAPTER TWO LITRATURE REVIEW

2.1 Resource planning and management

A resource is anything that contributes to the completion of project tasks, and it includes the project manager, skilled laborers, and equipment such as plant and fleet. Resources are major contributors to project success because each project task must have sufficient and adequate resources allocated for the activity to finish on time and within budget. The construction industry is riddled with problems such as increase in labor prices, shortage of skilled labor and stagnant productivity (Nagaraju & Reddy, 2012).

Resource management is really a difficult task due to the resource driven nature of construction projects. It is carried out to plan the resources prior to the start of the work. A resource can be manpower, material, money, equipment, time, or space in a construction work. Each activity in construction is allocated with specific resources. The time and cost are directly dependent on the availability of resources. The time required to perform an activity is determined with the resource's productivity and the quantity of the work for an activity (Karaa, Nasr, & management, 1986)

There are two parts of resource management namely resource allocation and resource leveling. Resource allocation is concerned with the supply of the demanded resource, while resource leveling is concerned with reducing the fluctuations in peaks and troughs in a resource profile and how to minimize scenarios of under and over allocations. Both scenarios would have to consider the skillsets needed and the availability and the workload of the resources (Karaa, Nasr, & management, 1986). Resource allocation to a project is dependent on the nature of the project and some key attributes. First, it is essential that the complexity of the project is understood, and a robust methodology is developed for appropriate delivery. Then, a detailed project plan/schedule is developed outlining all the activities singularly with the duration each activity should take. Following the successful execution of these steps, a resource schedule is created that lists the details of the required resource per activity. Subsequently, the productivity of each resource type is used to calculate the quantities of human resource and equipment needed to safely deliver a project of the required standard. These schedules are then used to prepare an estimate that is sent to the client and serve as baseline data for allocating resource during the delivery phase (Brown, 1984).

Resource management is a difficult but an important process in construction projects. However, there are several factors that prevent effective resource allocation of projects. Generally, effective resource management requires sophisticated data collection and storage, integration of separate departments' databases and robust optimization models with high-tech user interfaces.

Mismanagement of water and land resources is putting human health and sustainable social and economic development at risk. Explosive growth of urban centers, unsustainable exploitation of natural resources, uncontrolled industrialization, increasing water demand for food production, and expanding populations lacking proper environmental sanitation have led to progressive depletion and degradation of freshwater resources. Many of the problems in the drinking water supply and sanitation sector (DWSS sector) are related to the improper management of water resources. To safeguard the sustainable supply of safe drinking water, concerted action is needed on all fronts, including agriculture, forestry, industry, transport, urban and spatial planning, population planning, and electricity generation. To prevent further depletion and degradation of freshwater resources, a more holistic approach is being promoted, which is known as integrated water resources management (Kleinmuntz, 2007).

2.2 Water as a resource

Water is the most important natural resource in the world since without it, life cannot exist and most industries could not operate. Although human life can exist for many days without food, the absence of water for only a few days has fatal consequences. The presence of a safe and reliable source of water is thus an essential prerequisite for the establishment of a stable community. Water, a valued resource, is used as the main raw material by our civilization. It is usually found in lakes, rivers, reservoirs, and underground sources. From the sources it is abstracted and pumped or gravitated into supply network systems. Water supply systems are mandatory for supplying water to the users. The main components of water supply systems are water source, treatment works, transmission and distribution network and electromechanical components(McGee, 1909).

Water demand is defined as the volume of water quested by users to satisfy their needs. In other way it is often considered equal to water consumption, although conceptually the two terms do not have the same meaning (Wallingford, 2003). In most developing countries, the theoretical water demand considerably exceeds the actual consumptive water use. Urban water demand is classified in to different categories: the domestic water demand that includes in house use and out of house use is among the others. Urban water demand is usually quoted in terms of liter per capital per day (l/cap/day) (Wandera, 2017). In many African towns, urban water demands are often non-homogeneous.

The accessibility of water is a vital component of socio-economic development. Swift and sustainable developments have been registered in water abundant areas in temperate zones. Countries that have serious water shortages faced serious difficulties in realizing their development programs. It is an obvious fact that inadequate, inaccessible, and unsafe water supplies have greatly restrained the health status, economic growth, food security, biodiversity and environmental sustainability of societies or countries (McGee, 1909).

Sustainable water resource systems are those designed and managed to best serve people living in the future as well as those of us living today. The actions that we take now to satisfy our own needs and desires should not only depend on what those actions will do for us but also on how they will affect our descendants. This consideration of the long-term impacts on future generations of actions taken now is the essence of sustainable development. While the word “sustainability” can mean different things to different people, it always includes a consideration of the welfare of those living in the future. While the debate over a more precise definition of sustainability will continue, and questions over just what it is that should be sustained may remain unanswered, this should not delay progress toward achieving water resource systems that we judge best serves those of us living today as well as our children and their children living in the future (Nitivattananon, Sadowski, Quimpo, & management, 1996).

Water resources professionals have learned how to plan, design, build, and operate structures that together with nonstructural measures increase the benefits people can obtain from the water resources contained in aquifers, lakes, rivers, and estuaries. However, there is a limit to the services one can expect from these resources. Rivers, estuaries, and coastal zones under stress from over development and overuse cannot reliably meet the expectations of those depending on them. How can these resources best be managed? And used? How can this be accomplished in an environment of uncertain and varying supplies and uncertain and increasing demands, and consequently of increasing conflicts among individuals having different interests in their management and use? The central purpose of water resources planning, management, and analysis activities is to address, and if possible, answer, these questions. These questions have scientific, technical, political (institutional), and social dimensions. Thus, water resources planning processes and products are must (Loucks, 2000).

Water resource systems have benefited both people and their economies for many centuries. The services provided by such systems are multiple. Yet in many regions of the world, they are not able to meet even basic drinking water and sanitation needs. Nor can many of these water resource systems supports and maintain resilient bio diverse ecosystems. Typical causes include inappropriate, inadequate and/or degraded infrastructure, excessive withdrawals of river flows, pollution from industrial and agricultural activities, eutrophication resulting from nutrient loadings, salinization from irrigation return flows, infestations of exotic plant and animals, excessive fish harvesting, flood plain and habitat alteration from development activities, and changes in water and sediment flow regimes. The inability of water resource systems to meet the diverse needs for water often reflect failures in planning, management, and decision-making and at levels broader than water. Planning, developing, and managing water resources to ensure adequate, inexpensive, and sustainable supplies and qualities of water for both humans and natural ecosystems can only succeed if we recognize and address the causal socioeconomic factors, such as inadequate education, corruption, population pressures, and poverty (Mysiak, Giupponi, Rosato, & software, 2005).

2.3 Construction of Water Supply Infrastructure

Since ancient times human beings have always strived to access drinking water and colonizing the surroundings of water bodies. They have also attempted to purify it (by the standard of the time) using various methods. People built aqueducts to transport water from distant areas since Roman times. To make the water safe, they used charcoal, exposing it to sunlight, boiling and using straining methods. They also made every effort to protect (where the water was secure, easier to get, and treatable) water sources such as springs, hand-dug wells, rain water, boreholes/tube wells, public standpipes/taps, household connections. Some of these water sources are, in fact, recent in origin. Ancient and medieval cities, for instance, did not have access to standpipe/tap and house to house connection water systems. The causal effect of unsafe (contaminated) water for microbial diseases was not known. (Sargentis et al., 2019)

A well-intended water distribution network is very crucial in the development of urban areas. The goal of water distribution systems is to deliver drinking water for all areas satisfying design demands and pressure (Ayad, Khalifa, Fawy, & Moawad, 2021). In the design stage it is of concern to arrive at the least-cost solutions that satisfy a set of limits including demand and pressure requirements. Often it is also of interest to arrive at less expensive solutions that, however, interrupt slightly the constraints. Consequently, research interests have been concentrating on the development of efficient evolutionary algorithms (optimization techniques) to search for the optimal combination of decision variables (e.g. pipe diameters) from many solutions(Alves, Muranho, Albuquerque, & Ferreira, 2014).

2.4 Common defects of current Ethiopia water supply system

Commonly water scarcity has enhanced by adverse pressure within distribution system. High leakage and pipe failure (due to unmaintained maximum pressure) as well as provision of inadequate supply (due to unmaintained minimum pressure) are situations, which transmit water shortage within distribution system. Hence, studying the factors, which control the performance of the water supply networks for increasing the efficiencies of the water supply distribution systems, is necessary to mitigate the problem. Therefore, this study aims to assess the performance of water distribution network of Adama City Water Supply System and further illustration by using computer automated system as a model.(Gebrehiwot, 2006)

2.5 Water Supply Performance Indicators

Water covers three quarters of the earth’s surface. The shortage of fresh water is considered one of the most critical global issues to be resolved. According to World Health Organization, more than one-fifth of the world’s population (1.2 billion people) lives in areas where physical water is scarce. Also, almost one quarter of the world’s population (1.6 billion people) face economic water shortage where they do not have the appropriate infrastructure to extract water from its sources. Although the countries which do not suffer from water scarcity at moment might experience water shortages in the future due to population growth and the climate change worldwide such as drought and desertification. Thus, extract the additional fresh water sources are vital to be considered by all countries. The water distribution on earth consists of 97.5% saline water in oceans and 2.5% fresh water, which is made up of ice caps and glaciers, groundwater, lakes, rivers, soil moisture and atmospheric moisture. Realizing the fact that this precious 2.5% fresh water supports the global human activities ranging from basic needs to leisure, commercial and development purposes, the importance of water supply management is becoming more significant and appreciated. Thus, it is necessary to have an organized system that could assess the performance of the water supply services. This is to ensure that safe drinking water is supplied within an acceptable quality and at a reasonable price through effective and efficient practices (Alegre et al., 2016).

Access to safe drinking water in sufficient quantity and at afford able cost is the right of every human being, irrespective of the location and size of their community (WHO 2012). Like all other infrastructure systems, the water sectorial of aces several global challenges in the 21st century, including population growth, uncertain climate changes, socio-environmental issues, limited water resources, and economic crises (Danilenko, Van den Berg, Macheve, & Moffitt, 2014). A water supply system (WSS) may face several problems associated with its continuous aging process, including low pressure, water loss, and water quality deterioration (Alegre et al., 2016). To operate and maintain a WSS at its maximum possible efficiency at a viable cost is one of the prime objectives of any water utility. This goal can only be achieved by adopting rational and optimum maintenance, rehabilitation, and renewal (M/R/R) strategies. Even small sized water supply systems (S-WSSs) can adopt advanced but sustainable asset management tools to enhance their effective service life by improving the efficiency of all the components of the WSS (R. L. J. E. Brown, Asia, & Pacific, 2004).

The first step towards a sustainable WSS is to evaluate the performance of a given WSS, which further provides the basis for detailed investigations (detailed condition assessment and (or) M/R/R strategies). The performance of a WSS can be assessed by selecting suitable performance indicators (PIs) (Danilenko, Van den Berg, Macheve, & Moffitt, 2014), (Alegre et al., 2016), (R. L. J. E. Brown, Asia, & Pacific, 2004). The general concept of evaluating the performance of a WSS is to compare its performance with established benchmarks through cross-comparison with similar utilities (Alegre et al., 2016). Cross comparisons at the international level require wider application of the overall performance evaluation framework, as well as the individual PI. Most of these performance evaluation systems have been developed for large-sized water supply systems (L-WSSs) because they are vulnerable to frequent operational problems (e.g., small leakages to large pipe bursts, loss of amenities during vandalism) (T. C. J. L. e. Brown, 1984). Moreover, the small- and medium-sized water supply systems (SM-WSSs) are serving fewer people using smaller diameter pipelines, but they are also less involved in management activities owing to the lack of technical and financial resources. Another reason for being neglected could be that some of these systems are not old enough to have conventional structural deterioration phenomena. However, right now several SM-WSSs are facing several technical, socioeconomic, and environmental challenges to meet the regulatory guidelines (Braden, Mankin, & Education, 2004).

A systematic approach is adopted to comprehensively review the reported PI systems, keeping in mind the specific requirements of the SM-WSS. A PI system usually consists of general asset information, baseline data variables, the categorization of given PIs, linkage between data variables and PIs, the formulae, or equations to calculate the PI, and the comparison with benchmarks. Appropriate grouping of selected PIs provides an effective mechanism to assess the category wise performance of the WSS (e.g., personnel, customer service, operational). This categorization further aids decision makers in identifying and then rectifying the weaknesses of the WSS in a more systematic manner. For example, a relatively new system is performing worse than an old system of the same size and socioeconomic conditions because of staff inefficiencies. In this case, the utility management may receive many customer complaints, even though all the other categories might be working efficiently. An extremely complex or comprehensive PI system might not be feasible for the SM-WSS. In this respect, PI systems proposed by various agencies have been evaluated based on the simplicity, comprehensiveness (i.e., all aspects of a WSS are covered), and their potential to be applicable to SM-WSSs. Moreover, the data required to estimate the PIs are either not available or missing in most situations. Suitability of PIs for SM-WSSs is assessed based on their understandability, availability of existing data, and the data that can be frequently collected in future. It is also important for the utility operators and managers to establish the important PIs for which data must be collected and recorded. The last part of the review consists of a selected list of suitable PIs (with relevant classification) taking into consideration their significance and comparability, and accuracy and reliability of the required data for SM-WSSs (Braden, Mankin, & Education, 2004).

2.5.1 Performance indicator (PI)

A PI is a parameter or a value derived from other parameters, which provides information about the achievements of an activity, a process or an organization with a significance extending beyond that directly associated with the calculated value of the parameter itself. For example, the average number of liters of water supplied per person per day. Indicators are typically expressed as commensurate or non-commensurate ratios between the variables (Dziegielewski, Bik, & Education, 2004).

Performance Indicators (PIs) have been widely used as an assessment tool to transform the collected data into decision-making information through the organization of data. A framework delivers a general set of factors which can be employed to analyze institutional arrangements. Various water-related organizations have introduced their own set of performance indicators to assess the performance of water supply service. These organizations include International Water Association (IWA), The World Bank Group, and Office of Water Services United Kingdom (OFWAT). The International Organization for Standardization (ISO) is currently proposing a set of guidelines for establishing PIs in both water and wastewater services (Haider, Sadiq, & Tesfamariam, 2014).

The selection of suitable PIs depends on type of the source type and water quality. A more detailed framework, including a larger number of PIs, might be required for the same size SS with a different water source. Factors are site specific and might not be applicable to all SM-WSSs, particularly in the case of privately operated, organized water supplies in developed countries. These factors may include Lack of financial resources, Low capital and operation costs (if compared based on same water source type), Lack of technical staff, equipment, and vehicles, Lack of awareness and access to recent technologies (true for both public and private water suppliers), and Less intention to manage and more to replace and (or) renew the system components (Ahmed Reda Hamed, 2022).

Performance is the degree to which infrastructure provides the services to meet the community expectations and it is a measure of effectiveness, reliability, and cost (NRC 1995). The performance of a WSS depends on efficient and reliable working of all functional components including water resources, physical assets, operational activities, personnel, and environmental and financial activities. The performance of a WSS is evaluated to indirectly estimate the conditions and rehabilitation needs to ensure continuous and reliable working of all these components of a WSS during their entire service life before the occurrence of a failure. Once a failure has occurred, the cost of corrective action is much more than planned preventive action would have been. The difference between the planning and management cost and the cost of corrective actions justifies the need for PA (Ahmed Reda Hamed, 2022).

2.5.2 Variables

Performance indicators involve the measurement of data variables generated by analysis of the service performed. The selected variables should be easy to understand; accurately measurable with available equipment, staff, and funds; easily reproducible or comparable; should refer to the geographical area and reference time of the study area; and be relevant to the indicator to be developed. These are basically the baseline data required to determine the associated value of a PI, e.g., number of service connections, population served, total water main length, and annual costs (Haider, Sadiq, & Tesfamariam, 2014).

2.5.3 Benchmark

This is a numerical point of reference generally for the past or present. For example, in 2008, the average supply of water to residential customers was 350 L/person/day. The benchmark values established for the future should be considered as targets (Lambert, Brown, Takizawa, Weimer, & Technology—AQUA, 1999).

2.5.4 Target

A target in reference is a determined value for the PI, which is to be achieved over time (future) through the conduct of a program. For example, a target for average water supply would be to reduce average demand to 300 L/person/day by 2012 (Ganjidoost, Knight, Unger, Haas, & Management, 2018).

2.5.5 International Water Association manual of best practice

A summary of PIs along with several sub indicators is presented in Figure 1 below

Indicator category	Indicator subgroup	Description of subgroups with number of PIs in each subgroup*	Total No. of PIs in each indicator category
Water resources	2	• Water resources availability (2) • Usage efficiency and reuse (2)	4
Personnel	7	• Personnel data (2) • Personnel per function (7) • Technical services personnel per activity (6) • Personnel qualification (3) • Personnel training (3) • Personnel health and safety (4) • Overtime work (1)	26
Physical	6	• Treatment (1) • Storage (2) • Pumping (4) • Transmission and distribution (2) • Metering coverage (4) • Automation and control (2)	15
Operational	9	• Inspection and maintenance of physical assets (6) • Instrumentation calibration (5) • Electrical and signal transmission equipment installation (4) • Mains, valves, and service connection rehabilitation (5) • Pumps rehabilitation (2) • Water losses (7) • Failures (6) • Water metering efficiency (4) • Water quality monitoring (5)	44
Quality of service	6	• Coverage (5) • Public taps and standpipes (4) • Pressure and continuity of supply (8) • Quality of supplied water (5) • Service connection and meter installation and repairs (3) • Customer complaints (9)	34
Financial and economic	13	• Revenues (3) • Costs (3) • Composition of running costs for type of costs (5) • Composition of running costs per main function of the water undertaking (5) • Composition of running costs per technical function activity (6) • Composition of capital costs (2) • Investments (3) • Average water charges (2) • Efficiency indicators (9) • Leverage indicators (2) • Liquidity (1) • Profitability (4) • Water losses (2)	47
Total	43		170

*Only the types of indicators are described with number of subindicators in parentheses.

Figure 1 International water association manual of PI of water supply services

Source: International water association manual of PI of water supply services

Water supply systems have generally been classified based on their size according to their population, number of connections or the flow water demand). However, the most used classification is population served. Every water supplier wants to operate this important and asset at its maximum possible efficiency with minimum cost throughout its design period. This can only be achieved by evaluating the existing efficiency of all the components of a WSS using a suitable PA framework, consisting of the relevant PIs and identification of areas that require improvements. The PA of SM-WSSs has specific constraints associated with data availability and accuracy, lack of technical personnel, public health risk, inefficient management systems, and lack of financial resources. Little work has been done on performance evaluation of the SM-WSS (Vilanova, Magalhães Filho, Balestieri, & reviews, 2015).

Various agencies and organizations around the world have developed detailed performance evaluation frameworks including several indicators to comprehensively cover all aspects of a WSS. The selected PIs (sometimes further divided into sub indicators) have also been categorized into groups and subgroups. This review revealed that the water resources, operational, customer services, and financial indicators have been given more importance in the past, whereas indicators associated with physical assets, personnel, water quality, and public health categories have been relatively neglected so far. Environmental indicators such as GHG emissions are relatively new but need to be considered even in cases of SM-WSSs (Ganjidoost, Knight, Unger, Haas, & Management, 2018).

A systematic and measurable assessment tool is needed to assist the regulators in assessing the services. This is to ensure that drinking water supplied to the consumers is always of acceptable quality and delivered at a reasonable price. The performance indicator systems suggested by IWA, OFWAT and the World Bank Group, present their own uniqueness and priority areas. It is necessary to compare and consolidate performance indicators suggested by these organizations into the respective key areas, such as water resources, personnel, physical asset, operational, quality of service and financial aspects. This list should later be assessed in terms of its suitability to be applied to the water supply services industry (Ganjidoost, Knight, Unger, Haas, & Management, 2018).

2.6 Performance of Urban Drinking Water Supply on Ambo, Ethiopia

Ambo Town is in the Oromia National Regional State (Ethiopia) about 110 km to the West of Addis Ababa. Ambo Town is the capital of West Shoa Administrative Zone of the Oromia National Regional State. Ambo Urban Water Supply and Sewerage Service Enterprise (AUWSSSE) is responsible for urban drinking water service in Ambo (Debela & Troupin, 2015). The estimated total population of the town is 68,000. In 2013 the AUWSSSE produced 1,030,355 m3 of water and served 7,106 households, 174 public institutions, and 168 private business enterprises, and had a 115km water distribution network. The enterprise generated about $ 335,000 revenue with the total expense of $ 210,000 in 2013. The enterprise uses progressive water tariffs for private connection (the higher the consumption, the higher the price for water service), and flat rate for public stand users. Surface (Hulka River) and underground water (4 in number) were the sources of urban drinking water supply (AUWSSSE, 2013).

Interviews and review of official documents of AUWSSSE allow identifying five relevant outputs of the drinking water enterprise, those are volume of water produced and consumed, water and water service revenue, number of clients served, water utilities constructed and maintained and outputs related to human resource management. The amount of water produced by water supply enterprise and consumed by citizens is the main output of the enterprise. The difference between produced and sold water corresponds to water loss, which is due to illegal connections, non-billed water consumption, and leakages in the distribution network. It is thus important to go beyond the leakages' hypothesis for water loss and consider illegal connection and non-billed water as well. It also matters not equating sold water with consumed water, because a water meter can read by the wind instead of water pressure (Shanmugham & Tekle, 2011).

The number of clients served by the enterprise through direct/private connections by customer category (household, businesses, and non-businesses) and public stand pipe is also an output indicator of water enterprise. Informants said that poor people and students usually use public stand pipe. Furthermore, if the public stand pipe is not nearby, citizens may prefer to buy water from resellers in the neighborhood at a higher price, which in turn forces them to consume less water. This entails that the water supply enterprise should support and encourage private connections, and build public stand pipe at optimal distance to meet its objectives (Shanmugham & Tekle, 2011).

The number of constructed and maintained water utilities is another output indicator of water supply enterprise. The number of water utilities constructed and maintained (reservoir, treatment plants, boreholes, public stand pipe), the length of water distribution network and the length of water lines renewed/replaced and maintained can be measured. They depend on many factors such as the financial capacity of the enterprise to expand the distribution network, the settlement pattern of residents (the more scattered the settlement, the higher the length), the urban topography (a plain slope requires less length), the master plan of the town and the position of water utilities (collection chamber, treatment plants and reservoir). Maintenance, renewal/replacement activities are influenced by the quality of constructions, the availability of financial and other inputs. Poor design and construction quality of water utilities lead to frequent maintenance and renewal/replacement, which in turn increase repair and maintenance cost. Furthermore, the availability of qualitative human resources also matters: sometimes people with special skills may be needed for repair and maintenance activities. The local community may contribute in cash or in kind to construct and maintain water utilities (GUTEMA, 2023).

Accessibility, quality, equity, reliability, health (water-borne diseases) and socio-economics as most important outcomes indicators to evaluate the performance of drinking water supply. The community uses water for drinking, cooking, sanitation, medication (to treat patients in hospitals and health centers) and business activities (hotels and other private businesses). When accessibility, quality, and acceptability, degree of equitable distribution, reliability of water is insufficient, it thus has consequences for the health and socio-economic conditions of individuals. When these quality criterions are not met, individuals tend to use water from unprotected sources, running a risk for their health (Shanmugham & Tekle, 2011).

2.6.1 How to improve the performance?

Research allows identifying a range of strategies for local governments to improve their performance in supplying drinking water to their citizens.

2.6.1.1 Efficiency improving strategies

The Ambo case allowed identifying four possible strategies to improve the efficiency. First, local water enterprises can lead a commercial policy aimed at cost recovery, for instance by providing financial disincentives for additional private connections, especially for the poor people and at remote places. The case study indeed reveals that the installation of public pipes has a lower cost but negates the equitability dimension. Second, procurement policies can deliver significant efficiency gains. Because local water enterprises need to buy significant amounts of materials (chemicals, pipes, meters, infrastructures for storage and treatment) to deliver drinking water, it is of utmost importance that the lowest price is obtained for a given quality of the material (GUTEMA, 2023).

Third, the quality of delivered water must be sufficient to be sold to customers. The Ambo case indeed revealed that customers have alternatives to the monopolistic supply of water by the local government's enterprise: they can collect and consume rainwater on their own, can travel to natural springs to fetch water, or consume bottled beverages (Shanmugham & Tekle, 2011).

Finally, the sources of water used have an impact on efficiency. The Ambo case reveals that the treatment costs are higher for the surface than ground water. Furthermore, ground water has the unique advantage of predictability: its quality and quantity do not depend as much on the last rainfalls and other climatic events as with surface water. Thus, this pleads for a preferential reliance on ground waters, when available (Shanmugham & Tekle, 2011).

2.6.1.2 Effectiveness increasing strategies

To increase effectiveness in supplying drinking water means, for local governments, to improve the accessibility of water, its quality, the equitability of supply, and the reliability of the service. The Ambo case showed some ways of improving effectiveness. The reliance on ground instead of surface waters is an example of such strategies. Treatment does not always suffice to bring surface waters to acceptable levels of quality. Moreover, the quality of surface waters is subjected to seasonal variation, and an excessive reliance on it can lead to service interruptions. In such cases, the absence of water in the distribution lines leads to corrosion and proliferation of bacteria, ultimately damaging the quality and acceptability of upcoming flows of water. Stakeholder management can provide a significant contribution to effectiveness, by helping to protect catchment areas and by training to test and improve water quality and enhancing cooperation for sustained inflow of inputs (Mersha, Masih, De Fraiture, Wenninger, & Alamirew, 2018).

Finally, there exist specific strategies for certain facets of an effective water supply. The chemicals used in the treatment process will significantly impact quality: their quality and quantity matter in that framework. The commercial policies also will have the greatest impact on equitability: the initial costs of private connections can prevent poor people from accessing water, as do the consumption tariffs. Seen through the lens of equitability, the water enterprise, therefore, needs to revisit commercial policies (Evans & Sadler, 2008).

2.6.1.3 On the added value of citizen involvement

Many treatments costs arise out of pollution of water sources by citizens. Also, by boiling distributed water, citizens can share the treatment costs with the water company, and contribute to an overall better performance. This experiment thus suggests that citizen involvement could be a win-win situation. The paper allowed identifying three input indicators: sources of water, human resources, and other nonhuman resources. These inputs are converted into outputs through two ranges of activities: operational activities, involving catchment, treatment, and distribution of water, and management ones including investment decisions, commercial policies, and participatory processes with customers or other public organizations; all constitute activity indicators. These activities lead to outputs, essentially: cubic meters of water (produced, sold, consumed, and leaked), financial revenues for the enterprise, number of customers, and output related to water utilities and human resource management, all are identified as outputs indicators. This production chain should lead to effective water supply, what customers define in terms of equitability, quality, reliability, accessibility, and acceptability, and which are distinguished as outcome indicators. Investing in the maintenance of the distribution network to avoid leakages, involving the community in the production process, ensuring a minimal quality of water, improving procurement policies, relying on ground water (Mersha, Masih, De Fraiture, Wenninger, & Alamirew, 2018).

2.7 Performance of Urban Drinking Water Supply on Alem Gena, Ethiopia

Alem Gena is situated in the Awash River Basin, along the main Addis-Jimma Road in Hawas Wereda, Oromia Regional State. It is in the central highlands of Ethiopia within latitude 8° 52‟ to 8°57'N and longitude 38° 33' to 38° 42'E with an elevation ranging from 2050-2500 meters above mean sea level. Hills and steep slopes are bounding the town in the northeastern, Woletie in northern and eastern and Sebeta southern part with moderate and gentle slopes spanning to the town.

The whole town except the small area served by existing boreholes. About seven-kilometer transmission mains with diameter of 150mm to 350mm convey water from Furi Pumping Stations to service reservoirs and from borehole sites to the respective distribution networks from where majority of the currently served villages are fed either through pumping to the commanded areas or by gravity from reservoirs to the lower areas. The existing boreholes are widely dispersed and the water is directly pumped to the distribution pipe network which was developed through time. According to the information obtained from the water service enterprise, it is impossible to fulfill the requirements of the existing industrial demand. Therefore, most of the industries prefer to drill their own boreholes. The technical detail of these boreholes is not available in the office of the water enterprise. The amount of water extracted by each industry is not known. This has got a negative impact to appraise the groundwater balance of the town. Consequently, the hydro geological study report done by the client, OWRB, reveals that using the existing boreholes is not necessary and consequently proposing new boreholes with greater depth and larger diameter expected to give better yield to be drilled in three different proposed well fields‟ sites at Furi (Debela & Troupin, 2015).

In Alem Gena, because of the growth of the socio-economic activity in both governmental and private sectors, there was the high-water demand in the town. Using the annual water consumption and population figure in (2016), the average per capital consumption of the town was calculated to be 32.04 l/c/d. But, according to existing town water supply design report; the average per capital water demand of the town at the end of the design period (2011 G.C) was estimated and adopted as 70 l/c/d. As per the revised design report of Alem Gena town water supply system, obtained from the regional water, mineral and energy bureau; the current (2016) average per capital water consumption for Alem Gena town were estimated and adopted as 85 l/c/d for various activities of demand category (Kefyalew & Technology University, 2018).

2.7.1 Water loss Analysis and Findings

One of the major challenges of water utilities is high volume of water loss in their distribution networks. If a large quantity of supplied water is lost; it is difficult to meet the required quantity to demands, and correspondingly made challenges to keep the water tariffs in the system at a reasonable level. Unaccounted for water include water losses due to leakage in the water supply system, illegal connections, legitimate unmetered for flushing, overflow from reservoirs, improper metering and others for which bills are not paid. It is very crucial to estimate this quantity as it usually varies from 15 % to 50% depending on the age of pipelines in the system and the size and complexity of the distribution system (Kefyalew & Technology University, 2018).

2.7.1.1 Percentage of water loss

The percentage of NRW in 2016 in the town is 37.38 which is greater than the permissible water loss percentage which is 25%. The possible reasons may arise from overflow from tankers due to absence or malfunction of automatic flow control valve or float valves, leakage from transmission and distribution pipes, leakage due to high pressure at transmission and distribution pipes, leakage due poor workmanship and using of non-standard pipes and fittings and lack of sudden maintenance during burst of pipes (Kefyalew & Technology University, 2018).

2.7.1.2 Data handling errors

Data handling error in the meter reading and billing process were contributed for apparent losses. Customer meter reading practice; especially unbilled metered trends were the common problem of Alem Gena town water service office. Whereby, recording of under/overestimated figure lead the water utility to improper collection of revenue, and at the end of the month the authority was lost money. Accordingly, as per the authority 2016 annual report; the town water authority has lost 3,497m3/year of water due to poor data handling process (Kefyalew & Technology University, 2018).

2.7.1.3 Illegal connections

As a developing town; there are a significant number of illegal users of water within Alem Gena town water distribution network, and were contribute to the reduction in service level to authorized consumers. The town water utility was not known the actual figure of residences that do not pay water tariffs but received water from the distribution system. But as per the feedback from the water utility; construction sectors, different enterprises and hotels in the town are mainly contributing in large number. Due to limitation of data, water losses as result of illegal connections cannot be figured clearly in Alem Gena town (Kefyalew & Technology University, 2018).

2.7.2 Summary of Water quality findings

The PH value of all taken water samples is within the range of the national and international standard TDS value for all samples is within the national and international standards. Total hardness for all samples is within the limit of both national and international standards. The chloride content for the samples is within the relevant range. Turbidity the samples taken from all sources are less than both national and international standards. From this it is possible to conclude that the possibility of the system to be contaminated by the soil particles or other surface particles is very low or null. The total coliform for all samples is much departed from both the national and international standards. This shows that the drinking water sources can be contaminated by storm water run-off from roadways, farms and livestock operations, and discharges from sewage treatment or septic systems. Disease-causing bacteria may use this pathway to enter the water supply. Since coliform bacteria usually persist in water longer than most disease-causing organisms, the absence of coliform bacteria leads to the assumption that the water supply is microbiologically safe to drink (Kefyalew & Technology University, 2018).

2.7.2.1 Customer Satisfaction

As per the information obtained from Alem Gena town water utility customers‟ service department, there are a total of 5584 private houses, institutional, commercial, and industrial customers. The number of private house customers estimated up to 65% of the total customers. Out of 280 customers, asked for effective usage of water, 275 answered that they use water effectively, and no one responded that they don't use water effectively. This clearly shows that everyone is responsible for effective usage of water. The water utility must care about how to control the quality of the pipe water as contaminated water cause several diseases (Kefyalew & Technology University, 2018).

Out of 277 valid respondents asked for the pressure of pipe water, 102 responded the pipe water reach to them with enough pressure, 175 responded that the pipe water have no enough pressure at their tab. Out of 242 valid respondents about what they think about the quality of pipe water they use, 227 think that the pipe water is clean, 15 customers responded that the pipe water is not clean. Alem Gena water utility office must work on the quality of the water they are providing as more than eighty percent of the customers directly use the pipe water without cleaning it. The laboratory output from sample taken shows that there is a high amount of coli bacteria which is more than both national and international standard (Kefyalew & Technology University, 2018).

Out of 268 valid respondents about water utility office respond quickly on maintenance 175 answered yes and 93 responded no. Although the best practice on water supply operation and maintenance is providing adequate water supply and following up the system day to day, more than twenty nine percent of the customers in Alem Gena town must wait at least a month to get water meter at their home. The customer is not familiar with how water meter works and they cannot think that the water meter may read error. So, all respondent answered that the water meter works properly (Kefyalew & Technology University, 2018).

Out of 255 valid respondents' about "How many days you get water per week?" 89 responded five days a week, 56 responded three days a week, 110 responded twice a week. According to the respondents, no one can get water seven days per week. Although Alem Gena town is served from twelve bore holes found in the town, there is no continuous access of water in the town (Kefyalew & Technology University, 2018).

2.7.3 Recommendations from researchers

The following recommendations in relation to water loss, water quality, customers‟ satisfaction and operation and maintenance have been proposed respectively to improve the performance of existing Alem Gena town water supply system. There should be structured operation and maintenance practice to improve the whole pipe water system in the town, there should be planned and regular routine inspection for leakage from water supply system components such as transmission and distribution pipes, reservoirs, collection chambers and pump houses. And there should be immediate rehabilitation and maintenance when leaks are observed, Inspection should also be done for transmission pipes and for main distribution pipes for assessing damage of the transmission system following a heavy storm, unauthorized construction activity near or on the utility pipeline, Water meters should be installed at all sources, reservoirs and collection chambers inlet and out let pipes and proper water production recording should be in place.

Faulty water meters should be maintained or replaced, stand by generators shall be installed in pumping stations in case the power interruption, and as it is indicated on the Ethiopian guideline for drinking water quality the bacteriological test should be accompanied with turbidity and free residual chlorine and pH where chlorination is applied, the water utility should respond immediately to maintenance requests of customers to avoid water loss and complaints from customers and need to regular discussions with the customers. The water utility should also conduct a regular survey to know customers satisfaction level and the service deficiencies and should make improvements on its service to increase the customer's satisfaction, There must be updated water supply system map which provide an overall view of the water supply system components like distribution and transmission pipes layout, sizes and length, location of valves, flow meters, fire hydrants, reservoirs, pumping stations, and sources should be prepared and be available in the water utility office for proper operation and maintenance of the system, The water production and water consumption recording system should also updated in order to have a clear water balance and water loss (Kefyalew & Technology University, 2018), (Debela & Troupin, 2015).

2.8 Performance of Urban Drinking Water Supply on Debre Tabor, Ethiopia

The town is in the northwest part of Ethiopia, at 666 km road distance from Addis Ababa, at latitude and longitude of 11°510N and 38°010E, respectively, and an average elevation of 2,706 m above mean sea level. The main source of Debre Tabor Town's piped water supply system is groundwater. There are 12 boreholes, out of which only eight are functional. According to the data from the water supply office of the town, the designed gross water production capacity of the boreholes is 78 L/s; however, currently, only around 48.02 L/s of water is produced from the boreholes with an average pump working hour of 9 per day. The raw water from each functioning borehole in the town is pumped to the existing three main ground service reservoirs. A 70-m3 circular masonry reservoir, a 300-m3 rectangular concrete reservoir, and a 50-m3 circular masonry reservoir are in the town. Water is distributed to consumers by both pressurized and gravity systems. The total length of the main and the secondary distribution lines is 128 km (Yezina, 2021).

2.8.1 Water quality of the system

The average value of residual chlorine was more than the maximum value of 0.5 and at 50% of the sampling sites the values are below the 0.2 value, set by the Ethiopian standard. Almost all the values are below the WHO recommended range of residual chlorine for domestic purposes, which is 0.5–1.5 mg/l. Coliform organisms have long been recognized as a suitable microbial indicator of drinking water quality. The result showed that coliform was detected at a well; however, three of the wells had no coliform counts. The water quality of three of the boreholes was classified as excellent water, two of the reservoirs were classified as good water and for a well and in two of the reservoirs it was under the poor water class (Yezina, 2021), (Tekile, Legesse, & Development, 2023).

2.8.3 Water production versus revenue collection

After the Water Aid Ethiopia capacity building was provided to Debre Tabor Town, the NRW is reduced from 19.5 to 13.85%, the maintenance cost is reduced to 9.3% of the total operating cost and the revenue collection efficiency reached 98.5%. Currently, the utility sells water to customers in a rising block tariff type on average at 14 birr/m3 and the operating cost of water production is 31.68 birr/m3 (birr is Ethiopian currency, (1-birr = 0.02 USD). Thus, considering the revenue collection efficiency and the NRW, the income collected and the total water production costs are 11.88 and 34.63 birr per m3 of water. This shows that only 34.31% of water production cost is collected from customers (Tekile, Legesse, & Development, 2023).

2.8.4 Customer satisfaction

The majority (94.5%) of the respondents use piped water supply, 2.5% use spring water, and 3% use hand-dug wells. However, the piped water flows in an on-and-off manner for a few hours that customers store water in containers to use until the water comes again. Improper storage may result in contamination. To overcome the existing water supply shortage, the community uses untreated alternative sources of water, such as surface water, spring, and rainwater (in the rainy season), and 76.9% of them hand-dug wells. Thus, due to the intermittent supply of piped water, people are forced to use water from unimproved sources that may be contaminated with infectious microorganisms and may be subject to waterborne diseases (Abel, 2020).

Only 54% of the households fetch their main drinking water within 100 m of their home and 16.1% travel more than a kilometer to get water. Only 22.9% of the residents had private meter connections, 71.6% of them use yard meter connections of their own, and 5.5% depend on group meter connections/shared by neighbors. Thus, the society has limited access, which may expose them to the use of water of poor quality and a public health risk (Gizachew, Admasie, Wegi, & Assefa, 2020). On the other hand, 60.6% had to wait for more than 30 min to collect water, which is below the service level stated by WHO standards for safe drinking water. It is common to see a queue line at the water point, which leads consumers to wait for a long period. Households were also asked about the quality of water they use for domestic purposes. Most of the respondents had good awareness toward their water quality. More than 50% of them feel safe that the quality of water is good for domestic purposes. Some households stated, 'sometimes there will be sludge at the bottom of water holders when the water is finished' (Yezina, 2021).

The system needs solutions such as pump operational changes, providing pressure control valves, and/or adjustment of network components such as a booster pump installation and replacement of old pipes with new ones of proper diameter to operate within required pressure and velocity and then to upgrade the service level. Moreover, the study on water and sanitation service levels of 16 small and medium towns in four regions of Ethiopia showed that a small minority of households receive services, with characteristics such as reliability, quality, quantity, and accessibility of water meeting the standards set by the government (Yezina, 2021)

Coming to the financial issues, the 34.31% cost recovery of the utility agrees with ADB (2020), which concluded financial viability to be the weakest performance indicator in the region. If a water supply service could not recover its costs, this would restrict chances to develop and extend networks; particularly affecting the poor. For domestic users, the price is decided considering affordability, which varies depending on the local situation, but for water to be affordable; its price should not exceed 5% of the income of households. Generally, it is assumed that the potential for long-term performance improvement in urban water supply systems can be established through the application of all the indicators studied. Water quantity and quality should be together studied and managed to attain a better water supply service for urban areas. It should also be emphasized that cost recovery and financial capability and fairness and effectiveness (affordability) in drinking water supply need to be balanced in developing countries simply, trade-offs are expected (Debela & Troupin, 2015).

Debre Tabor Town's per capita water consumption was also lower than the regional and country-level standards set by the country's ministry of water resources and WHO domestic water standards. On the other hand, only 34.31% of water production cost is covered by revenue collected from customers, showing that the system is currently far from being economically viable. Generally, the overall performance of the system is weak and improvement of the coverage, quality and thus satisfaction of the community needs due attention. Using additional alternative sources of clean water, reducing water loss, and expanding distribution networks in areas where it is not available are required to upgrade the system's performance (Gizachew, Admasie, Wegi, & Assefa, 2020).

2.9 Performance of Urban Drinking Water Supply on Adama, Ethiopia

The existing water supply system of Adama city does not satisfy the water requirement of the tremendously increasing population of the city, large industrial development, and a complaint regarding service provision from customer side. So that, there is a need to investigate the performance situation of the water supply system of the city. Among the International Water association Indicators (IWA) of water supply service, water resource indicator shows better performance, from quality of service indicators, average water tariff performance was better but need improvement, water resource indicators result shows better performance, from personnel indicators employees per connection, and operation and maintenance personnel shows poor performance, and from physical indicators treated water storage shows better performance, metered customer good, and microbiological and chemical test carried out shows poor performance (Desta, Befkadu, & Environment, 2020).

2.9.1 Performance indicators used in the study

Water resources and financial performance indicators selected were, water resources availability, nonrevenue water by volume and average water charges for direct consumption. Personnel performance indicators selected were, employees per connection, operation and maintenance personnel, water resources and catchment management personnel, abstraction and treatment personnel, transmission, storage and distribution personnel, water quality monitoring personnel, meter management personnel, employees per water produced. Physical and operational performance indicators selected were, treatment plant utilization, treated water storage capacity, metered customers, water losses per connection, microbiological tests carried out, physical chemical tests carried out, unmetered water. Quality of service performance indicators selected were, population coverage, population coverage with service connections, population coverage with public pipes or standpipes, per capita water consumed in public taps and stand pipes, population per public tap or stand pipes, microbiological tests compliance, physical-chemical tests compliance (Fekrudin, 2019).

To evaluate non-revenue water by volume, non-revenue water and system input volume during the assessment period were collected. To analyze water resource availability system input volume during the assessment period, annual yield capacity of own sources and annual imported water allowance were collected from Adama water supply and sanitation enterprise (AWSSE). Variable data used to evaluate the performance of microbiological and physical-chemical tests compliance, number of microbiological and physical-chemical tests of treated water complying with the applicable standards or legislation during the assessment period and total number of microbiological and physical-chemical tests of treated water carried out during the assessment period data were collected (Desta, Befkadu, & Environment, 2020).

2.9.2 Average daily per capita consumption

Average domestic water coverage of the city was 38.25 l/p/d. when it compared with other African cities Abidjan and Nairobi respectively 72 and 98 l/p/day; Adama city Per capita water consumption was lower and need to improve (Fekrudin, 2019).

2.9.3 Level of water connection

Level of connection of the total households in different kebele's were calculated and it was on average 5.56% of the households were found to water use 40 l/c/d. Average level of water connection per family of the city was 0.59. This implies that at average more than 1.7 families or seven persons were sharing one connection or water tap, in other words the average in-house or yard connection of the town was 59% (Fekrudin, 2019).

2.9.4 Water loss of Adama city water supply system

Total water loss of the system in 2018 was 34.67% of the system input volume and is approximately 3,288,055m3/year; this amount of water loss was big when compared with the developed countries water loss in water supply system. Water loss in water supply systems ranges from 15% to 30% in the developed country but, elsewhere it is likely to range from 30% to 60% (Fekrudin, 2019).

2.9.5 Performance analysis Adama city water supply system

Water resources availability ratio was 73.05%. The value of this water resources performance indicator for Adama city water supply system was higher than that of selected areas of Addis Ababa 24.25%. This indicates that the available water resources were used better. A higher value (100%) of this parameter means that all the available resources are being used. From financial performance indicators, Average water charges for direct consumption of Adama city water supply system was 0.27(US$/m3). From physical and operational performance indicators, treated water storage capacity of the water supply system was 0.63/days. This shows all the registered customers in the city were metered and it shows good performance. Treatment plant utilization was 54.2% which means 45.8 % of the treating capacity of the treatment plant was not used due to different reasons, this shows lower performance. Water loss per connection (m3/connection /year) was 48.22, when this value compared to the value for selected areas of Addis Ababa 119.92 (m3/connection /year) (Bereket 2006), Adama city water supply system have better performance but not enough, 48.22 m3/connection/year mean too large for Ethiopia, because it pays or loses large cost for this amount of water. Unmetered water of the city water supply system was 34.02%. Microbiological tests carried out were 66.67% and physical chemical tests carried out were 55.56%, When these values compared to the value of micro biological test carried out 96.96% and physical-chemical test carried out 100% for selected areas of Addis Ababa (Bereket 2006), Adama city performance was too low (Fekrudin, 2019), (Desta, Befkadu, & Environment, 2020).

Performance indicators selected to analyze the quality of service of the water supply system were, Micro biological and physical chemical test compliance of the city water supply system were 100% and 100%, when these values compared to the selected areas of Addis Ababa, i.e. micro biological, and physical-chemical quality of supplied water 98.8% and 99.57% (Desta, Befkadu, & Environment, 2020). Adama city water supply and sewerage enterprise performance was better. Population coverage of the water supply system was 100%, population coverage with service connections 86.71%, population coverage with public taps or standpipes 13.29%, Per capita water consumed in public taps and standpipes 16.03(l/person/day), but the per capita water consumed in public taps and standpipes were on average 16.03 l/p/day, this was below the world health organization standard 20 l/p/day, Population per public tap or standpipe 244.21(persons/tap) (Fekrudin, 2019).

2.9.6 User perception analysis

Analysis of the selected performance indicators shows that among the IWA indicators of water supply service, water resource indicator shows better performance, operational indicators shows smaller performance, from quality of service indicators, average water tariff was better but need improvement, water resource indicators result shows better performance, from personnel indicators (employees/connection) and operation and maintenance personnel shows poor performance, and from physical indicators treated water storage shows better performance, metered customer good, and microbiological and chemical test carried out shows poor performance when compared with other water supply service in Ethiopia. And, the results were shows that, average Per capita water consumption of Adama city was 38.25l/c/d and the water loss was 34.67% of the system input volume (Fekrudin, 2019).

To improve the performance of the water supply services of the city, the following recommendations may be helpful. The city water supply and sanitation enterprise have to look seriously into water demand and water loss management, operational and maintenance personnel and personnel per connection performance should be improved for better operational performance, the performance of chemical and biological test carried out should be improved, and also the city water supply and sanitation enterprise should be improve the treatment plant utilization capacity for better usage of its capacity and also educating community is very important for better rain water collection strategy (Fekrudin, 2019).

2.10 Overview of SCADA system

The earliest gadgets related to remote command and monitoring appeared in the end of 19th Century. Those early electromechanical systems are very often used only for monitoring or only for control, but rarely for both at the same time. During twenties and thirties, the various commercial systems for monitoring and control appeared. These systems were appropriate for remote transmission, more measuring in a canal and they supported an elementary operation of remote control. Also, they are used for remote simple commands like turn on/ turn off. Measures taken from remote stations were indication of equipment state, in fact the sum which has just two possible values turned on /turned off. The first commercial systems were completed by usage of electromechanical relays. Solutions based on electromechanical relays, because of their complexity and unreliability of such equipment, made transmission of large number indications and analogous measuring impractical. These systems were used for remote control and acquisition of small number of measuring information. These systems are called systems for ‘supervisory control’ (Anton et al., 2017).

Later, in sixties, because of development of telecommunication, measuring equipment and appearance of mini-computers, the first computer systems for remote monitoring and management were appeared. They had all important components and functions of system which are called SCADA Systems, today. The computer technology and SCADA system developed at the same time(Pliatsios, Sarigiannidis, Lagkas, & Sarigiannidis, 2020).

2.11 Components of SCADA system

Essential components of SCADA system are

2.11.1 Field instrumentation

Field instrumentation refers to the sensors and actuators that are directly interfaced to the plant or equipment. Devices like measures of level, flow, pressure, temperature, and others acquire data on which experienced operators may estimate state of system. Signals are also conditioned to make sure they are compatible with the inputs/outputs of the RTU or PLC at the Remote Station. Outputs can either be in analog (continuous range) or in digital (discrete values). Digital outputs are used to differentiate the discrete status of the equipment. Usually, <1> is used to mean EQUIPMENT ON and <0> for EQUIPMENT OFF status. This may also mean <1> for FULL or <0> for EMPTY. Actuators are used to turn on or turn off certain equipment. Likewise, digital, and analog inputs are used for control. For example, digital inputs can be used to turn on and off modules on equipment. While analog inputs are used to control the speed of a motor or the position of a motorized valve (Bailey & Wright, 2003).

2.11.2 Remote stations (RTU-Remote Terminal Units)

RTU-Remote Terminal Units are used for performing the functions like remote monitoring and management. Information which is received from sensors and actuators must be transformed in shape which is compatible to SCADA 'language'. Remote stations are robust industrial computers which take data (measuring and indication) from measuring equipment, primarily process data, manage and communicate with superior center. They are used in situations where communications are more difficult. RTUs hold data gathered in their memory and wait for a request from MTU to transmit the data. One of RTU's disadvantages is a bad programmability. However, modern RTUs offer a good programmability comparable with PLC. The functions of superior centers are very often performed by Programmable Logic Controllers thanks to their good programmability(Chan & Ebenhoh, 1992).

2.11.3 Central Monitoring Station (Master Terminal Units)

Central Monitoring Station represents the host processor of SCADA system where all acquired and telemetric data are received. At the heart of the system is the master terminal unit (MTU). The master terminal unit initiates all communication, gathers data, stores information, sends information to other systems, and interfaces with operators. The major difference between the MTU and RTU is that the MTU initiates virtually all communications between the two. The MTU also communicates with other peripheral devices in the facility like monitors, printers, and other information systems. The primary interface to the operator is the monitor that portrays a representation of valves, pumps, water level in reservoirs, etc. As incoming data changes, the screen is updated.(Bailey & Wright, 2003)

2.11.4 Communication Network (WAN, LAN, GSM)

Communication Network is the medium for transferring information from one location to another. SCADA system for transferring information uses different communicative media like optical fibers, directed radio lines, telephone lines, and local computer networks in area of plant. Remote management or monitoring of SCADA system often relates to telemetry. SCADA protocols are designed to be very compact and many are designed to send information to the master station only when the master station polls the RTU. Today, it is possible to transmit data and manage the plants which are a few hundred kilometers away thanks to GSM network and cell phone (Bailey & Wright, 2003).

2.11.5 PLC (Programmable Logic Controller)

Programmable Logic Controllers is a digital computer used for automation of electromechanical processes. Typical tasks of PLC mean acquisition of more tens or hundreds analog and digital values, in fact measurements from system, processing of these measurements and formation of control analog or digital outputs in real-time(Tomar & Kumar, 2020). Modern RTU also may perform control activities, typical for PLC, but modern PLC are expanded with communicative interfaces which allow transmission of gathered information to remote, central site MTU. Differences between modern implementation RTU and PLC are minor so that the term ‘RTU’ is used for identical devices with different configurations, when we talk about remote field interface device. When we talk about the device which has control program, then the term ‘PLC’ is used (Upadhyay & Sampalli, 2020).

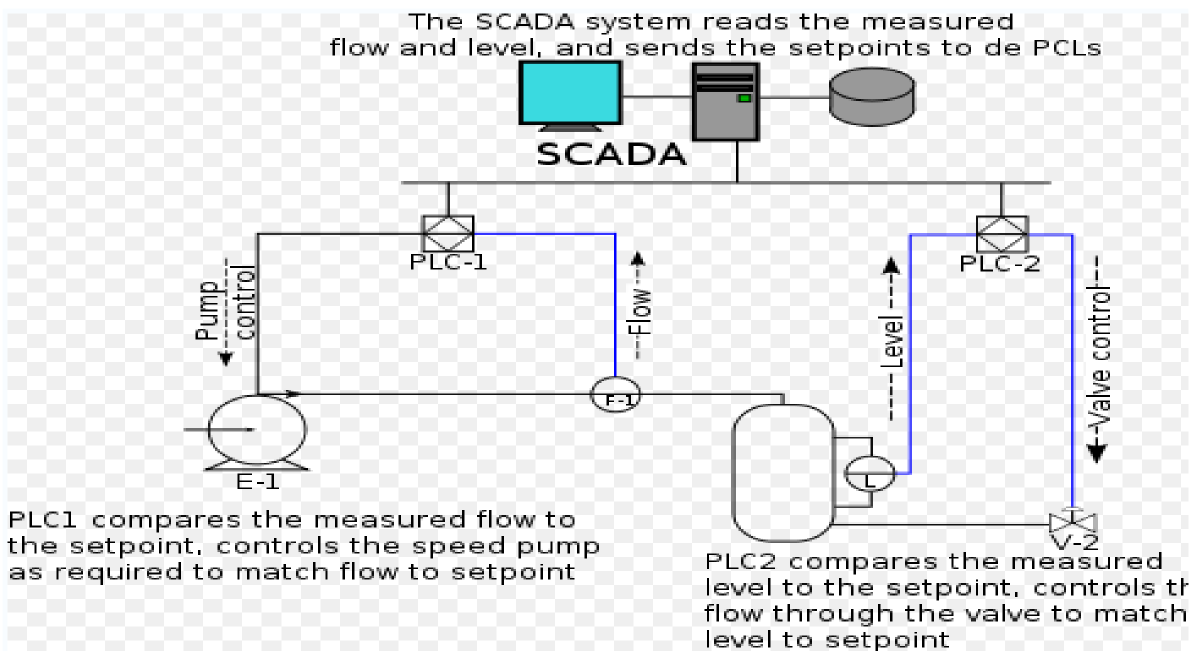

Figure 2 SCADA system management by PLC

2.11.6 Alarm

Alarms may be generated by equipment at remote location and transmitted from relevant RTU to MTU. Alarm handling is based on the edge and state which is checked and accomplished in data of server. Generating and processing of alarm are one of the most important functions of each SCADA system. Real-time presentation of alarm situations allows the real-time corrective actions and removing the situation which led to alarm situation to the user (operator, dispatcher) for example fall of absorbing, pump reset, break of communication, maximal level in chamber, minimal level in chamber, damage on chlorine sensor, damage on pump, fire in plant, burglary, etc. When SCADA system is used for control the large waterpower systems, the alarm indications have significance for security and accuracy of system works and they occur very often. On the monitors of an operator (dispatcher), alarms are displayed like flashing red light and in that way; they show that it came to the changes of state in the system (Tomar & Kumar, 2020).

2.12 Research Gap

Water is what makes our planet so unique and virtually everything on our planet relies on it. Having clean water is vital to our individual health, our collective agricultural needs, and the needs of our environment. It is the foundation of all life and important to sanitation, human rights, urbanization, sustainability, economic growth, etc. Therefore, creating automated system for controlling and supervising the water supply process is the preferable way to keep the efficiency of water supply projects.

A few researchers have attempted to assess the issues and challenges of Urban Drinking Water Supply (UDWS) in specific cities in Ethiopia (i.e., not at the Ethiopian level but in the selected city), but all were focused on specific topics and cities. For instance (Alemu & Dioha, 2020) on water supply and demand in Addis Ababa city; ((Bekele & Teka, 2023; Getachew, Mulat, Mereta, Gebrie, & Kelly-Quinn, 2021) on water quality/environmental issues; (Berhane & Aregaw, 2020; Bhagat et al., 2019) on technical issues related to Water Distribution System and non-revenue water, whereas (Debela, 2021) on institution and governance issues. It may be noticed that only a few studies were carried out to focus on the challenges of UDWS in very few Ethiopian cities (not at the Ethiopian level). Also, there are several gaps/missing information as elaborated here the past studies have focused on the capital city of Ethiopia (Addis Ababa) only, which is not representative of other Ethiopian cities. Previous studies had several limitations on UDWS challenges assessment methods, but the current study is more elaborative as it considers a mix of methods involving key informant interviews, field observations, and various advanced computer-aided applications for water supply controlling techniques, and analysis for supply and demand. Previously mentioned studies have investigated specific challenges/complexities, but none has incorporated application of automated water supply system for each challenge. This study addresses the provision of Supervisory Control and Data Acquisition system for complexities of the UDWS with possible demonstration for better resource management.

In order to improve the performance of the water supply services of the city, water supply utilities should focus and enhance their system on addressing water supply and demand balance, water loss management, operational and maintenance techniques, chemical and biological tests on water quality and adoption of automated water supply systems. (Fekrudin, 2019).

In addition to boosting water quantities and qualities in Ethiopia the trends of communities in which highly dependent on public water point and used in house storage must be changed. Unmanageable and unstructured urban expansion in Ethiopia which is exerting high pressure in water supply and sewerage is coupled with need of urgent work need in reducing high water systems' losses, increasing networks in water distribution system and capacity development in water sector also need more action than ever (Siraj & Rao, 2016).

A detailed report is written by gathering a variety of study publications. It is discovered by doing a thorough literature review that several references recommends that automated water supply system after analyzing the performance of the specified water supply projects the town water supply and sanitation enterprise should think to install the automated network system **(**SCADA**)** to manage and control the whole water supply system network including the issue of water loss.

CHAPTER THREE   MATERIALS AND METHODS

3.1 Description of study area

Adama Town is in Oromia Regional State, East Shewa Zone, about 100km south east of Addis Ababa, the town is found at geographical location 8032.437'N, and 39016.129'E, situated in the Great Rift Valley. The town is also accessible by Adama -Addis Ababa Express-way, and the maximum topography of the town is 1850m above sea level and the daily temperature varies between 5.5 ^{o}C to 35 ^{o}C, and the mean annual temperature falls between 10 ^{o}C to 35 ^{o}C and the town has a population of 478,174 in 2017 including Wonji town. After all assessments on performances of water supply projects resource management techniques, analysis on Supervisory Control and Data Acquisition system challenges, constraints and application the paper develops a frame work for successful implementation automated system for water supply projects of Ethiopia. To explore the application of Supervisory Control and Data Acquisition System for water supply projects Adama town is selected as a case study area due to the experience of the city water supply project on implementing Supervisory Control and Data Acquisition System through Adama Water Supply and Sanitation Improvement Project (AWSSIP).

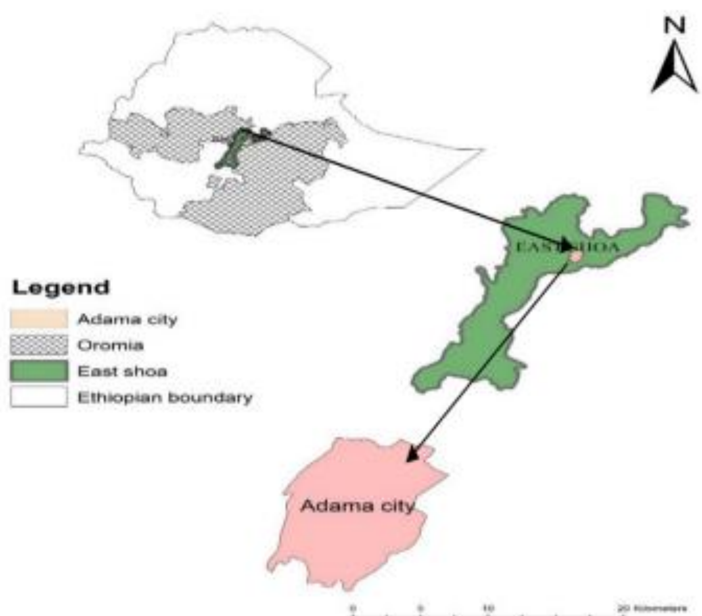

Figure 3 Case study area location

3.2 Research Design

The strategy followed in carrying out the research was started with problem identification which has been done through unstructured literature review, archival study and informal discussion with colleagues and professionals in the sector; and then the research design was formulated. Following this data and information sources were determined based on the formulated research design. Based on the data and information sources the research instruments were decided; and available documentary sources relevant to the research were reviewed. The review includes books, journal and articles, internet sources and archival document search such as management techniques applied by different water supply projects in Ethiopia. In consideration of the nature of the research question, qualitative research method is selected for this study as the research questions relates to the personal attitude, opinion and view. The research is carried out using a four phased approach to achieve the objectives of the research. It was attempted to collect data from the relevant population through questionnaire to assess the current performances of selected water supply projects with aspect of their resource management techniques for the first objective from the reference of Key Performance Indicators (KPI), to achieve the second objective which is to identify major challenges, constraints and application of SCADA system for water supply projects open ended questionnaire is conducted. Also, the third objective to develop best practices for successful implementation of Supervisory Control and Data Acquisition System (SCADA) for water supply projects of Ethiopia is achieved through compiled findings of previous objectives. Finally, Adama town water supply and sanitation improvement project (AWSSIP) implementation of SCADA system is selected as a case study for the fourth objective achievement to address application of the automated system.

After a literature in-depth review and desk study, a questionnaire was designed and distributed to actively participating parties on water supply projects of Adama including contractors, consultants, Supervisory Control and Data Acquisition System experts and the water supply utility of Adama (AWSSE) to get their professional opinion based on their experience. Based on the findings the research paper develops best practices for successful implementation of supervisory control and data acquisition system for water supply projects of Ethiopia. The case study mainly intended to address the application of supervisory control and data acquisition system and its contribution on resource management for Adama town water supply project.

3.3 Study Variables

The study variables used in this research are performance indicators, sustainability and efficiency related resource management techniques, maintenance related resource management techniques, constraints, challenges and application of automated system, water saving technologies, preventive measures of maintenance.

3.4 Target Population and Sampling method

The populations used in this research were experienced personnel's actively participating on water supply construction project of Adama town (AWSSE), engineers from Contractor and consulting firms including Supervisory Control and Data Acquisition experts.

3.4.1 Sampling Technique

The purposive sampling technique was used to achieve all objectives and answer research questions. The questionnaires were distributed to contractors, consultants and clients at their offices and respective sites. The research population was drawn from four sectors which are participating in water supply construction projects namely clients (AWSSE), contractors, and consulting firms and finally Supervisory Control and Data Acquisition (SCADA) experts. As much as possible attempts have been made so that the samples drawn from the population are representatives. Professionals include those reputed experts engaged in the construction industry and were involved in water supply construction projects in the near past and are currently working on those firms.

3.4.2 Sampling size distributions

Sampling is a process of selecting representative units of the population for the study in research investigation. A sample is a small portion of a population selected for observation & analysis. Statistical equations were used to calculate the sample size for contractors and consultants, clients. Equation 3.1 was used to determine the sample size of the unlimited population.

$SS = ((Z^2*P*(1-P))/C^2$ developed by William G. Cochran…………………. [Eq. 3.1]

Where: SS= Sample Size

Z = Z value (e.g. 1.96 for 95% confidence level)

P= Percentage picking a choice as a decimal (0.5 used for sample size needed)

C = Margin of Error (9%)

$SS = ((Z^2*P*(1-P))/C^2$

$SS= ((1.96^2*0.5*(1-0.5))/0.09^2$

$SS = 118.57 \approx 119$

Correction for Finite Population

SS new = SS/(1+((SS-1)/POP)) developed by William G. Cochran ………. [Eq. 3.2]

Where POP is the population from the client, Contractors and Consultants which are involved only in water supply projects with experience of automated controlling system. The total number of sample size from each target population is summarized in table below as per the equation 3.1 & 3.2.

Table 1 Sample size distributions

No.	Target population	POP	SS new
1	Professionals on Adama water supply utility	15	15
2	Engineers from the Consultant	10	10
3	Engineers from the Contractor	10	10
4	SCADA experts (Electro-Mechanical Engineers)	3	3
Total			38

Source. Field survey data, 2024

The respondents included in the survey comprised of a total of 38 professionals: 15 from Client (AWSSE), 10 from contractors, 10 from consulting offices and 3 SCADA experts those who are currently involved on water supply project of Adama town. The numbers were determined based on the equation and by considering the experience of the respondents on the subject matter, time available for conducting the research work as well as reliability of the respondents.

3.5 Source of Data

To achieve the intended objective and to answer the research questions of the study, different sources of data were used. As a primary data questionnaire and site observation sources were used. To collect secondary data literatures, archival documents were used. To assess performance and water resource management techniques of current water supply projects from reference of key performance indicators, to evaluate challenges, constraints and application of SCADA system for water supply projects of Ethiopia, a desk study approach and questionnaire survey was carried out.

The review provided the basis to design the open and closed ended questionnaires which was distributed to professionals involved in the water supply programs. The developed questionnaires were to address the research objectives having three main parts in order of sequence; the first set is about general profile and background information of the respondent, their experience in water supply project. The second set of questions was to assess performances of current water supply projects. That is to rate the existing major gaps on techniques of resource management applied by the water supply programs based on listed key performance indicators. The third set had two parts addressing water resource management techniques and challenges, constraints and application of SCADA system for Ethiopian water supply projects by allowing the respondents to express their opinion with the space provided on how to apply SCADA system and develop strategic benchmarks for successful implementation the automated system for water supply projects of Ethiopia. For the questionnaire survey the respondents were selected from the employer organization (AWSSE), contractors, consultants and construction professionals who have been involved in the water supply sector. The questionnaire which consists of both open and closed ended questions was distributed among these professionals.

3.6 Research Measurement

To indicate the status and performance current water supply projects based on performance indicators and to rate management techniques of the projects, the survey respondents asked to take an appropriating rating on the scale against each resource management techniques implemented by the utilities that reflected their opinion on the satisfaction level. Using Likert type Scale the respondent was, asked to various degrees of opinion, and attitude a response to each item of the management techniques and their performance in terms of five degrees. The numbers assigned to the agreement or degree of implemented techniques (1, 2, 3, 4, and 5) does not indicate that the interval scales are equal, nor do they indicate absolute quantities. They are merely numerical labels. Based on this scale, see table 2:

Table 2 Likert scale

scale	5	4	3	2	1
Assigned scale	Excellent	Good	Average	Below Average	Poor

Source, Field survey data, 2024

3.7 Data collection procedure

The study relied on both primary and secondary sources of data. This study used a questioner and site observation for a data collection method. The primary data was collected from respondents by Likert scale type, open and closed ended questionnaires. The secondary sources of data were obtained from literatures, archival documents. The research had a descriptive and qualitative approach to achieve the objectives.

3.7.1 Questionnaire

The first objective which is to assess the current performances of existing Ethiopian water supply systems in case of Adama town with aspect of resource management techniques which is developed based on Key Performance Indicators (KPI) mainly focused on sustainability and maintenance related techniques, therefore it is achieved through literature reviews, questionnaire and interpretation of findings from those questionnaires through statistical approach. The second objective is to evaluate the challenges, necessity and constraints of SCADA system for Ethiopian water supply projects is achieved through open ended questionnaire type which is distributed to the target population including experts on water supply utility of Adama town, Also SCADA experts.

3.7.2 Site observation on automated system

Through check list, besides to investigate the nature of the SCADA system review on literatures and journals are used to collect data. Same as that of first objective qualitative approach is used to summarize the findings through thematic analysis. Based on major findings from the first two objectives a strategic approach is developed for successful implementation of Supervisory Control and Data Acquisition system for Ethiopian water supply projects which covers the third objective. The factors and key drivers are discussed on qualitative aspect based on summarized findings of Questionnaires and site observations.

Finally, the research had a case study on the application of the automated system based on the Adama town water supply and sanitation improvement project (AWSSIP) to illustrate on the functionality, resource management approaches of the system based on actual implementation from reference of the water supply utility of Adama town. To achieve the last objective the Adama town water supply and sanitation improvement project references are adopted including check lists on site observation in addition to photographs.

3.8 Data Presentation and Analysis

The results of the closed ended questionnaires were analyzed using statistical techniques and the results used to form the basis for recommendations as well as areas for further research. The methods of analysis used software's such as SPSS and Microsoft Excel data in a descriptive and statistical method including mean, frequencies and percentages. Finally, data is processed and presented in a graphical and descriptive ways. The statistical technique is a method of analysis which provides a general overview of results. Frequency distribution, which shows the frequency of observation of each response to each variable under investigation, is used to analyze the result of some questions.

The results of open-ended questionnaires are analyzed on thematic approach based on their categories. The thematic approach had its own contribution on developing systematic and formalized document as per the content of each response as per the research objective.

3.9 Data Reliability

Reliability is the overall internal consistency measure. The acceptance value for alpha if it equals to 0.70 or higher. In this research the logical process of constructing knowledge through brain storming is essential in providing concrete validity (Weston, et al., 2001). The reliability test was conducted using Cronbach's alpha coefficient of internal consistency and reliability test was used. As a result, the survey presents Fifteen (15) factors generated for factors for assessing the performance of current water supply projects from reference of key performance indicators.

Cronbach's alpha is computed using equation 3.1

$$\alpha = K/K-1\ [1- \Sigma S2y/S2x]$$ ………………………………. Equation.3.1

Where: -

- α = Cronbach's coefficient
- K= Number of items
- ΣS_2y = sum of item variance
- S_2x = Variance of total score

3.9.1 Interpretation

Interpreting ALPHA for Likert scale question Cronbach's alpha

Table 3 Cronbach's alpha interpretation

Cronbach's alpha(α)	Internal consistency
0.9 and above	Excellent
0.8 – 0.89	Good
0.7 – 0.79	Acceptable
0.6 – 0.69	Questionable
0.5 – 0.59	Poor

The results as presented in table 4 shows a coefficient of 0.89, implying that the data are reliable and internally consistent and therefore accepted as depicted in table 3.

Table 4 Cronbach's alpha computation

Variables	Description	Values	Internal consistency
K	Number of items	15	Good
ΣS2y	Sum of the item variance	21.4	
S2x	Variance of total score	126.37	
α	Cronbach's alpha	0.89	

Source, Cronbach's alpha computation based on field survey data, 2024

CHAPTER FOUR RESULT AND DISCUSSION

4.1 Introduction

This chapter provides explanations for data collection such as distribution of the questionnaire, collection of responses and subsequent analysis of the data acquired through the responses from professionals who are working for the client, consultants and contractors, SCADA experts those who are involved on water supply sector of Ethiopia. The principal purpose is to assess the performance of water supply projects with aspect of resource management especially for Adama town, investigating constraints and application of SCADA system on water supply sector and to find out the way how to enhance the application of SCADA system for future water supply projects.

A questionnaire survey has been conducted to gather the required information from professionals, who have been involved in water supply sector of Ethiopia working on behalf of a client, consultant, contractor and experts on SCADA; towards answering the basic research question. A total of 38 questionnaires were sent to the selected sample of respondents which comprise of 15 from the client (AWSSE), 10 from consultants, 10 from contractors and 3 SCADA experts. A sample of the questionnaires is attached in Appendices.

4.2 Questionnaire Response Rate

The study targeted a sample of 38 respondents from the client, contractors, consultants and SCADA experts and out of which 34 filled out and returned the questionnaires giving a response rate of 89.47%.

Table 5 questionnaire response rate

Firms of experts	Total Questionnaire Distributed	Total Questionnaire Returned	Response rate (%age)
Client	15	12	80
Consultant	10	10	100
Contractor	10	9	90
SCADA expert	3	3	100
Total	38	34	89.47

Source. Questionnaire response rate based on field survey data, 2024

4.3 Respondents Academic Background

The purpose of section one was to know the educational and professional capability of respondents to undertake the work. The questionnaire was to be completed by respondents who were involved in water supply projects, utilities, preparation of design document and supervision of the site work.

The survey result shows that 32.35 percent of the respondents have MSc. Educational qualification and the rest 67.65 percent BSc. Degree Educational qualification as shown in the figure below. The percentage distribution of the various professionals indicates that most of the questionnaires were completed directly by professionals involved in the water supply and related industry. The survey also shows that it was well represented by better qualified professionals in the water supply sector and these groups of respondents are expected to have plenty of knowledge on the subject matter.

4.3.1 Experience of Respondents and Their Company

Out of the 12 respondents on the client side 16.67% of the respondents had less than 5 years of working experience, 8.33% had 6 to 10 years of experience, 25% had 11 to 15 years of experience and 50% had more than 15 years of experience. Out of the 9 respondents by the consultant 11.11% of the respondents had less 5 years of working experience, 27.27% had 6 to 10 years of experience, 11.11% had 11 to 15 years of experience and 44.44% had more than15 years of experience.

Out of the 10 respondents by the contractor 30% of the respondents had less 5 years of working experience, 10% had 6 to 10 years of experience, 40% had 11 to 15 years of experience and 20% had more than 15 years of experience. Out of 3 respondents from SCADA experts 100% had more than 15 years of experience.

Furthermore, 17.64% of the survey participant companies have an experience of less than 5 years, 14.70% of the respondents have an experience of 6 to 10 years, 23.52% had an experience of 11 to 15 years of experience and 44.11% have an experience of more than 15 years of quite a reasonable working experience in the water supply sector.

4.4 Analysis and Discussion of Results

4.4.1 Assessment on resource management techniques of current water supply project of Adama town

Statistical analysis is conducted to summarize the findings from questionnaire response distributed to target population. The response rate is discussed on the previous section with total of 89.47%. The resource management techniques used to assess the performance of water supply project of Adama town is obtained from reference of International Water Association manual of Key Performance Indicators (KPI) for water supply services (Vilanova, Magalhães Filho, Balestieri, & reviews, 2015). The results from the questionnaire are presented on the table below with statistical approach. The respondents fill the questionnaire with Likert scale based on their experience.

Table 6 results on assessment of resource management techniques

Description	Resource management techniques	Mean	Remark
Sustainability and efficiency related techniques	Implementing measures to reduce water wastage through public awareness campaigns	2.29	needs feasible improvement
	Adoption of water-saving technologies.	2.5	needs feasible improvement
	Managing water demand through measures such as metering, pricing mechanisms (e.g., tiered pricing), and incentives for water-efficient practices.	3.58	Better implementation
	Investing in the construction, maintenance, and improvement of water to enhance water storage, distribution, and treatment capacity.	2.29	needs feasible improvement
	Implementing measures to protect and improve water quality through pollution prevention, source water protection, and water quality monitoring programs	2.32	needs feasible improvement
	Compare the performance of the water supply project against established benchmarks or industry standards	3.71	Better implementation
	Collect and analyze data related to water supply operations, including water production, distribution, consumption, losses,	2.00	needs feasible improvement

	energy usage, and costs		
	Conduct systematic assessments of water supply systems to identify sources of water losses, including leaks, unauthorized connections, and meter inaccuracies	2.32	needs feasible improvement
	Use hydraulic modeling software to simulate the behavior of water supply systems under different operating conditions	2.08	needs feasible improvement
Maintenance related techniques	Develop and implement a preventive maintenance schedule for all critical components of the water supply system, including pumps, pipelines, valves, treatment plants, and storage facilities	2.21	needs feasible improvement
	Utilize condition monitoring techniques such as visual inspections, non-destructive testing, and sensor-based monitoring to assess the condition of infrastructure assets	2.38	needs feasible improvement
	Develop comprehensive maintenance plans and budgets that outline the scope of maintenance activities, resource requirements, and schedules	3.29	Better implementation
	Establish protocols and procedures for responding to emergencies such as pipeline bursts, equipment failures, and natural disasters	2.06	needs feasible improvement
	Provide training and capacity-building programs for maintenance staff to enhance their technical skills, knowledge of equipment, and safety awareness	2.41	needs feasible improvement
	Maintain comprehensive records of maintenance activities, including inspection reports, work orders, equipment manuals, and maintenance logs	3.56	Better implementation

Source. Results on assessment of resource management techniques field survey data, 2024

Note N = 15 (number of resource management techniques), Weighted average = 2.6

Based on the analysis which is gathered from the responses of questionnaires distributed to the samples it can be concluded that most of the techniques are not actively implemented from the water supply utilities on their current resource management and maintenance related techniques. For those techniques with score of less than weighted average labeled as “needs feasible improvement” from water supply utilities whereas those scored value of greater than weighted average labeled as “Better implementation” on current performances.

As it is illustrated on table above the following techniques needs feasible improvement from the stake holders including sustainability and efficiency related techniques namely implementing measures to reduce water wastage through public awareness campaigns, adoption of water-saving technologies, investing in the construction, maintenance, and improvement of water to enhance water storage, distribution, and treatment capacity, collect and analyze data related to water supply operations, including water production, distribution, consumption, losses, energy usage, and costs, conduct systematic assessments of water supply systems to identify sources of water losses, including leaks, unauthorized connections, and meter inaccuracies, use hydraulic modeling software to simulate the behavior of water supply systems under different operating conditions.

Among those techniques which deals on assessing implementation and application of computer-based trends most of the respondents agree that there is a gap on defining and addressing proper solution for the drawbacks and limitation of resource management techniques, as an example some of them are presented by chart as follows (Results on assessment of resource management techniques field survey data, SPSS, 2024)

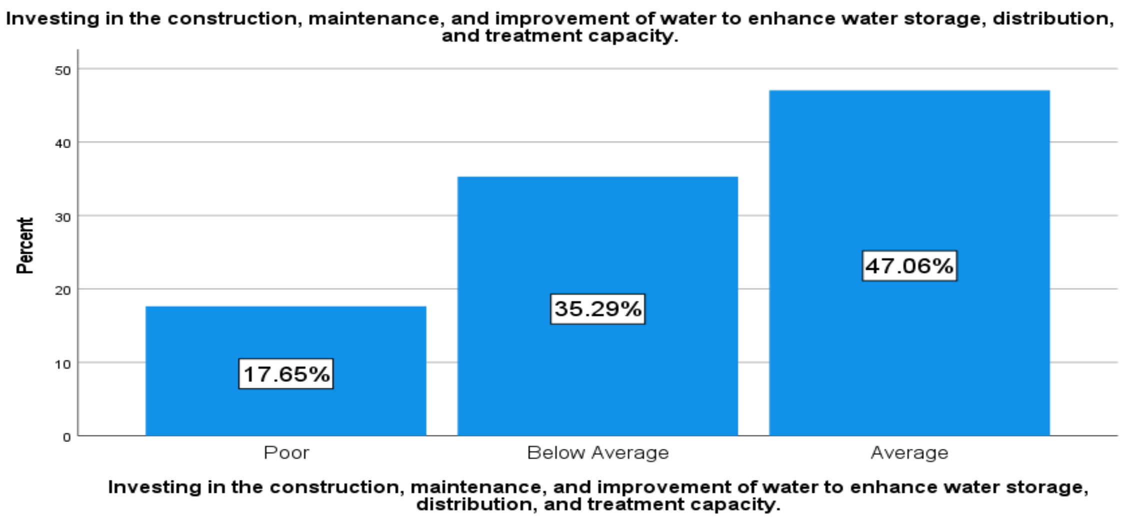

Figure 4 Investing in the construction, maintenance, and improvement of water storage, distribution and treatment capacity

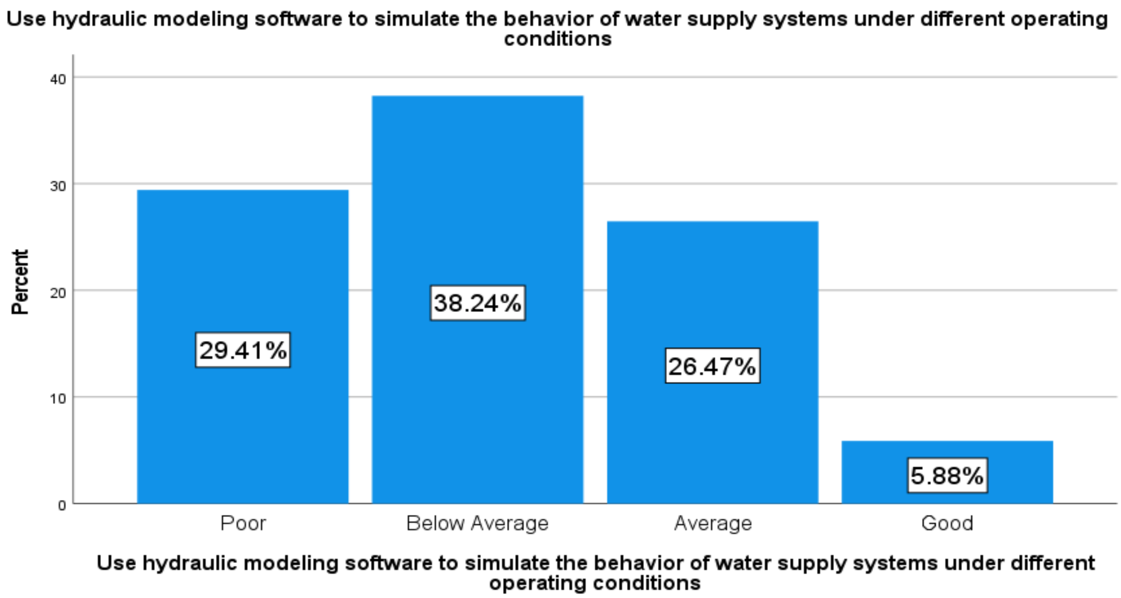

Figure 5 Use hydraulic modeling software to simulate behavior of water supply systems under different operating conditions

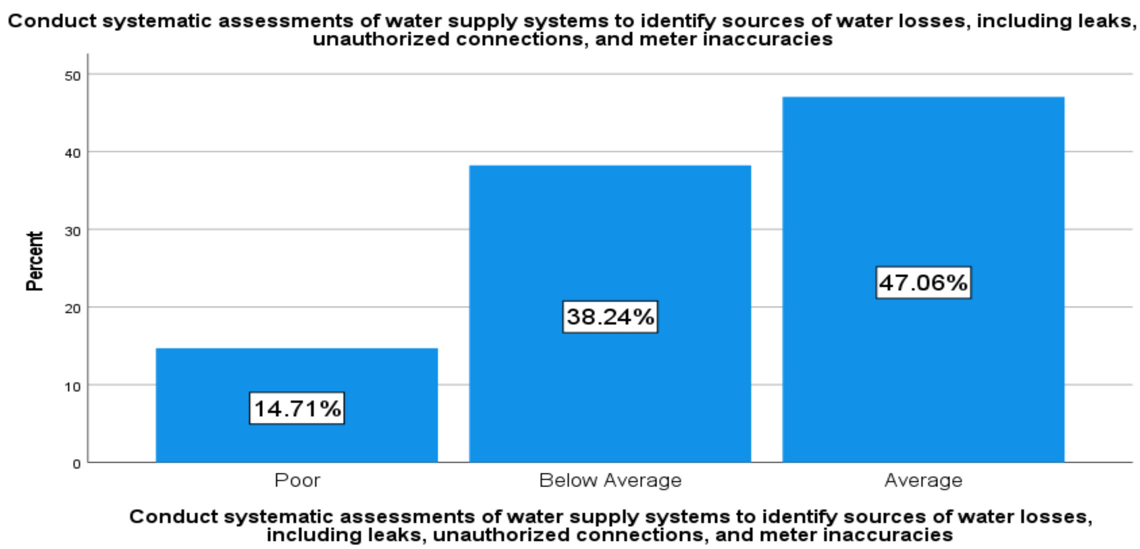

Figure 6 conduct systematic assessment of water supply systems to identify sources of water losses, including leaks, unauthorized connection and meter inaccuracies

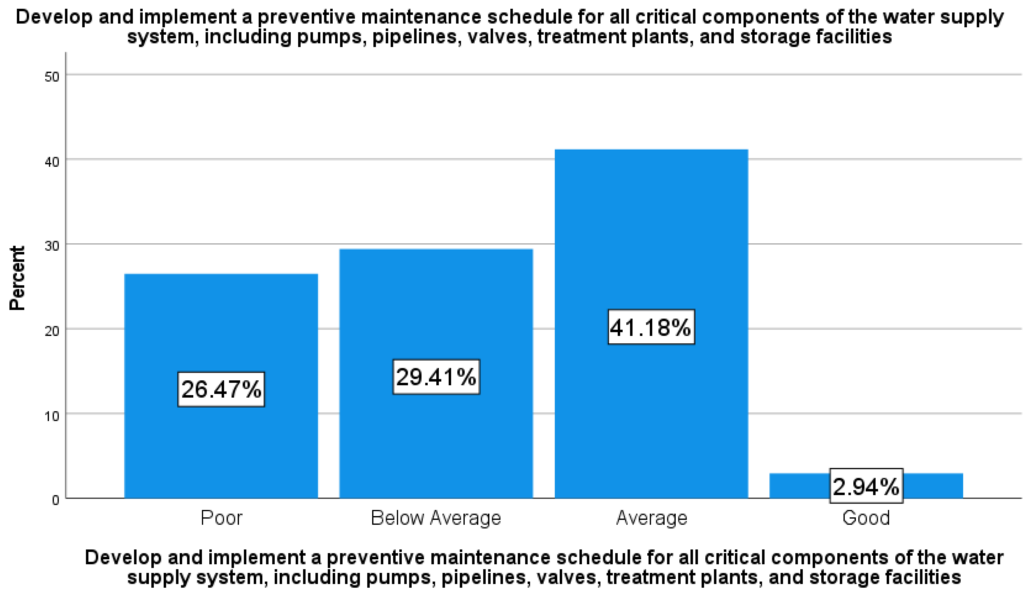

Figure 7 develop and implement a preventive maintenance schedule for all critical components of the water supply system, including pumps, pipelines, valves, treatment plants, and storage facilities

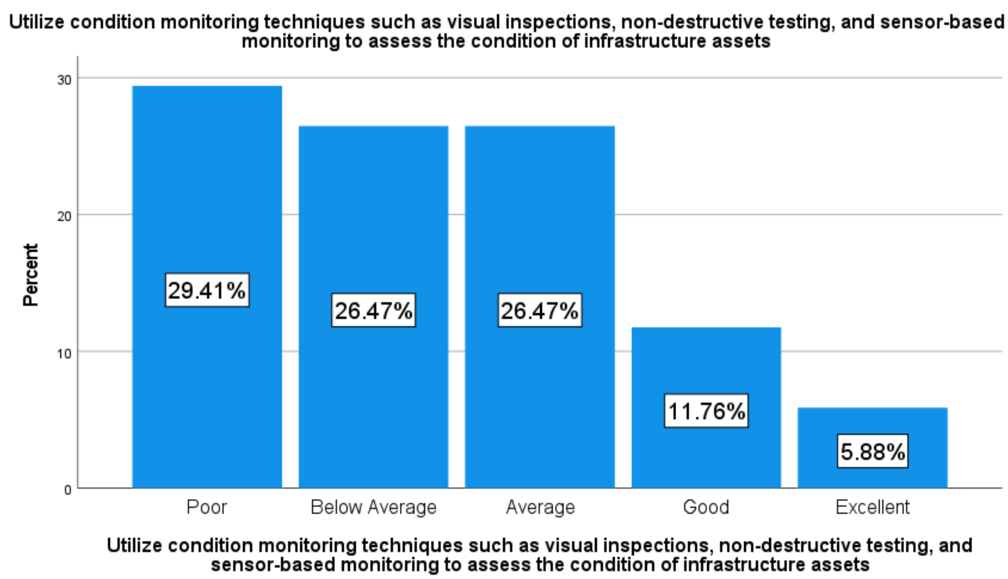

Figure 8 utilize condition monitoring techniques such as visual inspections; non-destructive testing and sensor-based monitoring to assess the condition of infrastructure assets

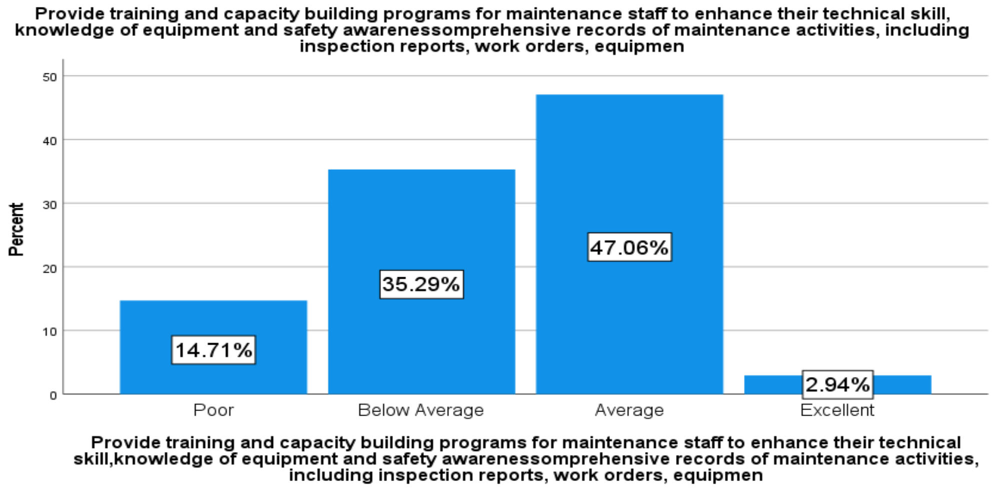

Figure 9 provide training and capacity building programs for maintenance staff to enhance their technical skill, knowledge of equipment and safety awareness including inspection reports

4.4.2 Summary on assessment of resource management techniques of current water supply project of Adama town

In general, most of the respondents agreed on that existing water resource management techniques are on poor performance or need improvement for sustainable and reliable water supply system due to high demand from the population. Also, they have no doubt on necessity of automated system (SCADA) for proper resource management and achieving their initial goal of the project.

Among those questionnaires distributed to the respondent's technology-based resource management techniques observed that they are under poor performance for existing water supply system implemented by utilities. A better performance is observed from the responses on sustainability and efficiency related techniques. Besides most of the respondents agreed on the requirement of technology-based management techniques due to globalization and high demand from beneficiaries, to achieve their objectives projects should focus on consistent water supply throughout their life cycle of service.

In addition to that maintenance related techniques also require better improvement on the trends and systems those exist on the water supply sectors of AWSSE, namely those techniques are develop and implement a preventive maintenance schedule for all critical components of the water supply system, including pumps, pipelines, valves, treatment plants, and storage facilities, utilize condition monitoring techniques such as visual inspections, non-destructive testing, and sensor-based monitoring to assess the condition of infrastructure assets, establish protocols and procedures for responding to emergencies such as pipeline bursts, equipment failures, and natural disasters, provide training and capacity-building programs for maintenance staff to enhance their technical skills, knowledge of equipment, and safety awareness.

4.5 Evaluate constraints, challenges and application of SCADA system for water supply projects

The open-ended questionnaires for achieving the second objective which is to evaluate constraints, challenges and application of Supervisory Control and Data Acquisition had been distributed to the target population and their response is analyzed through thematic analysis approach. The target population is drawn through purposive sampling technique based on the experience and knowledge of respondents. The target populations are experts on water supply projects those who had previous experience on the implementation SCADA. The purposive sampling technique address 34 experienced respondents based on their previous experience and educational background on the system.

4.5.1 Respondents Level of Understanding on SCADA system

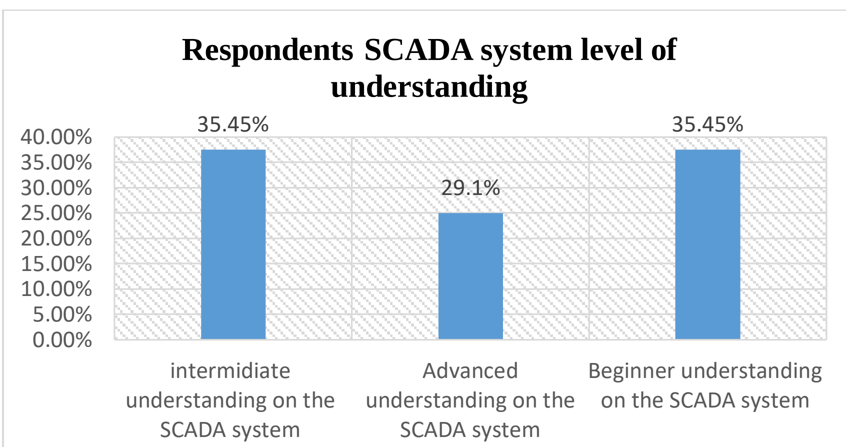

Figure 10 Respondents level of understanding on SCADA system

Source. Results on assessment of factors for evaluating challenges, constraints and necessity of SCADA system for water supply projects field survey data, 2024

From total of 34 respondents 12 of them (35.45%) had intermediate level of understanding, 10 of them (29.1%) had advanced level of understanding and the remaining 12 (35.45%) had beginner level of understanding on the SCADA system. The levels are adjusted based on their familiarity and experience on the automate system.

4.5.2 Respondents previous project's location on experiencing SCADA system

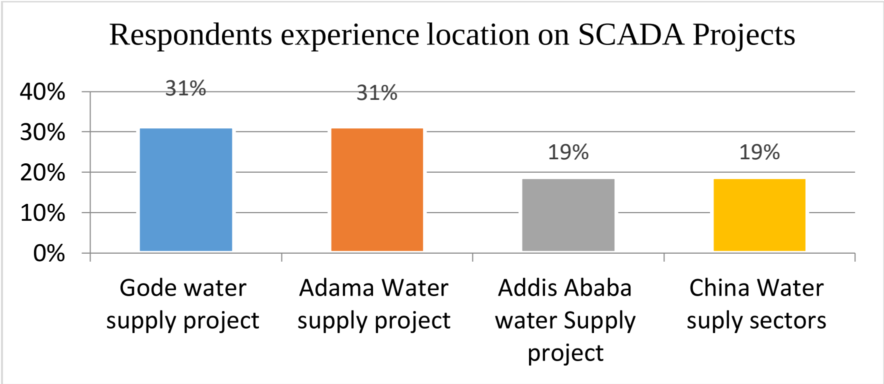

Figure 11 Respondents experience location on SCADA Projects

Source. Results on assessment of factors for evaluating challenges, constraints and necessity of SCADA system for water supply projects field survey data, 2024

The sample population is classified into 4 different firms through which they had developed their experience on the automated system namely Gode water supply project, Adama water supply project, Addis Ababa water supply project and foreign experiences (mainly on China) with the distribution of 31%, 31%, 19% and 19% respectively.

4.5.3 Respondents experience on SCADA system

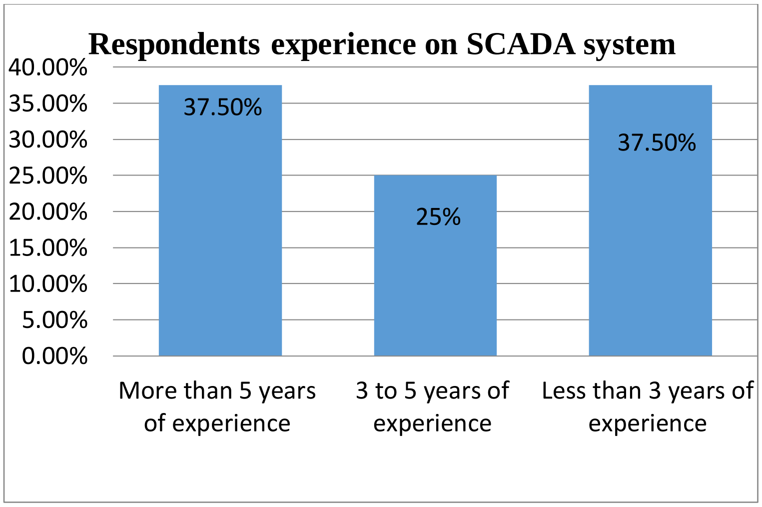

Figure 12 Respondents experience on SCADA system

Source. Results on assessment of factors for evaluating challenges, constraints and necessity of SCADA system for water supply projects field survey data, 2024

4.5.4 Analysis on evaluating factors challenges, constraints and necessity of SCADA system for water supply projects

The thematic analysis is used to distinguish responses of target population for developing brief analysis and discussion on the factors related to challenges, constraints and necessity of SCADA system with a scope of water supply projects. Responses from open ended questionnaires are finalized and summarized as shown in table below, they are coded and categorized as a form of transcripts as per their assigned code and theme for further analysis and interpretation.

Table 7 Thematic analysis for factors on challenges, constraints and necessity of SCADA system

S.no	Questionnaires distributed to the respondents	Response from target population/coded	Theme category
1	main challenges or limitations encounter with the current SCADA system	Absence of qualified man power to operate and carry out frequent maintenance	Challenges of SCADA system
		Lack of awareness on data management and quality	
		Limitation on financial resources	
		Economic and political factors	
2	Effect of cyber security concerns on use of SCADA systems in water supply management, measures taken to ensure the security and integrity of SCADA systems and data	The system is exposed to Internet of Things therefore it will be affected by cyber security issues.	Constraints of SCADA system
		Through denying access to the system	
		By adjusting authorization mechanisms only for allocated staffs	
		By upgrading the system gradually	

3	Challenges in finding qualified personnel with the required skillset to work with SCADA systems	Yes, it is the main challenge Updated knowledge is required to be in moderate status	Challenges of SCADA system & best practices for future implementation
4	User-friendly level of the current interface of your SCADA system	Good and easy to understand Not complex to control but should develop interfaces to be friendly adjusted	Challenges of SCADA system
5	Limitations in terms of data storage, retrieval, or processing capabilities of SCADA systems	Not observed regarding storage limitations Historical data is recorded and stored for futuristic measures and further investigations	Constraints of SCADA system
6	Budget constraints or resource limitations that need to be considered	The SCADA system implementation requires its own budget as one part of water supply project Yes, the government should give priority to address the budget constraint.	Constraints of SCADA system
7	SCADA systems preferable for water supply management compared to traditional methods	Real time monitory and super vision It saves money and time It provides precise management technique Enhance preventive measures	Necessity of SCADA system
8	Proactive decision-making and response to operational challenges through SCADA systems	The system can detect pipe bursts and leakage in advance Through alarm system the operators	Necessity of SCADA system

		can identify exact location of maintenance requiring sites	
		Supervise the performance of each pump and all facilities	
9	Data analysis capability of SCADA systems support informed decision-making in water supply management	Historical record guides the operators to assess the occurrence of those problems periodically/ routine	Necessity of SCADA system
10	SCADA systems evolving to meet the future needs and challenges of water supply management	All water supply projects should incorporate SCADA system as part of their project from initiation phase.	Necessity of SCADA system/ Best practices for future implementation of the system
		Political and social factors should be addressed based on the status of water supply projects.	
11	role of government to play in promoting the adoption of SCADA systems in water supply projects	Securing working environments and budget constraints should be considered	Best practices for future implementation of the system
		Training for operators should be a routine process for updating the trend	

Source. Results on assessment of factors for evaluating challenges, constraints and necessity of SCADA system for water supply projects field survey data, 2024

4.5.5 Discussion on factors for evaluating challenges, constraints and necessity of SCADA system for water supply projects

The response from target population on the major factors to distinguish challenges, constraints and necessity of SCADA system on water supply projects is summarized on the thematic analysis as it is shown on the table above. Based on the analysis on the factors related to challenges, constraints and necessity of SCADA system for water supply projects the discussion is illustrated with reference to several literatures besides detailed responses from the target population. Each factor for challenges, constraints and necessity of SCADA system for water supply projects are discussed below.

4.5.5.1 Necessity of SCADA system implementation for water supply projects

SCADA systems provide control and data analysis functions that help to enhance the efficiency and performance of processes. SCADA systems are made up of both hardware and software. They are composed of sensors and monitoring equipment, Human Machine Interfaces (HMI), servers, and other components. These highly efficient systems provide a way to optimize water supply processes. SCADA systems have many benefits, like increased efficiency, data analysis, and more. With a SCADA system, water supply offices can remotely control their processes and optimize their efficiency while lessening risk of human error. Based on the response from the SCADA experts and from those who had experience with application of the system the following summary is concluded on necessity of the system.

SCADA systems make identifying and resolving problems a much smoother process for water supply projects. This decreases downtime and increases productivity as a result. SCADA systems can also be automated to adjust based on how they interpret data input. These systems reduce the risk of human error, which can effectively streamline services from water supply utilities. Also enhanced monitoring and control is obtained from the implementation of SCADA systems, which lessens the need for hands-on intervention. These systems provide construction industries the ability to store large quantities of data which is essential for process optimization. It collects real-time data through its sensors, which provide information that can help improve operation efficiency, avoid problems, and identify data trends. Additionally, this data can be presented in customizable visuals to help users easily read the data trends and information. By using their data interpretations, SCADA systems can provide early warnings of safety hazards, accidents, or equipment damage. These systems can be programmed to ensure the processes stay in line with water supply service standards. In cases of safety hazards, SCADA systems can even be programmed to automatically shut down the system or process to help prevent any damage to equipment or workers.

Benefits of automation through SCADA applications are price return of invested funds in the short term, significantly lower maintenance costs, smaller interventions and costs in revitalizing or reconstructing equipment and installations in water supply systems, simple expansion and replacement of system elements, higher safety because workers withdraw from potentially dangerous working conditions. The monitoring and command system enforces the beneficiary with a powerful working instrument which allows, Growth of productivity in functioning of the pumping stations, pumps command and energy consumptions reduction, Performance levels and water quality improvements, Continuous functioning in supplying water to the population, Permanent real-time monitoring the technological parameters state and the energy consumptions, User assistance in elaborating technical analysis and post analysis, offering information to the decision factors for taking optimum decisions, assuring informatics flows needed for management (Rohmingtluanga, Datta, & Sinha, 2021).

4.5.5.2 Challenges of SCADA System implementation for water supply projects

A. Integration with existing infrastructure

Integrating a new SCADA system with existing infrastructure and systems can be complex. Water supply projects often involve older equipment and disparate systems that may not be easily compatible with modern SCADA technology. This had the following effects increased risk of data inconsistencies, potential for system downtime during integration, higher costs and extended project timelines.

B. Data management and quality

Ensuring data accuracy and consistency is crucial for SCADA systems. Poor data quality can lead to incorrect decisions and unreliable system performance which includes inaccurate monitoring and control, misleading performance metrics, compromised decision-making processes. Those challenges can be addressed through implement robust data validation and cleansing procedures, regularly audit data sources and system inputs, train staff on best practices for data entry and management.

C. System scalability and future-proofing

Designing a SCADA system that can scale with future growth and technological advancements is essential. Inadequate scalability can limit system performance and flexibility which creates difficulty accommodating increased data loads or expanded operations, higher costs for system upgrades or replacements and reduced long-term value and utility. To prevent those challenges, it is recommended to choose a SCADA system with modular architecture and scalability options, plan for future upgrades and integration needs from the outset and stay informed about emerging technologies and industry trends.

D. Limited Financial Resources

Developing countries often face significant financial constraints that affect the ability to invest in advanced SCADA systems. Budget limitations can impact every stage of the project, from planning to implementation and maintenance. Limited budget may result in cutting corners, leading to a less capable system with fewer features. Ongoing costs for maintenance, upgrades, and staffing may strain limited resources. Financial issues can delay project timelines and hinder timely delivery. Therefore, it is preferable to seek international aid, development grants, and funding from non-governmental organizations (NGOs) or development banks, prioritize essential features and functionalities; explore modular or scalable SCADA solutions and collaborate with private sector companies to share costs and responsibilities.

E. Reliability and Power Supply

Unreliable power supply and frequent outages are common issues in developing countries, affecting the reliability of SCADA systems. Power interruptions can lead to system failures and loss of data. Inconsistent power supply affects the continuity of water supply operations. Backup power solutions add to the overall project cost. Therefore, it is suggested to invest in uninterruptible power supplies (UPS) or generators to ensure continuous operation, incorporate redundancy and fault-tolerant features in the SCADA design to mitigate power issues, implement energy-efficient technologies to reduce power consumption.

F. Regulatory and Policy Challenges

Regulatory frameworks and policies related to SCADA systems and water management may be underdeveloped or inconsistent in developing countries. Lack of clear regulations can lead to difficulties in meeting legal and operational standards. Inconsistent policies can affect the implementation of standardized practices. Those challenges can be addressed through working with government bodies to develop and clarify regulations and standards, ensuring adherence to existing regulations and seek legal advice to navigate complex policy environments and collaborating with industry groups to establish and promote best practices and standards.

G. Local Political and Social Factors

Political instability, bureaucratic inefficiencies, and varying local priorities can impact the implementation and success of SCADA projects. Shifts in local priorities or political dynamics may lead to changes in project scope or objectives. Conflicts with local stakeholders can hinder project progress.

4.5.5.3 Constraints of SCADA System implementation for water supply projects

Supervisory Control and Data Acquisition (SCADA) systems offer increased efficiency and other benefits but also come with various drawbacks. The SCADA system is an essential tool that contributes to the management and optimization of an automatic or semi-automatic process. It is made of sensors, monitors, hardware and software, and other elements. Despite their many benefits, there can be some drawbacks and limitations based on the responses from open-ended questionnaires with SCADA experts and utility of Adama those who had experience on the system on their water supply sectors.

A. Complex systems require trained operators

SCADA systems can be complex and require skilled operators and analysts for maintenance. Operators will need training to effectively use the SCADA systems, and resolving issues within the system will require specialized training and knowledge. Starting from installation of the system on its initial phase up to productive period of system it requires highly trained operators to handle and act as per the information gathered from the system. Misunderstanding the interpreted results not acting accordingly had its own risk on the productivity of the implemented projects may lead to fail from single damages to interrupting entire project from achieving its goals.

B. Installation costs

Upfront installation costs of a SCADA system can be high, as utilities will be paying for the hardware, software, personnel, and any specialized training. Urban drinking water supply projects should take SCADA system as a part of the project to be included on their bill of quantities during bid time as well as when they prepare to commence actual construction.

C. Cyber Security Risks

SCADA systems are vulnerable to cyber-attacks if not secured properly using the correct cyber security measures. Cyber-attacks and data leaks could damage the systems and processes they control. Cyber-attacks on SCADA systems are a serious concern because these systems control critical infrastructure like water treatment plants, pipe line and industrial processes. The attacks had different forms such as software can be introduced into the SCADA system to disrupt operations, steal data, or cause physical damage, attackers may use phishing techniques to gain access to the system by tricking employees into revealing credentials or installing malicious software, overloading the system with traffic can make it unavailable for legitimate users, disrupting operations, intercepting and altering communication between the SCADA system and its components can lead to data manipulation and control issues and finally attackers may exploit known or unknown vulnerabilities in the SCADA software or hardware to gain unauthorized access.

In order to keep the system from any cyber-attacks the following preventive measures should be taken to assure the safety of the system, those are ensure that all SCADA software and hardware are regularly updated to address known vulnerabilities, separate the SCADA network from other networks to limit the spread of potential attacks, implement strong authentication and authorization mechanisms to control who can access the SCADA system, continuously monitor the system for unusual activity and maintain logs to aid in detection and response, finally develop and regularly update an incident response plan to quickly address and mitigate the impact of an attack.

D. Maintenance

SCADA systems will require regular maintenance to ensure that it is running efficiently. Maintenance tasks will include updating software, and hardware, and ensuring the correct security measures are in place. This specialized maintenance can be time-consuming and costly long term. In summary, SCADA systems are an essential part of the automation process and provide water supply industries with a centralized way to monitor and control their processes.

4.5.6 Summary on Evaluating constraints, challenges and application of SCADA system for water supply projects.

To assess the constraints and limitation of the SCADA system site visitation and open-ended questionnaires were conducted to get reliable data. Based on the response from experts and water supply utilities those who had experience on application of the system the following factors were illustrated on the discussion part in details, those are cost, skilled man power required, cyber-attacks, maintenance related issues were listed as constraints whereas sustainability, consistent supply, data recording quality, ease of access, preventive measure are listed as basic advantages of SCADA system.

The implementation of SCADA systems in water supply projects is essential for improving efficiency, reliability, and sustainability in developing countries. While the necessity for such systems is clear, addressing the accompanying challenges and constraints through targeted investments, capacity building, and robust policy frameworks will be critical for successful adoption and long-term benefits. A collaborative approach involving government, local communities, and international partners can enhance the effectiveness of SCADA systems, ultimately leading to better water management and service delivery. Developing countries often face significant challenges, including outdated infrastructure, a lack of technical expertise, and limited funding. Addressing these issues requires targeted investments and strategic planning to modernize existing systems and build the necessary capacity within local workforces.

4.5.7 SCADA System Vs Existing resource management system of AWSSE

The currently serving water distribution pipe network system of Adama town is inaugurated in November 2002. However, the town population is growing rapidly with expansion of the town to pre-urban areas. Due to burden on the water distribution system now it is facing some problems associated with demand-supply misbalance. Frequent pipe bursts and excessive leakages in the network due to the existence of old pipe lines have also decreasing the coverage capacity of the service. Recent studies have shown that unaccounted for water has been increasing from 15.44% to 45.46% of water production. Furthermore, there is no alternative water source for emergency case; if supply fails from Awash River; water supply situation is becoming worst in the town due to lack of emergency water supply (OWWDSE, 2011).

The major difference between PLC and SCADA is that PLC is hardware whereas SCADA is Software. In industry, a PLC is a microcontroller device used to control and automate a machine. PLCs are primarily intended to replace hardwired relay logic controllers to improve productivity processes. In SCADA system the software that integrates with multiple PLCs and RTU for controlling and monitoring purposes. PLC is a centralized controller is used for automation tasks.

Modern SCADA systems allow water facility operators to efficiently oversee wastewater treatment and manage equipment. SCADA solutions provide actionable data, which result in huge cost savings. System operators can mitigate equipment failures or downtime and manage hundreds of assets without going to each asset location. Many SCADA systems can provide diagnostic information. Once the problem is identified, system operators can plan to remedy the problem. The current system of resource management technique which is implanted on Adama town water utility had its own drawbacks and limitation when it is compared with the automated (SCADA) system. Comparison of SCADA system versus the existing system based on standardized criteria with reference to data collected from questionnaire and interview with all concerned parties in the table below.

Table 8 Comparison of SCADA system versus the existing water supply system of Adama Town

S.no	Factor description	Existing system (PLC)	SCADA system
1	Preventive measure	Poor performance	Good performance
2	Investment Cost	Low	High
3	Skilled man power	Moderate	Highly skilled
4	Consistency and reliability	Less consistency	High consistency and reliable
5	Cyber security attack	Not exposed	Moderately exposed
6	Maintenance requirement	immediate	Fixed term/regular
7	Complexity of the system	Easy	Complex
8	Resource management	Poor	Advanced
9	Technology based	less	High
10	Data storage/record	Manual	Automated
11	Investment cost recovery	Long period	Short period

Source: Results on assessment of factors for evaluating challenges, constraints and necessity of SCADA system for water supply projects field survey data, 2024

4.5.8 How Does SCADA Improve Current Water System Operations?

Enhancing SCADA system to the construction industry especially for water supply sector had the following contribution including by improving water operations and processes, reducing costs, reducing downtime, integrating reports, and providing remote control from anywhere at any time. With SCADA solutions, operators are empowered to track production and deploy preventative equipment maintenance. Reduce costs in which SCADA systems provide data in real time, i.e. pump run times, power usage, power failures, flow data, etc. With these essential data operators can optimize operational efficiency and reduce overhead costs, on the other hand the system will improve processes such as unexpected downtime adversely affects an operator's bottom line therefor by enhancing SCADA system operators can identify inefficient processes and any equipment problems prior to a massive impact to the bottom line.

The other contribution of SCADA system application is often equipping operators with diagnostic tools they can use to repair equipment failures quickly. Modern SCADA solutions have alarm management built-in. Diagnostic tools and alarm management work together to support operators in their efforts to reduce downtime. HMI screens, or user screens, provide operators with a history of trend data. Operators can make quick decisions based on contextual and historical data. Also, enhancing SCADA system will give the utilities to remote control anywhere and anytime for their running project. Besides cloud-based SCADA systems provide operational visibility and control. Modern SCADA systems with mobile applications give managers or stake holder's remote access to the status of assets on their active and ongoing status. Additionally, they had the ability to set controls without requiring an on-site visit.

Finally enhancing SCADA system will give integrated reports of the system which is running based on the signals transmitted from each site to controlling stations, those canned reports or custom reports help operators streamline their reporting responsibilities. User-friendly HMI allows users to display, download, and schedule the distribution of their reports.

4.6 Develop best practices for successful implementation of the SCADA System for Ethiopian water supply projects on resource management aspect

On previous sections on analysis and discussion parts for assessment of current performances of water supply projects of Ethiopia especially on Adama town for resource management techniques and evaluation of challenges, constraints and necessity of SCADA system for water supply projects were achieved through questionnaires and site visit on implementation of automated system those who had experienced on their water supply utilities (Objective 1 and Objective 2). The third objective which is to develop a frame work for successful implementation of SCADA system for Ethiopian water supply projects on resource management aspect is achieved through formalized and summarized report from the previously achieved objectives and experience of respondents on the automation system is used as a reference to develop best practices and frame work for water supply projects of Ethiopia especially on resource management aspect.

As a developing country to entertain demand and supply of water for the community it is recommended to address the following main best practices and frame works for successful implementation of SCADA system based on suggestion and experience of experts and water supply utilities in addition to literature review.

4.6.1 Needs assessment and feasibility study

Conduct a comprehensive study of the existing water supply system, identifying critical control points such as water treatment plants, pump stations, and areas with frequent failures or high-water loss. The assessment will inform the design of the SCADA system, ensuring that it addresses the most pressing issues (e.g., water quality monitoring, leak detection, pump automation). Involve local authorities, community representatives, and water utility personnel to ensure that the system meets the actual needs and builds local support. Feasibility study ensures that the SCADA system is designed to address a specific and high-priority issue which involves key stakeholders, which can improve project support and sustainability.

4.6.2 Modular and scalable design

Implement the system in phases, beginning with the most critical parts. Use open standards base the design on standard communication protocols to allow future upgrades and prevent vendor lock-in. Ensure the infrastructure can scale to handle more sensors, data, and automation as the system expands. Modular and scalable design reduces initial costs and risks besides it supports long-term growth without requiring complete overhauls.

4.6.3 Reliable communication infrastructure

Evaluate what communication methods (cellular, radio, satellite) are available and reliable in the area. Choose the right method cellular often cheaper but unreliable in rural or remote areas. Radio (UHF/VHF) good for remote locations with line-of-sight between communication points. Satellite Reliable but more expensive, often used as a last resort. Reliable communication infrastructure ensures reliable data transmission even in areas with poor communication infrastructure and increases system resilience, reducing the risk of data loss or system outages.

4.6.4 Robust and low-maintenance hardware

Rugged equipment chooses hardware that is durable and can withstand harsh environmental conditions like heat, dust, or humidity. Outdoor-rated enclosures protect sensitive components. Energy efficiency use components that are energy-efficient, especially in areas prone to power outages. Consider using solar power and backup batteries. Remote monitoring includes select devices that support remote monitoring and diagnostics, reducing the need for frequent physical maintenance. Low maintenance hardware minimizes downtime and maintenance costs besides it reduces the impact of environmental conditions on system performance.

4.6.5 Cyber security and data protection

Implement basic protections like encryption for data transmission, firewalls, and secure passwords for access points. Even in developing areas, cyber threats can pose risks. Segmentation keeps the SCADA system isolated from the public internet to prevent unauthorized access. If remote access is required, use secure methods like VPNs. Regular backups set up automatic data backups, both locally and in the cloud, to prevent data loss in case of cyber-attacks or system failures. It protects critical water infrastructure from cyber threats and ensures continuity of service and data integrity.

4.6.6 Capacity building and training

Local trainings and train local engineers and technicians to manage and maintain the SCADA system. Make sure the training covers both operational and troubleshooting aspects. Partnerships Collaborate with local universities or technical institutes to develop courses and internships focused on SCADA systems, ensuring long-term technical capacity. Documentation provides clear and comprehensive system documentation, including manuals and troubleshooting guides in local languages. Capacity builds local expertise, reducing dependence on external specialists and ensures the long-term sustainability of the SCADA system.

4.6.7 Equipment/Vendor selection and support

Work with vendors that have a local or regional presence to ensure timely support and access to spare parts. Service-Level Agreements (SLAs) Establish detailed SLAs with vendors to ensure timely maintenance, updates, and troubleshooting. Include clear response times for system issues. Vendor selection and supports ensures quicker response times for repairs and maintenance. It reduces the risk of extended downtime due to unavailability of parts or technical support.

4.6.8 Pilot projects and phased implementation

Implement the SCADA system in a small, controlled section of the water network (e.g., a single treatment plant or pump station). Use this as a test bed for hardware, communication, and data management. Adjust based on feedback use the pilot project to gather feedback, troubleshoot issues, and refine the system before scaling it up to the entire water network. Pilot projects and phased implementation reduces risks by testing the system on a smaller scale first and finally it provides valuable insights for improving system design before full deployment.

4.6.9 Data analytics and continuous improvement

Use Data for decision-making and leverage data from the SCADA system to identify inefficiencies (e.g., leakages, pump inefficiencies, energy usage). Use real-time monitoring to quickly address issues and optimize water management. Automated reporting set up dashboards and automated reports for utility managers to monitor system performance and make informed decisions. Alerts for critical system failures can also be automated and it improves overall water distribution efficiency finally it helps utilities make data-driven decisions, reducing operational costs and improving service quality.

4.6.10 Regulatory and compliance considerations

Align with Local regulations which ensure that the SCADA system complies with national and regional water management regulations, such as water quality monitoring and environmental standards. Regular reporting should also meet regulatory requirements. It promotes transparency for using SCADA data to meet regulatory standards and promote transparency in water management operations. In addition, it ensures compliance with local laws and avoids regulatory penalties. Finally, it builds public trust by promoting transparency in water management practices.

4.6.11 Cost management and funding

External funding explores international funding opportunities, such as grants or low-interest loans from organizations like the World Bank or regional development banks. These can help cover capital expenses. Cost optimization focus on balancing capital expenditures with operational expenses. For example, invest in energy-efficient components to lower long-term operating costs. Cost management reduces the financial burden on local utilities by providing the system remains cost-effective over its operational lifetime.

4.6.12 Sustainability and environmental considerations

Leak detection and water conservation helps the SCADA system to detect leaks in the water distribution system, reducing water loss and conserving this valuable resource, especially in water-scarce regions. Other form of sustainability is renewable energy where possible, power SCADA components (e.g., sensors, communication equipment) with solar energy, especially in remote or off-grid areas and promotes sustainable water use by reducing waste. Sustainability and environmental considerations lower environmental impact through renewable energy integration.

4.6.13 Summary on developing best practices for successful implementation of SCADA System for Ethiopian water supply projects on resource management aspect

A successful SCADA system implementation in water supply projects, especially in developing countries, hinges on a thoughtful, phased approach that emphasizes local needs, scalability, capacity building, and sustainability. Each of those best practices plays a critical role in ensuring the system is effective, cost-efficient, and resilient in the long term.

Throughout developing best practices for the successful implementation of SCADA systems in water supply projects in developing countries the following key factors are required. Stakeholder collaboration, effective SCADA implementation requires the cooperation of government agencies, local communities, private contractors, and technology providers. Clear communication ensures that project objectives align with local needs and expectations. Tailored technology: SCADA systems should be designed to fit the specific environmental, economic, and technical realities of the country, this includes considering the local climate, the level of automation needed, and the availability of skilled labor for maintenance. Infrastructure investment and a well-planned investment in infrastructure, such as power supplies, communication networks, and hardware, is critical. In many developing countries, power supply and communication reliability can be major challenges, so the system must account for these limitations with backups or alternative energy sources like solar power. Capacity building through training local engineers, technicians, and operators is crucial for long-term system success not only the initial training but also continuous professional development to keep up with evolving technology.

Reliable power and communication create SCADA systems rely heavily on uninterrupted power and communication links besides ensuring backup power sources and redundant communication channels (e.g., wireless networks, satellite) can mitigate the effects of unreliable infrastructure. Maintenance and support plans by establishing clear maintenance schedules and having support readily available (whether local or remote) ensures that the system remains functional and up-to-date. Finally, scalability and flexibility allow design systems that can be expanded or modified as needs change, without requiring major overhauls which is especially important in fast-growing urban areas or regions with unpredictable water demands. These best practices can help ensure that SCADA systems are not only implemented effectively but also sustainable in the long run, contributing to improved water management in developing countries.

4.7 Case study on the application of SCADA System for Adama Town Water Supply and Sanitation Improvement Project

4.7.1 Background on Adama Town Water Supply and Sanitation Improvement Project (AWSSIP)

Adama town water supply and sanitation improvement project (AWSSIP) is aimed to build an urban water supply and sanitation improvement project in Adama town to build a water supply SCADA system to monitor and control the safety, energy saving and stability of water source deep well lifting pumps, water pipeline lifting pumps, collection reservoir, and service reservoirs for water distribution Operation. The work content of this project includes Control system of 13 water source deep well pumping stations namely Borehole 07, 10, 12, 13, 14, 13, 20, 21, 22, 23, 24, 25 and 26, each pump station is equipped with a PLC on-site control station, 1 Booster pump station, 1 collection reservoir PLC and monitors the operation of the dosing system, and 7 reservoirs Stations namely Sire Aba bune Reservoir (SAR1), West Adama Reservoir (WAR4), North Adama Reservoir (NAR5), East Adama Reservoir (EAR8), Lugo Reservoir (LUR9), East Boku Reservoir (EBR10) and West Boku Reservoir (WBR11) and 1 Break Pressure Tank.

In addition to that the project is expected to establish a wireless communication network and flexibly configure the station network according to the actual data transmission and reception communication sensitivity, Set up a water supply SCADA monitoring platform, On-line instrument supply, installation and commissioning, Guide on-site installation and commissioning, Detailed design, supply, guidance on installation, debugging, joint debugging, full system joint debugging, test acceptance, and acceptance, Software development and system software development of each site, Data integration, statistics, analysis and various reports SCADA systems should be designed and implemented with unlimited scalability and expansion capabilities in mind to incorporate future water supply projects.

The overall goal of the SCADA system is to use the SCADA system of the Adama City Water Supply and Sanitation Improvement Project to monitor and control the operating parameters of the deep well pumping station, lifting pump station, collection reservoir, service reservoirs, and pressure relief valve in the water source area, so as to realize the deep well in the water source area Optimum operation of pumping and lifting pumping stations, safety and durability of equipment and installations, optimization of energy use and optimal management of drinking water systems. The SCADA client will be installed in the utility office to monitor the operation of the water supply network.

The SCADA system has been built into a real-time monitoring system that integrates water supply production and treatment (collecting well group water pumping), water pipeline network control, and user reservoir control for the entire process of production automatic control, data processing and statistics, fault diagnosis and guidance, and intelligent analysis. Construct an automation system with advanced technology, complete functions, efficient operation, flexible use, convenient maintenance, easy expansion, low investment, safety and reliability, open system, resource sharing, and full-automatic control of the high-quality domestic water treatment process. According to the requirements of users, it can fully combine the computer information network to realize the "integrated management and control" monitoring system, realize the unmanned or few people on duty at each independent process site, and integrate the automatic control system, well group SCADA system, pumping station video monitoring, dosing System, control center dispatching system and other information systems are organically integrated.

Implementation of SCADA system for AWSSIP project planned to achieve the following goals including the system has a high degree of automation which can fully reflect the reduction of labor intensity and increase of labor productivity, Good real-time performance which can reflect changes in process parameters in time and realize real-time control of the production process, Reliability must be guaranteed and high availability can be maintained in the production environment. The whole design scheme should maintain the best cost performance, and obtain the best benefits with the lowest investment which can bring obvious effects to energy saving of enterprises and can provide decision-making data for management.

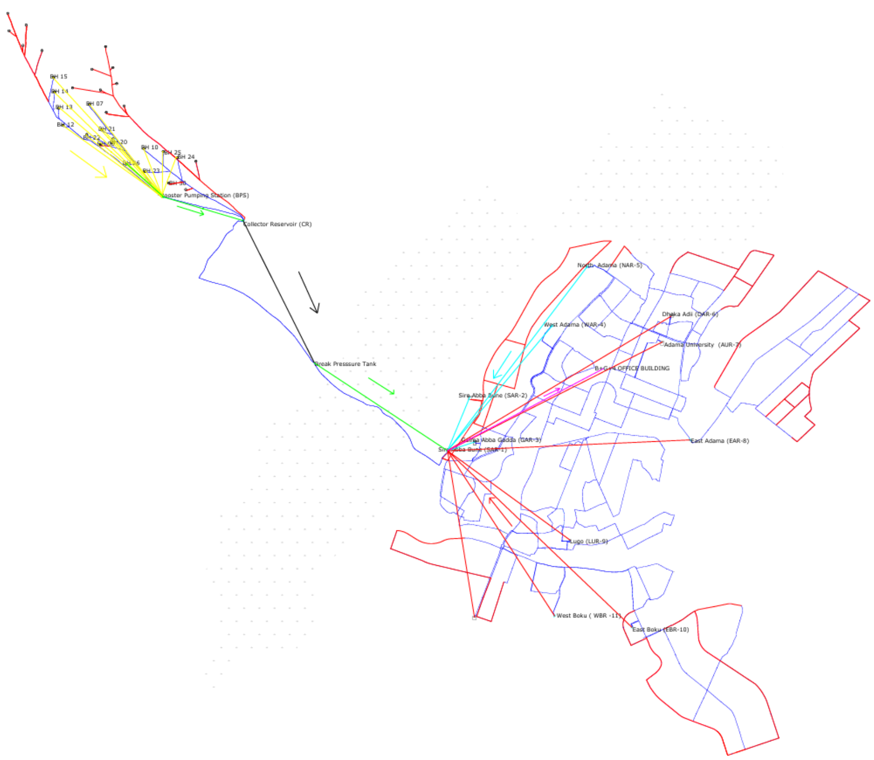

Figure 13 AWSSIP water supply project system flow

Source. Results on case study of SCADA system on AWSSE field survey data, 2024

4.7.2 SCADA system control mode and functions

4.7.2.1 Control mode

The operation control mode is as follows Local direct manual mode (transmission command via radio or telephone), Manual mode (keyed) via the SCADA system interface of the BPS pumping station, and fully automatic mode (automatic) from PLC station of BPS pump.

4.7.2.2 Automatic operation mode

When "remote" is selected on the local control cabinet, when the SCADA system in the control room of the BPS pumping station selects the "automatic" mode for the "keying/automatic" of the device, the PLC system of the BPS pumping station will control according to the water level of the reservoir, the water level of the user's reservoir, and the pump Automatically start/start deep well pumps based on factors such as water delivery volume and reservoir flow balance, and automatically adjust the number of startup pumps in the water source well area to work in rotation by increasing the number of operating pumps. The PLC system of the deep well pump station in the water source area cannot automatically start the operation of the deep well pump. When the water level in the reservoir exceeds the full reservoir water level, the operation of the deep well pump and lift pump will be automatically stopped.

4.7.2.3 Reservoir control

Each reservoir is set with a minimum water level and a maximum water level. The lowest water level opens the electric water inlet valve of the reservoir, and the highest water level closes the electric water inlet valve and stops water inflow. If the outlet water flow increases abnormally, close the outlet valve. The control authority is at the lifting pump station.

4.7.2.4 Automation control

To improve the stability of the Adama water supply system, when the reservoir water level rises to the set limit and the water level drops to the set minimum value, the lift pump of the deep well pump station is controlled to start/stop to ensure the stability of the water supply system and the safety of water supply. Equipment and associated software shall be suitable for each automatic water supply system. The maximum liquid level and the minimum liquid level are double detected by the water level switch and the reservoir water level gauge, and an alarm is sent to the SCADA system.

4.7.3 AWSSIP SCADA system software overview

4.7.3.1 SCADA server and SCADA client

SCADA system communication services and data service software will be installed on the data server. Servers will include the latest microprocessors with appropriate memory type and size, appropriate virtualization capacity, and hardware suitable to meet SCADA system performance requirements. The server should be equipped with enterprise-grade Microsoft Server 2016 or the latest approved Windows operating system for the SCADA system to be deployed. The computer should also come with the required drivers, licenses, anti-virus software, etc. Management software with all necessary operational and security features will be installed on the server to manage connected clients.

4.7.3.2 SCADA system security and access levels

The SCADA system will be configured with the following four indicative user levels Guest (view only), Operator User View (accept alarms, run historical trending utility, remote/manual control of pumps, drives and actuators), Supervisory User (Same as Operator, but able to modify control set points), Engineer User (Full system access and ability to modify SCADA system configuration or PLC program).

When a specific user logs in to a specific operator terminal, the system will record all operations of that user. Log records will include all actions taken during the login, including a record of the action taken; the relevant local control station; the date and time of the action (in hours, minutes and seconds format). This user table can only be retrieved at the engineer user level. Note that user permissions are defined by the system administrator. At the engineer level, it can create many levels of access to meet AWSSIP requirements. All necessary cyber security measures will be provided to prevent unauthorized access to systems through the AWSSIP corporate network and the Internet. This will include appropriate firewall equipment on the network connection as well as firewall and virus protection software.

4.7.3.3 Data transfer requirements

The SCADA system will monitor all alarms generated by digital equipment at the site or derived from analog measurements in PLCs. The SCADA system will monitor all analog and digital measurements. The SCADA system will provide all necessary set point changes in interaction with the PLC. The SCADA system will monitor and record all PLC diagnostic information. The

SCADA system will provide all necessary control interactions with the PLC including flow meters, level and pressure transmitters, soft starter enable/disable functions, alarms and reset functions.

4.7.3.4 Graphical display requirements

A graphical display will be provided on the SCADA system screen for each local control station to ensure that all SCADA terminals are visually similar for ease of operation, the following standard symbol libraries will be used for graphical displays. The process flow will be uniform, from left to right and top to bottom. Off-screen flow will enter from the left and exit from the right, and flow lines will be vertical and horizontal only. Equipment elements are displayed as numerical values or bar graphs in engineering units. When the device is controlled, the actual and desired values are displayed. By clicking on the primitive object, further information about the simulation settings will appear via a pop-up window showing the label reference and description, range, alarm settings and a link to the simulation trend. The number will be displayed along with its name, status (on/off) and further information such as normally open or normally closed contact.

4.7.3.5 Data storage

The SCADA system will provide short-term and long-term data storage for recording: all analog data, flow data, power consumption data, and equipment running time data are recorded once every minute, and all alarm data and operation record data are recorded as they occur. The recorded data is automatically saved in the historical database, and the data is saved for more than 5 years.

4.7.3.6 Historical trend query

The system will be configured to provide real-time and historical trends. All analog signals, including inputs and outputs, will display instant real-time trends. These trends will start when the operator is invoked and continue recording as a background task as needed. All analogs will be trending. Trend recording will occur at selected intervals. All data will be stored in the database and can be exported within 24 hours. Historical trends will provide operators and managers with information on project performance. These are configurable by the operator to specify a time base, ranging from one hour to one year. The system will be set up to access several pre-configured historical trends associated with the main system. Operators can select trends via the menu or screen buttons and then specify the desired time base.

4.7.3.7 Site and System Reporting Requirements

The SCADA system will provide the functionality to generate reports on site and system data. Two report types will be provided Scheduled reports (automatically generated by the system on a regular basis) and User-Defined Reports (allows operators to build custom reports based on data and boundary conditions selected from the database). A standard table layout will serve as the basis for reports, which will be developed in conjunction with AWSSE. Each type of report layout will contain the following standard basic information AWSSE name and standard logo, Site name, Report date, the date and time the information is included in the report, the name of the user who generated the report, Site areas/site items covered by the report, Industrial production flows, and report type. The final content and layout of these reports will be agreed upon and approved by the AWSSE Project Manager. Scheduled reports are automatically compiled and generated at preset designated times. The report will be stored for retrieval at any time.

4.7.4 SCADA graphical interface functions

4.7.4.1 Process graphics screen

It can visually display the production process flow chart of the water supply system. The screen can display the operating status of the main equipment, operating parameters and production process data. If authorized, click on the corresponding device to pop up the control screen of the device. The operating status of the process equipment is distinguished by color (running - red, shutdown - gray, fault - yellow). When the equipment fails, the equipment will turn yellow and flash. Some of the outputs displays are as shown below as a sample those are taken during site visitation on AWSSE water supply utility and the remaining photos are attached on appendices part.

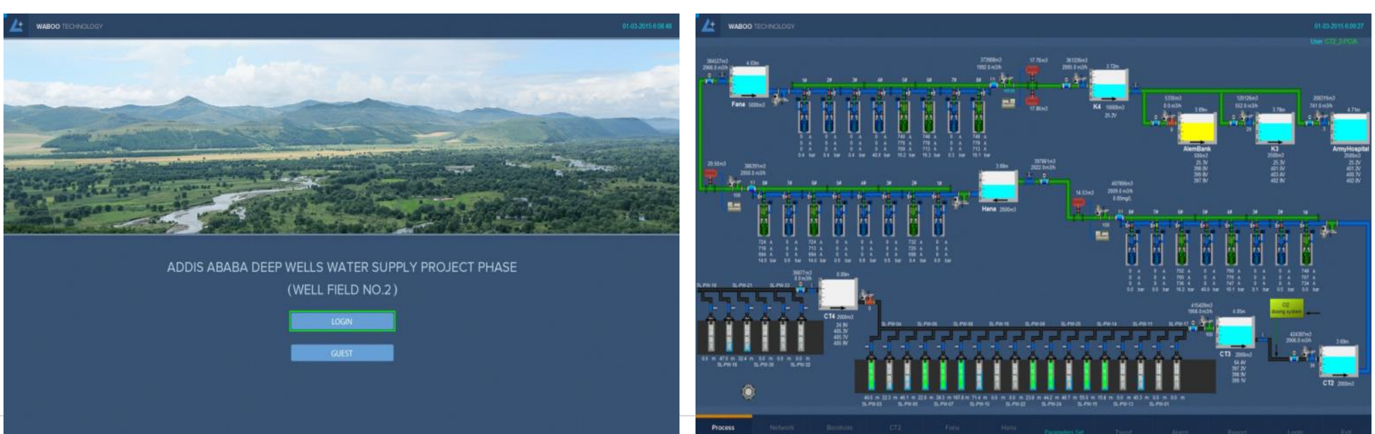

Figure 14 Sample display from SCADA system

Source: Results on case study of SCADA system on AWSSE field survey data, 2024

4.7.4.2 Network topology and communication status diagram

Display the communication status of each site in the SCADA system which includes the following information's whether field devices are operational, fault, offline. Also, RTUs/PLCs are connected, disconnected, error. Communication networks are on healthy degraded or down. Finally, SCADA Master Station is whether operational, warning, critical as shown on the picture on the appendices part.

4.7.4.3 Main site screen/ Pump house picture

It can display the operating status of the water pump, motor temperature, pressure, water flow, and the operating status of key equipment's visually display the production process and various parameters of the water delivery pump room. The water supply pressure can also be set for a time, and the pressure can be set according to the time to control the frequency conversion operation of the water pump. The main station screen adopts 3D screen display to vividly display the key point equipment of the production process and online instrument measurement parameters.

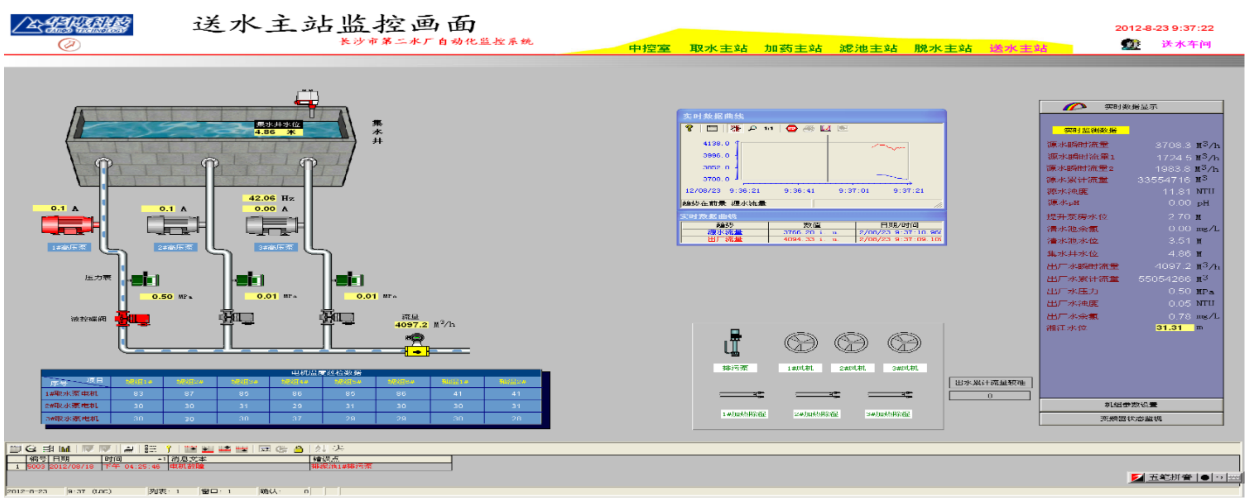

Figure 15 Main site/ Pump house site

Source: Results on case study of SCADA system on AWSSE field survey data, 2024

4.7.4.4 Well group station screen

Visually display the process flow of the deep well pump room, display the operating conditions of each equipment's, and display various power distribution parameters and operating parameters, historical operating curves of important parameters.

4.7.4.5 Dosing system screen

Visually displays the chlorination process and operating parameter of each equipment. In a SCADA system, the dosing system screen is crucial for monitoring and controlling the dosing of chemicals into the reservoirs of water supply. This screen typically provides real-time data and control options related to the dosing system.

4.7.4.6 Historical curve screen

Query and display historical operating data of each production process, the time range can be set arbitrarily, multiple historical trend curves can be displayed at the same time for comparison. It shows each up and down of the production or service provided by the system.

4.7.4.7 Report data query

The report query software can flexibly generate various query reports and generate them in real time according to user requirements, data query is divided into class, daily, monthly and annual reports, and operators can define the data type to be queried.

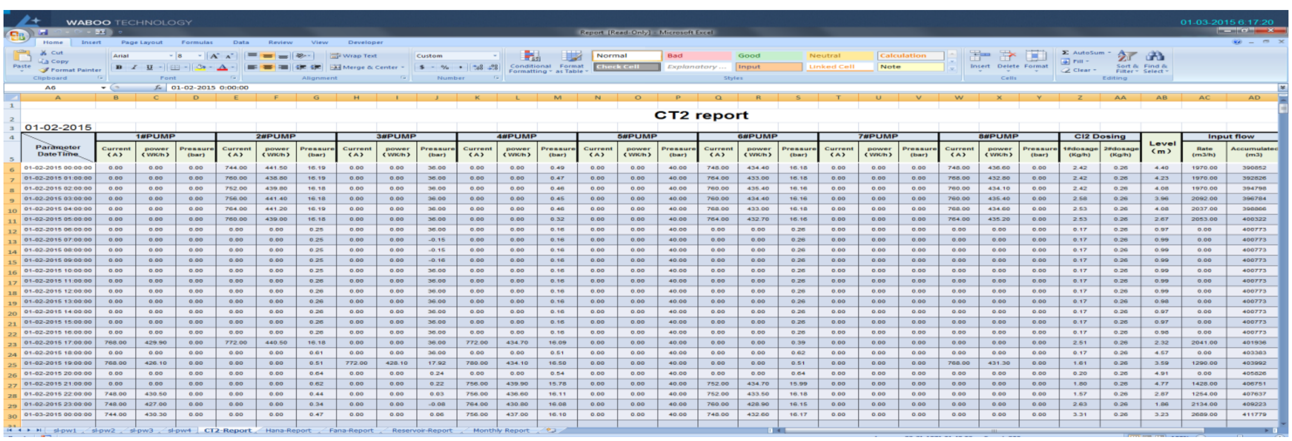

Figure 16 report data query

Source: Results on case study of SCADA system on AWSSE field survey data, 2024

4.7.4.8 Pump station power distribution screen

Display the power wiring diagram of the monitoring station, distribution parameters such as current, voltage, power, electrical energy, and power factor.

4.7.4.9 Alarm query

Automatically display the time, location and operating parameters of the equipment failure when the failure occurred, can query historical alarm data, historical operation records can be queried. Alarm query display is composed of alarm list, timestamp, alarm ID/Number, description, severity (indicates the urgency of the alarm), source, status, priority.

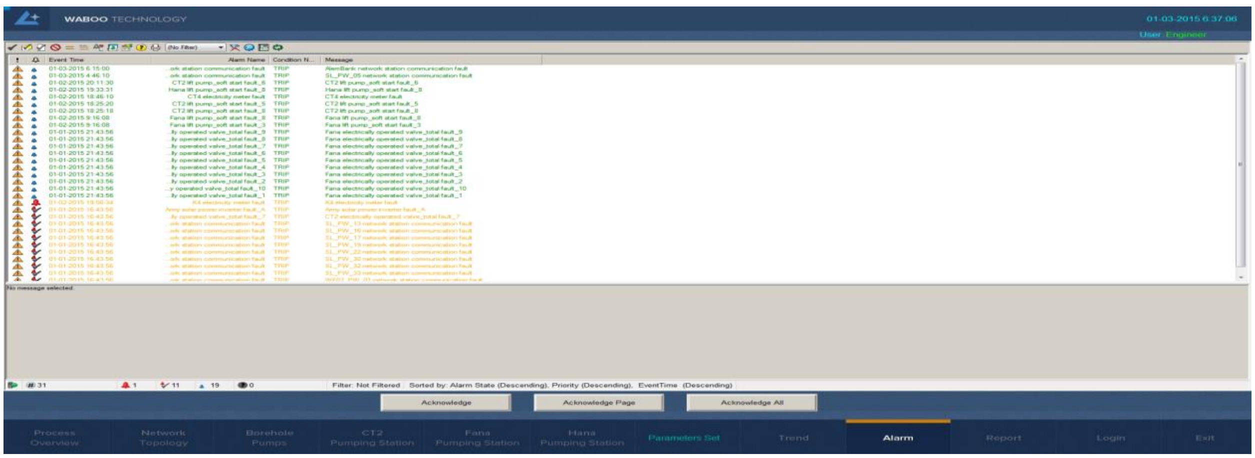

Figure 17 Alarm query

Source: Results on case study of SCADA system on AWSSE field survey data, 2024

4.7.4.10 Device control screen

The device control screen in a SCADA (Supervisory Control and Data Acquisition) system is designed to allow operators to monitor and manage various devices and equipment within the water supply process. This screen typically provides real-time control and status information for devices such as pumps, valves, motors, and other critical components.

4.7.5 Summary of AWSSIP SCADA System and Station Automatic Control

A Supervisory Control and Data Acquisition system (SCADA) will be installed at the booster Pumping station compound operation building to control and supervise the whole plant from a single central location. Data, control signals and system status are transferred to and from the central system to the main switch gear and all the motor control panels in the plant. The new SCADA master station would be located at booster pumping station compound and dedicated to the booster station, new wells and service reservoir. The new system will use dedicated antennas but these will (as far as possible) be mounted on antenna poles provided at each site for this purpose. The new system will use its own radio frequencies for communications between booster pumping station, the wellheads and service reservoir. It is expected that, the contractor will undertake frequency survey work for each site to fix communication frequency of the project SCADA system in consultation with the client and concerned authority.

The pumping station will be equipped with its own PLC which will be hardwired to all the new signals arising from the pumping station and the tank. The PLC will be connected into a SCADA master dedicated to the pumping station, well field and service reservoir. The station will be equipped with UHF radios to communicate with wells and service reservoir. The radios will be cabled to a new directional antenna mounted on the high mast to communicate with all well fields and service reservoir. This system will be networked to the PLC of higher-level SCADA master station and will be controlled or viewed from the master station.

4.7.6 Cost analysis of AWSSIP SCADA System

The estimation of costs of water supply schemes and their component for the project requires a number of factors including the implementation time, the available infrastructural facilities, availability and cost of labor and the distance from the port and also how and from where water is abstracted, treated, stored and conveyed. The following table shows the cost of the Adama town Water Supply and Sanitation Improvement Project (AWSSIP)

Table 9 Cost analysis of AWSSIP SCADA System

Item	Description	Total price (ETB)
Part A	Drilling Work	186,259,406.00
Part B	Civil Work	592,916,023.90
Part C	Supply of Pipes and Fittings	1,281,003,477.58
Part D	Supply and Installation of Electro Mechanical Works Including SCADA System	206,305,264
	Total	2,266,484,171.50
	Supervision Cost (2%)	45,329,683.43
	Total	2,311,813,854.93

	VAT 15% For the Local Portion	113,207,848.54
Grand Total		2,425,021,703.47

Source: Results on case study of SCADA system on AWSSE field survey data, 2024

Based on the information gathered from water supply utility of Adama town the AWSSIP project require total amount of 206,305,264 (Two Hundred Six Million Three Hundred Five Thousand Two Hundred Sixty Four) Birr to incorporate the AWSSIP project and for the implementation of automated SCADA System.

CONCLUSSION AND RECOMENDATION

In urban infrastructure with the continuous economic growth, the water demand of enterprises is also increasing. The water wastage is due to many reasons such as leakages, mankind laziness, operator error etc. There is also problem of irregularity of water supply. The water supply can be control by using automated SCADA system to reduce wastage of water. Therefore, the monitoring system of urban water supply has aroused extensive attention in recent years. The water distribution supply systems are crucial part; therefore, system must assure the continuity of the water supply distribution, the water quality control, monitoring and control of the technological process parameters and deal with the restrictions imposed by the water availability, hydrological conditions, the storage capacity of the tanks and water towers and the increasing diversity of water use.

The SCADA system includes pumping stations, filtering/chemical treatment utilities, storage tanks and towers, the piping distribution network and the central dispatching unit. The complete SCADA system structure includes one or more central PC main station that communicates with more PLCs implemented into the pumping stations or RTUs located in control panels throughout the network (pressure and flow measurement or valves remote control). The results obtained in the analysis of the questionnaire survey and case study have been discussed and presented in the previous Chapters in detail. Therefore, from the results of the analysis of desk study and respondents‟ responses the following major conclusions have been drawn

1. Most of the respondents agreed on the current water resource management techniques require further advancement due to increasing demand from beneficiaries and it is difficult to address with the system which is available at this time.
2. Response from utilities for certain interruption on the water supply system may take several days from identifying the exact location to adjusting required resource for maintenance, therefore enhancing automated system had its own advantage on creating reliable water supply system.
3. According to response from the questionnaires water supply utilities face several expenses for maintenance due to damages on the pipe line; however enhancing the

automation system may reduce those expenses by creating preventive measures before occurrence of those damages.

4. As a developing country to implement SCADA system in Ethiopia on its full context most of the SCADA experts shares common thought on it had its own constraints and challenges such as Cost, exposer to cyber-attacks, required skilled man power, integration of reports besides to its contribution on sustainable and consistent water supply system.
5. Based on the analysis on a case study the automated system which is going to be implemented on AWSSIP project is expected to bring several contributions to resource management techniques on achieving project its initial goal by creating safe and reliable system throughout the project life cycle.
6. Most of the respondents assure that water supply projects poor performance is due to their lack of proper management of resources and absence of forecasting the demand of the population on coming years.
7. According to the analysis on the successful implementation of SCADA system on developing countries for their water supply projects requires adaptation of best practices by including conducting study on the existing system, adding standards for future upgrades, choose the right method for communication, choose durable hardware's, implement basic protections against cyber, provide routine training for technicians, check workability of the system in advance on small scale and finally environmental and social issues should be addressed.
8. SCADA experts agree on automation system for construction industry especially on water supply sectors will bring proper resource management and balance on the demand and supply of utilities to create satisfactory service for their customers, Also SCADA system support to recover their investment cost within a short period of time if they are implemented properly.

Recommendation

Water supply utilities of selected towns on the literature review, questionnaire analysis had poor performance on resource management techniques implementation due to continuous increment of demand from the beneficiaries and nature of service they are providing which requires continuous improvement to achieve their goal, therefore those techniques for managing their resource require close follow up and checking through their service period to achieve the objectives of the water supply projects and to assure satisfaction of their customers.

- Water supply projects as part of construction industry they require high amount of capital investment to finish and commence providing service, therefore the most certain way to return investment cost on short period of time is by addressing consistent and reliable water supply for the population by applying all necessary technologies in which the automated (SCADA) system gives the utilities to recover their investment cost as per their plan.
- For water utilities and municipalities, adopting a SCADA system is a decisive step toward more sustainable, efficient, and reliable water management. As we face increasing challenges in water resource management, the role of SCADA systems becomes ever more critical, offering a path to a more water-secure future, therefore water supply projects should give attention for enhancing the system as one part of the project from initiation to completion of the projects.
- Nowadays, management systems as well as most of the production activities are emerging to automated or internet of things controlling mechanisms due to globalization and vast technology, therefore the construction sector and stake holders should focus on creating highly skilled man power to adopt and implement those automated system and this will help utilities to ascertain the consistency of their service by providing and mitigate the challenges those may occur during their production phase.
- Finally, preventive measures are the way to assure prevention of any interruption on the productivity of each sector, since it can direct occurrence of any damage in advance and will let any concerned stakeholders to take measures to halt the expected losses, therefore automated system will give all those advantages for utilities by adopting those preventive measures can guarantee reliable and consistent productivity instead of reactive measures.

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APPENDICCES

A. QUESTIONNAIRE

Adama Science and Technology University

Department of Civil Engineering School of Civil Engineering and Architecture

Office of Graduate Studies

Questionnaire prepared for fulfillment of Research purpose for Masters of Science Degree on Construction Engineering and Management entitled with "Application of Supervisory Control and Data Acquisition System (SCADA) for Ethiopian Water Supply Projects in Case of Adama Town Water Supply Project".

Prepared by Mesfin Arega

Dear Sir/ Madam

This is a questionnaire designed for a research purpose at Adama Science and Technology University in Partial Fulfillment of the Requirements for the Degree Master of Science in Construction Engineering and Management. The objective of this questionnaire is to obtain information to conduct a thesis entitled ‘‘**Application of Supervisory Control and Data Acquisition System (SCADA) for Ethiopian Water Supply Projects in Case of Adama Town Water Supply Project”.** The data collected and the information to be answered in this questionnaire will be used for academic research purpose only. All specific companies and interviewee information will be always kept confidential. Only a generalized analysis of the information contained within this completed questionnaire will be utilized in the research process.

Instruction

Please answer, rate, and thick (✓) the questionnaire by choosing the appropriate choices. The questionnaire and data collection contain two parts. Part, one contains the company and respondent’s general information which is part two deals with. I realize that there are numerous demands on your time. However, your involvement is a vital requisite for this.

Therefore, I kindly request your valuable cooperation to timely respond me the provided information data given in the questionnaire survey, and return the questionnaire paper as soon as possible. Thank you in advance for your cooperation and honesty in providing me your valuable response

Sincerely

Mesfin Arega

Email; Mesfinarega71@gmail.com

Section-1: General profile of the respondent

Tick (√) your responses under the box provided for the appropriate choice.

1.1 Name /Optional/………………………………………………….

1.2 Age ☐ 18-24 ☐ 25-34 ☐ 35-44 ☐ 45-54 ☐ 55-64 and ☐ 65 and over

1.3 Position:

☐ Project Manager ☐ Resident Engineer ☐ Site Engineer ☐ Designer

☐ Technical team Leader ☐ Project Officers ☐ Project supervisor ☐ Technical and financial services providers, ☐ Operator ☐ labor

☐ Others; please specify……………………………………….

1.4 Organization: ☐ Client ☐ Consultant ☐ Contractor

1.5 Educational status? ☐ Diploma ☐ BSc ☐ MSc ☐ PHD and above

☐Others; please specify……………………………….

1.6 How long have you worked in the Water supply sector?

☐ 0 – 5 years ☐ 6 – 10 years

☐ 11 – 15 years ☐ More than 15 years

Section-2: Water supply /resource management techniques

You are kindly requested to tick (√) your responses on the provided space for the appropriate answer. Hence, tick on 5 = Excellent, 4 = Good, 3 = Average, 2 = Below average and 1 = poor on the evaluators of performances for currently available water supply and implementation of resource management techniques on the projects.

Table 10 Questionnaire distributed to respondents

Description	**Resource management techniques**	**level of performances for resource management techniques**				
		1	**2**	**3**	**4**	**5**
Sustainability and efficiency related techniques	Implementing measures to reduce water wastage through public awareness campaigns					
	Adoption of water-saving technologies.					
	Managing water demand through measures such as metering, pricing mechanisms (e.g., tiered pricing), and incentives for water-efficient practices.					
	Investing in the construction, maintenance, and improvement of water to enhance water storage, distribution, and treatment capacity.					
	Implementing measures to protect and improve water quality through pollution prevention, source water protection, and water quality monitoring programs					
	Compare the performance of the water supply project against established benchmarks or industry standards					
	Collect and analyze data related to water supply operations, including water production, distribution, consumption, losses, energy usage, and costs					
	Conduct systematic assessments of water supply systems to identify sources of water losses, including leaks, unauthorized connections, and meter inaccuracies					
	Use hydraulic modeling software to simulate the behavior of water supply systems under different operating conditions					

Maintenance related techniques	Develop and implement a preventive maintenance schedule for all critical components of the water supply system, including pumps, pipelines, valves, treatment plants, and storage facilities					
	Utilize condition monitoring techniques such as visual inspections, non-destructive testing, and sensor-based monitoring to assess the condition of infrastructure assets					
	Develop comprehensive maintenance plans and budgets that outline the scope of maintenance activities, resource requirements, and schedules					
	Establish protocols and procedures for responding to emergencies such as pipeline bursts, equipment failures, and natural disasters					
	Provide training and capacity-building programs for maintenance staff to enhance their technical skills, knowledge of equipment, and safety awareness					
	Maintain comprehensive records of maintenance activities, including inspection reports, work orders, equipment manuals, and maintenance logs					

Please write extra water resource management techniques not listed under above table (if any) not listed --
----

Section-3:

In this section, the respondents are requested to express their opinion on the water resource management techniques based on their experience of respective project.

1. Challenges and preventive measures to be taken for water supply system
   a) What are the major challenges in ensuring reliable water supply system? ------------
   ----

   ----
   b) How to address those challenges effectively?--

-----

c) What do you think role of application of technologies for managing water resources? --
----
----

d) How does your water supply utility currently manage drinking water resources? ----
----

----

e) Are there any issues with aging infrastructure, leaks, or pipe bursts that affect water supply on your project location? ---
----

f) How often does maintenance or repair works need to be carried out on water supply infrastructure? --
----

g) How does your water supply office respond to incidents such as leaks, pipe bursts, or other emergencies?--
----
----

h) Are there any software systems, tools, or equipment used for monitoring, detecting, or diagnosing issues in water supply infrastructure? -------------------------------------
----

B. Open-ended questionnaires

The general view on the constraints of SCADA system and its application on water supply projects of Ethiopia.

a) Have you heard of SCADA (Supervisory Control and Data Acquisition) systems before participating in this survey? If yes, how would you describe your understanding of SCADA systems? ---
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----

b) Are you aware of any water supply projects in Ethiopia that utilize SCADA systems? If yes, please provide details about the project(s) you are aware of (if applicable) ---

c) Does your water supply project currently utilize a SCADA system? If yes, how long has the SCADA system been in operation? --

d) What are the main challenges or limitations you encounter with the current SCADA system? --

e) In your opinion, why are SCADA systems preferable for water supply management compared to traditional methods? ---

f) Can you provide examples of how SCADA systems have enabled proactive decision-making and response to operational challenges or emergencies? --

g) How does the data analysis capability of SCADA systems support informed decision-making in water supply management? --

h) In what ways do you foresee SCADA systems evolving to meet the future needs and challenges of water supply management? --

i) Are there any limitations in terms of data storage, retrieval, or processing capabilities of SCADA systems? --

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----

j) How do cyber security concerns affect the use of SCADA systems in water supply management? If any, what measures do you take to ensure the security and integrity of SCADA systems and data? ---
----

----

k) Do you face challenges in finding qualified personnel with the required skillset to work with SCADA systems? ---
----

l) Are there any budget constraints or resource limitations that need to be considered?
----

m) How user-friendly is the current interface of your SCADA system? -------------------
----

n) What role do you think the government should play in promoting the adoption of SCADA systems in water supply projects? ---
----

C. Assessment on resource management techniques of current water supply project of Adama town

Description	Resource management techniques	Poor (%)	Below Average (%)	Average (%)	Good (%)	Excellent (%)	Mean	σ	Remark
Sustainability and efficiency related techniques	Implementing measures to reduce water wastage through public awareness campaigns			12 (35.3)	20 (58.8)	2 (5.9)	2.29	0.57	needs feasible improvement
	Adoption of water-saving technologies.			17 (50)	17 (50)		2.5	0.51	needs feasible improvement
	Managing water demand through measures such as metering, pricing mechanisms (e.g., tiered pricing), and incentives for water-efficient practices.		6 (47.1)	12 (47.1)		16 (5.9)	3.58	0.61	Better implementation
	Investing in the construction, maintenance, and improvement of water to enhance water storage, distribution, and treatment capacity.	6 (17.6)	12 (35.3)	16 (47.1)			2.29	0.76	needs feasible improvement
	Implementing measures to protect and improve water quality through pollution prevention, source water protection,		1 (2.9)	13 (38.2)	16 (47.1)	4 (11.8)	2.32	0.73	needs feasible improvement

	and water quality monitoring programs								
	Compare the performance of the water supply project against established benchmarks or industry standards			15 (44.1)	14 (41.2)	5 (14.7)	3.71	0.72	Better implementation
	Collect and analyze data related to water supply operations, including water production, distribution, consumption, losses, energy usage, and costs			11 (32.4)	12 (35.3)	11 (32.4)	2.00	0.81	needs feasible improvement
	Conduct systematic assessments of water supply systems to identify sources of water losses, including leaks, unauthorized connections, and meter inaccuracies	5 (14.7)	13 (38.2)	16 (47.1)			2.32	0.73	needs feasible improvement
	Use hydraulic modeling software to simulate the behavior of water supply systems under different operating conditions	10 (29.4)	13 (38.2)	9 (26.5)	2 (5.9)		2.08	0.9	needs feasible improvement
Maintenance related techniques	Develop and implement a preventive maintenance schedule for all critical components		1 (2.9)	14 (41.2)	10 (29.4)	9 (26.5)	2.21	0.88	needs feasible improvement

	of the water supply system, including pumps, pipelines, valves, treatment plants, and storage facilities								
	Utilize condition monitoring techniques such as visual inspections, non-destructive testing, and sensor-based monitoring to assess the condition of infrastructure assets	10 (29.4)	9 (26.5)	9 (26.5)	4 (11.8)	2 (5.9)	2.38	1.21	needs feasible improvement
	Develop comprehensive maintenance plans and budgets that outline the scope of maintenance activities, resource requirements, and schedules		7 (20.6)	14 (41.2)	9 (26.5)	4 (11.8)	3.29	0.94	Better implementation
	Establish protocols and procedures for responding to emergencies such as pipeline bursts, equipment failures, and natural disasters			12 (35.3)	12 (35.3)	10 (29.4)	2.06	0.81	needs feasible improvement
	Provide training and capacity-building programs for maintenance staff to enhance their technical skills, knowledge of equipment, and	5 (14.7)	12 (35.3)	16 (47.1)		1 (2.9)	2.41	0.86	needs feasible improvement

	safety awareness								
	Maintain comprehensive records of maintenance activities, including inspection reports, work orders, equipment manuals, and maintenance logs		3 (8.8)	14 (41.2)	12 (35.3)	5 (14.7)	3.56	0.86	Better implementation

D. Photos from site visitation and SCADA system outputs

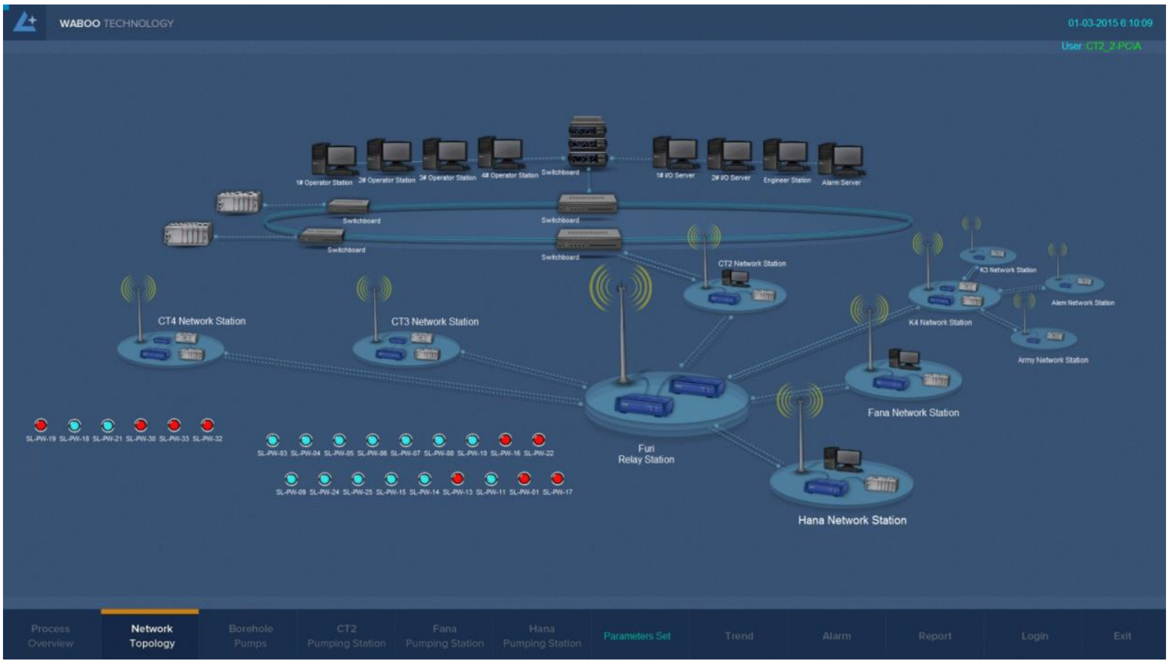

Figure 18 Display the communication status of each site in the SCADA system

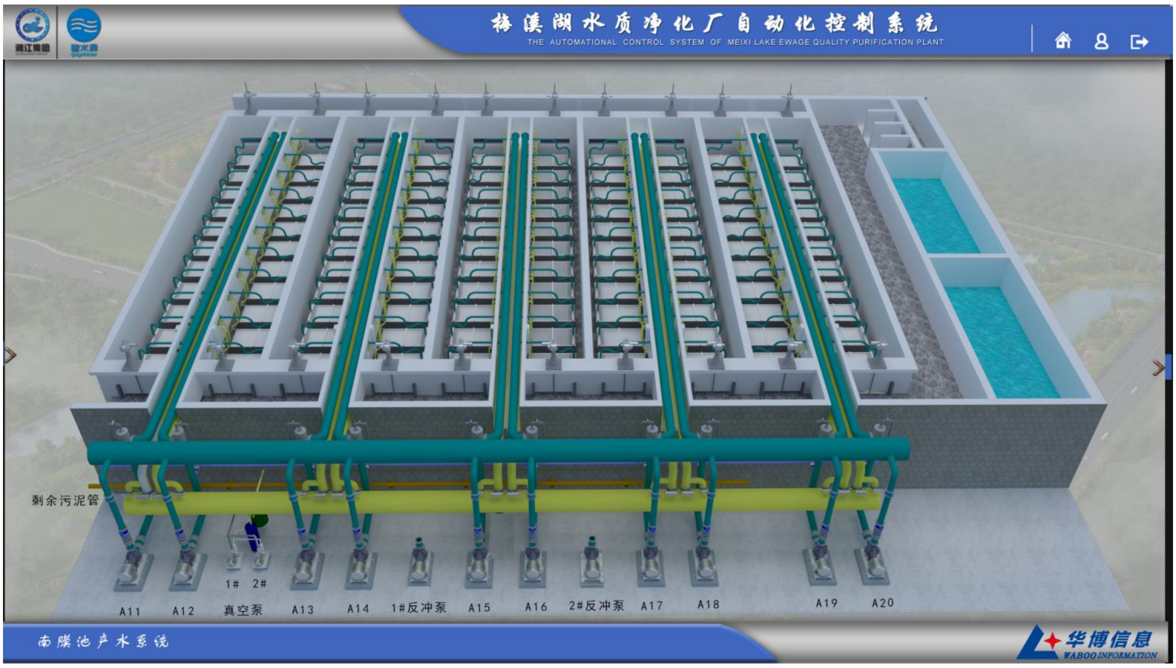

Figure 19 Main Pump house

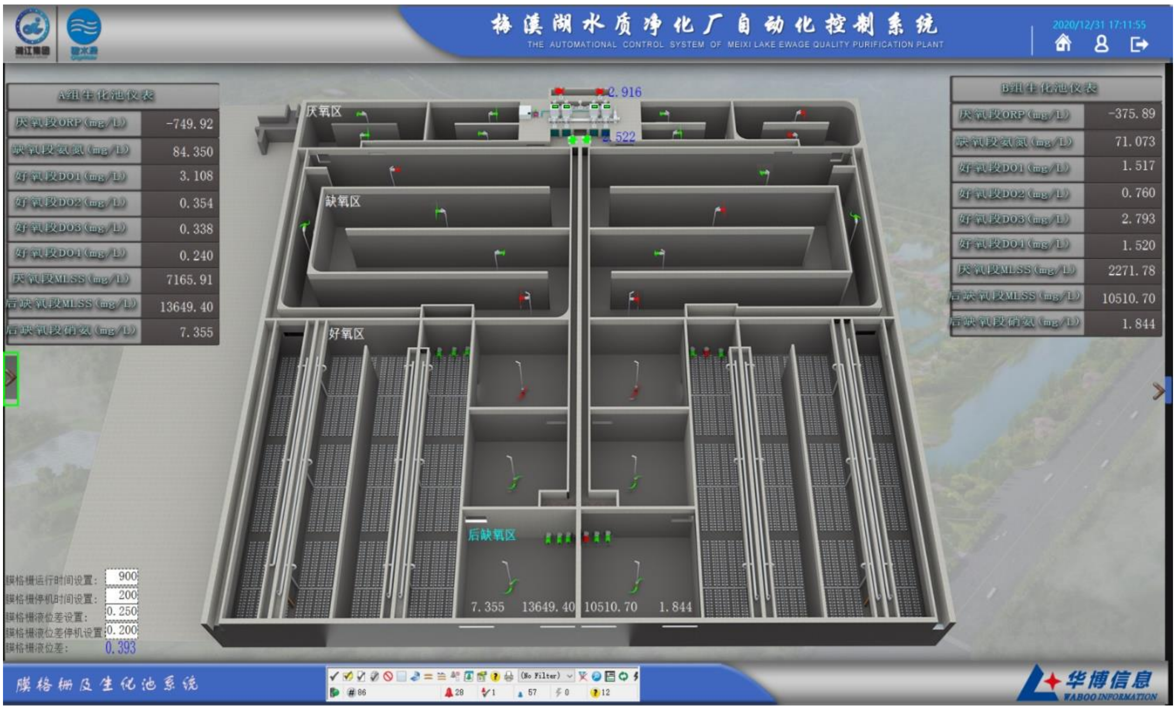

Figure 20 Main Pump house status of service

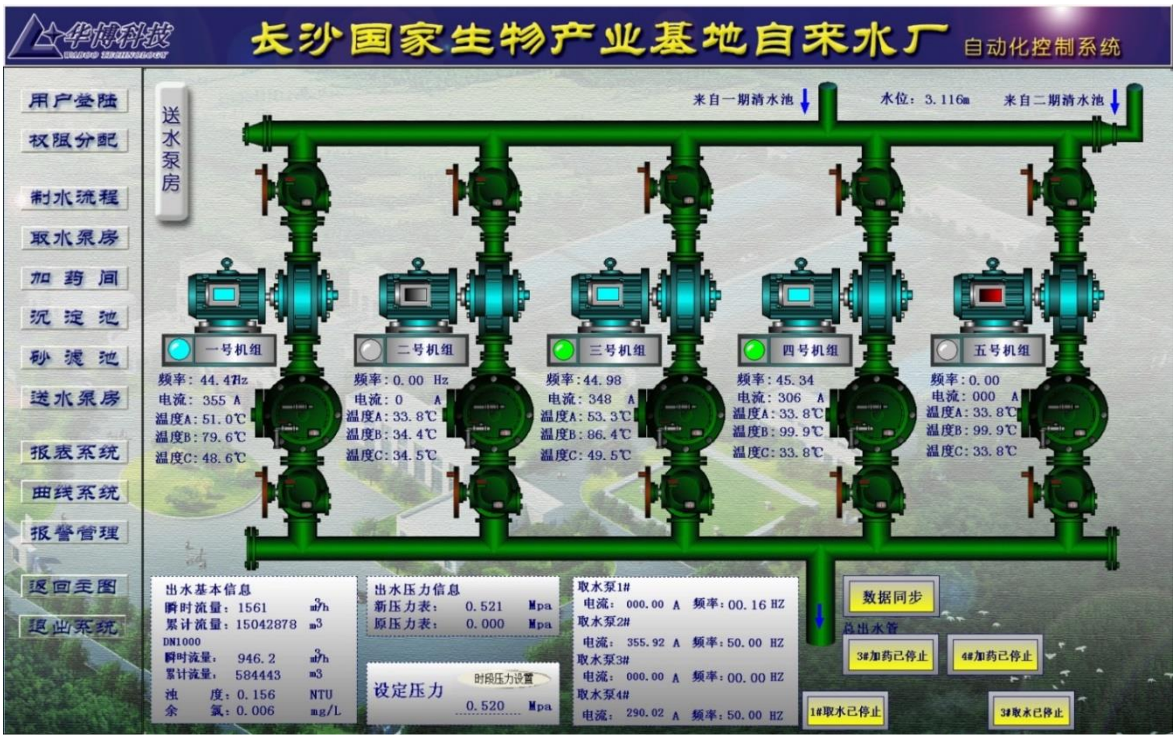

Figure 21 Main pump details display

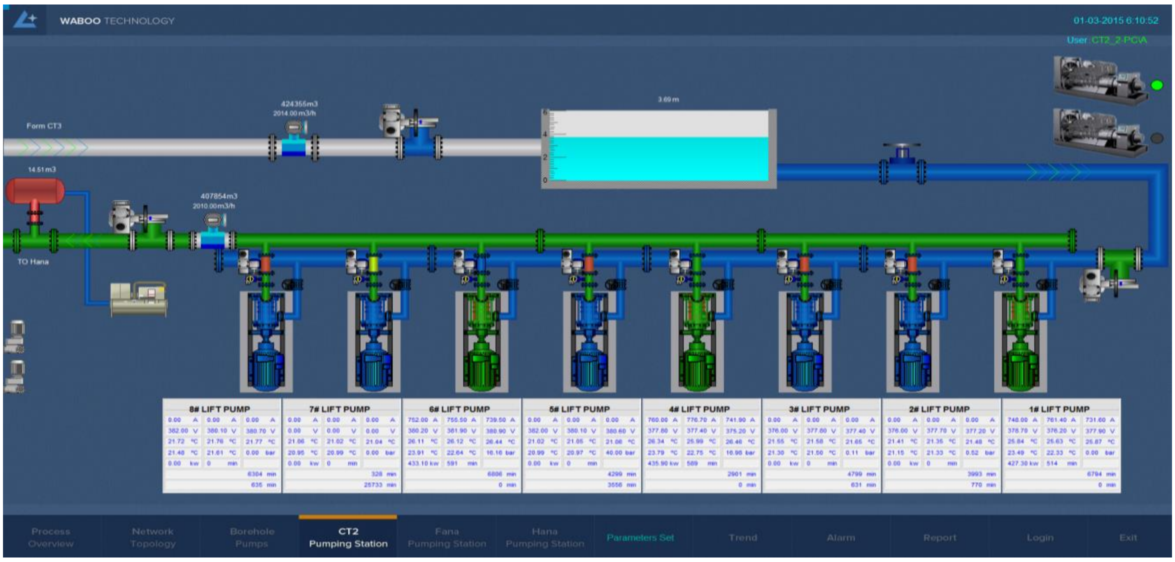

Figure 22 Main site screen details

Figure 23 Main site screen details

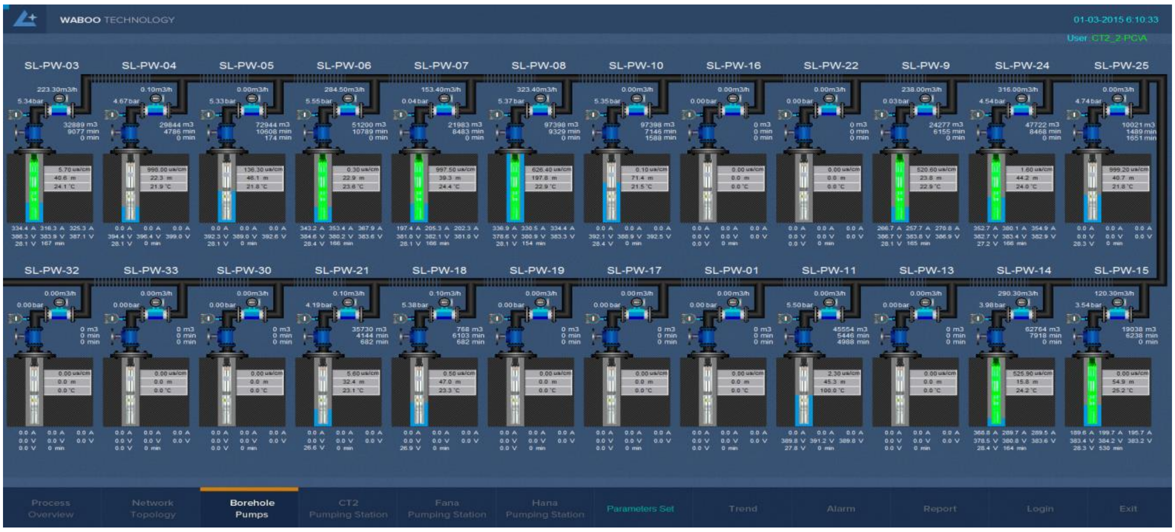

Figure 24 Visually display the process flow of the deep well pump room

Figure 25 Dosing system screen

Figure 26 historical curve screen

Figure 27 Report data query

Figure 28 Device control screen

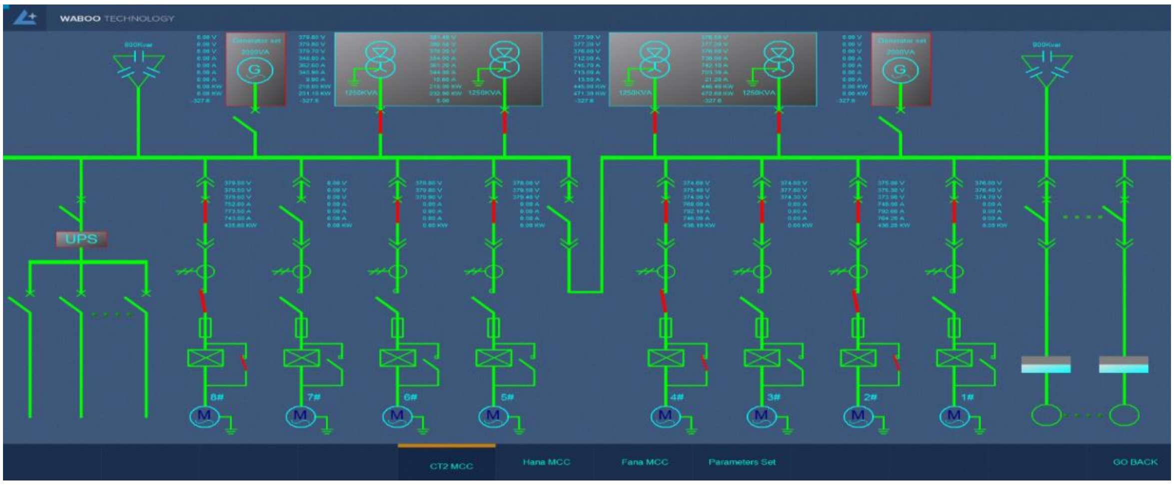

Figure 29 Pump station power distribution screen

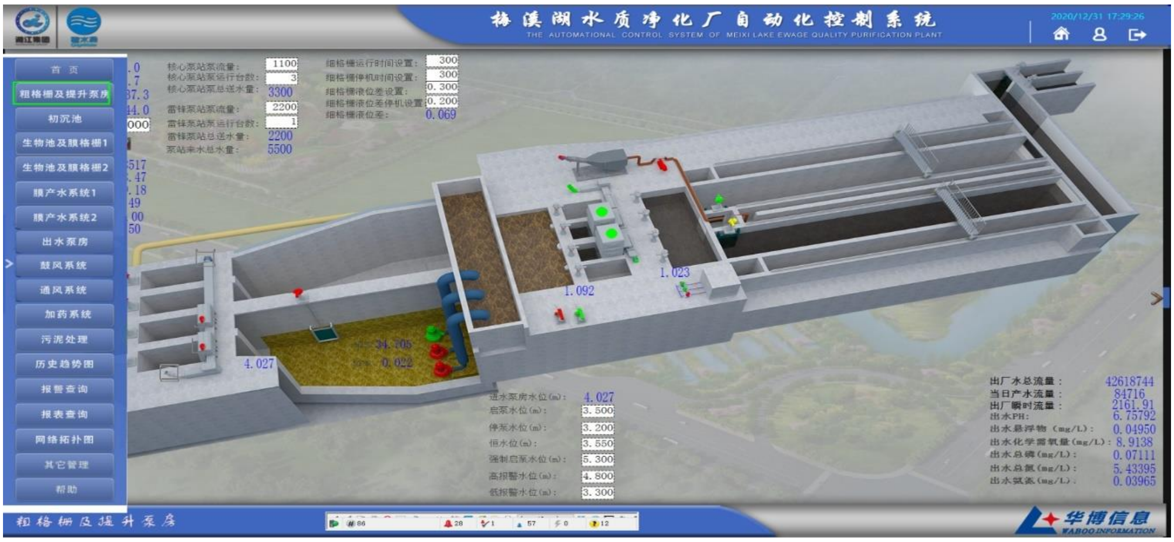

Figure 30 Device control screen