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Water infrastructure resilience and water supply and sanitation development challenges in developing countries

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ABSTRACT

Water supply and sanitation development in developing countries, specifically in Ethiopia, appear to be making substantial progress. Governments, international organizations, and other organizations are contributing to the development of water supply and sanitation systems. Water supply and sanitation challenges are linked to climate change effects and the quest for climate-resilient development. This paper evaluates the current challenges in water supply and sanitation development in developing countries and infrastructure resilience. The research is based on the data collected throughout the practical development task. Some of the findings were the climate change effect and temporary adaptation mechanisms, such as intermittent supply causing further pressure variation and water loss in the system. Resilient water supply and sanitation development require an integrated approach based on practical experiences, the latest technological development in water supply and sanitation system operation and management tools, and climate change adaptation. A seamless understanding of engineering, management, and technology is required for the development and management of water supply and sanitation systems. Dispersed skills may be available that were not effective at this time, which calls for a different approach to training provision and skill development as a package on design, management, and recent technological support.

Key words: development challenges, infrastructure, resilient, sanitation, water supply

HIGHLIGHTS

- Challenges in water supply and sanitation development in developing countries.
- Improved development needs pervious skills, recent technology, climate change, and resilience.
- Adaptations as a temporary solution to climate change in water supply system that makes water distribution systems inefficient.

1. INTRODUCTION

A major challenge facing developing countries is the provision of clean water and sanitation facilities. The government of the country, UN organizations, non-governmental organizations (NGOs), local communities, etc., are all playing a role in improving water supply and sanitation services. The water supply and sanitation sector needs comprehensive consideration of several issues for the effective development and management of the water system. Development work is challenged due to several factors such as climate change, policy implementation, development capacity, awareness, etc. Climate change, the capacity in the implementing sector, recent advancements in design and management, and additional technological tools required beyond the usual development trends make it difficult to achieve a resilient approach (Alaerts & Dickinson 2008). Even without taking the effect of climate change into consideration, the sector was far behind track in most developing countries. With the aid of the Millennium Development Goals (MDGs) at the end of 2016, water supply and sanitation development have improved in most developing countries in Africa. Even if there are some achievements, the challenges of the 2030 Agenda for Sustainable Development Goals (SDGs), which was adopted by world leaders in September 2017 at the United Nations (http://unesco.org/A/RES/70/1), were more complex (Howard & Bartram 2010). The SDGs' goals in water supply and sanitation were complicated due to the high vulnerability to climate change, which necessitates additional technology and financial investment requirements to address existing challenges (Lee *et al.* 2016; Weiland *et al.* 2021).

Water supply and sanitation are two of the great challenges in developing countries. Rapid population growth, climate change, urbanization, and industrialization are creating the need for more water provision for different purposes. As a result of high capital costs and inefficient project delivery, planned progress has been slowed. On the other hand, climate change, water loss, corruption in project development, and lack of skill and technology in water utility management are challenging the existing water system to operate under the normal plan (Dighade *et al.* 2014; Bishoge. 2021). Climate change has significantly altered the operation of water supply networks to an extent not considered during the designed phase (Work *et al.* 2019). A high fluctuation in water levels at the borehole forces the water utility/enterprises to pump water intermittently. As a result, the water network is subjected to intermittent water distribution. Initially, most of the water supply system was designed to the full capacity of the network unless zoning was assumed. The intermittent water supply on the distribution networks results in high pressure variation at different parts of the network, which will cause frequent pipe breaches and high water loss both under high- or low-pressure conditions (Alaerts & Dickinson 2008; Wilbanks *et al.* 2013).

Climate-resilient infrastructure development needs an integrated knowledge of climate change, customary project development, and practical recent incidents observed around the world. In most developing countries, the water supply and sanitation system design, operation, and management were not integrated at the planning stage (Deshkar 2019; Marks *et al.* 2020). Climate-resilient infrastructures need an integrated and knowledge-based path from planning to service delivery (Sadoff & Muller 2009; Pamidimukkala *et al.* 2021). The system design does not consider the system's operation and management (Howard & Bartram 2010). The water infrastructure even in large cities is not efficient in operation and maintenance. There are some recent initiatives by the World Bank and some donors to improve system management. These initiatives include the implementation of water loss and system management aid tools for water utilities/enterprises. In many places, the infrastructure was designed to provide immediate service. As a result, most systems already developed require some improvement to facilitate operation and management. An integrated water management system needs currently developed software to assist with water production, distribution, billing, monitoring, and regulations (Boldrin *et al.* 2022).

The water supply and sanitation sector needs reformation to respond to climate-resilient development requirements. Even if climate change is well known to everyone involved in the sector, there is a huge gap in how to link climate change effects to the practical implementation of the development work (Abubakar & Aina 2019). It is imperative to bridge the knowledge gap between the current theories in the design of water supply and sanitation systems, as well as the latest advanced technologies and tools to improve planning and management at all stages. Climate change effects and outputs were not readily available in a way that could be applied to practical implementation. Besides, local environmental changes were also challenging with many ambiguities and difficulties to be applied at a commonly agreed level. This is supposed to be ready to be implemented within the current agreement. Additional costs related to climate change resilience and advanced tool requirements for system management and operation are the dual challenges imposed over the large gap, to satisfy demand and supply for water supply and sanitation services.

This paper is a practical view from experience in water supply and sanitation development. It addresses challenges and gaps observed during practical project development, fund allocation, policy discussion, and technical and management issues in Ethiopia. The main aims were to provide insight into water supply and sanitation development in developing countries. Some of the issues are global challenges that need further efforts to improve the quality of life of urban and rural communities.

2. APPROACH TO THE STUDY

An overview of academic research and project development is provided in this paper. The challenges and gaps in water supply and sanitation development in developing countries were discussed based on the following issues: changes in the natural environment, capacity for development, policies, and operation and management of water supply and sanitation services in urban and rural contexts. Some data collection works and observations during the field were included to evaluate the problems and challenges in water supply and sanitation. The observation considers both urban and rural water supply and sanitation development. The observations were made during our work as a consultant and researcher on water supply and sanitation projects.

3. RESOURCE AND SKILL REQUIREMENTS FOR A CLIMATE-RESILIENT DEVELOPMENT APPROACH

Water supply and sanitation development need extensive technical and managerial knowledge of the science and engineering aspects. Climate resilience requires a sound understanding of climate change effects and coping mechanisms. The water sector development process was challenging even without a resilient development approach. This was a cumulative assignment that had not been completed in the past. Climate change and its dynamics are further a bottleneck problem ahead of development work. The usual development approach is in progress with all its drawbacks. However, it requires integrated knowledge to improve service, from planning to delivery. Surface water, springs, and shallow wells become increasingly unreliable. The variation in water availability after and before development was an enormous challenge. This is not due to a fault in the design, but rather to the information gap on climate change and unpredicted changes in the environment at the design stage. Requests for development are at the highest level, alongside the question of the sustainability of the existing system and unforeseen incidents.

Climate change prediction is relatively good in most metrological studies at large scales (Van Aalst 2006; Roberts *et al.* 2020). The data collected with a satellite above the area with relatively minimal interaction with humans has higher accuracy. Average climate change studies at large scale work well for most places, which is observed in most metrological studies. The challenge comes when the data on the ground station was used to downscale, calibrate, and validate the large-scale data to a local level, which was significantly affected by human interaction (Urban *et al.* 2013; Masson *et al.* 2020). The downscaling of remotely sensed data at a large scale with ground data significantly affected by human interaction was a major challenge. This is the major drawback of climate data downscaling for the local prediction. This is reflected in tremendous variation and leaves ambiguity in most predictions. In developing countries, the application of downscaled climate information was not readily available to meet the practical needs of the implementing sectors. Metrological science and engineering were not linked to climate research even at the highest level in universities. Climate change study outputs are available with many alternatives at a global scale. However, studies at the local level were not sufficiently available, and even those that have been conducted had significant variations which are not suitable for practical implementation.

The major gap in the climate-resilient development approach in developing countries is something to be implemented without sufficient knowledge of its effect. Most implementing sectors cannot readily drive climate change to the local scale. There is no common agreement or source to provide those variations to professionals working in sectors. The studies made at the different levels were not well organized to be used in practical implementation even with drawbacks. The challenge extends beyond this, as it requires a better prediction than the predicted information since it has been observed that some of the events taking place in our environment are beyond our prediction capability.

For climate-resilient development, additional investments are needed, which renders water supply and sanitation services unaffordable. The development of water supply was challenged due to inflation on the market and a lack of capacity for project development in developing countries. Climate change resilience is added to these issues, and the water supply and sanitation service become the toughest tasks. The resilience of the water sources is a challenge that demands more technology and studies on our prediction. Climate change strongly changes the availability and consistency of water from shallow wells and surface water sources. These were the major sources of community water supply in most developing countries due to their low price and ease of construction.

The development approach needs to consider all the options available to optimize water availability. Table 1 indicates that water supply and sanitation development require a combined effort for advancements in design, management, and technological support. The water potential from a river/borehole is not reliable and uncertain. Even after the appropriate pump test borehole yields varied with time. As it is known that the pumping test is carried out for up to 72 hours, this clearly indicates that further evaluation is needed. Similarly, river diversion works are not supplying water at the designed capacity. Climate-resilient development needs extra investment to use more deep wells and rivers with reliable potential. The development of such sources will require more advanced technology, knowledge, and cost. Providing intermittent water supply to the

Table 1 | Major challenges and adaptations to water supply and sanitation development in developing countries

Production capacity	Water loss	Expansion cost (new development)	Loss management cost	Extra capacity required for climate-resilient development	Climate adaptations observed
Challenged with climate and has much uncertainty	It is in a range of 20–50% in most projects (increasing on most projects) (Figure 1)	Increasing at an alarming rate	Needs additional investment costs and technology support	Extra-depth excavation and an increase in the number of boreholes	Intermittent pumping and distribution of water

system and searching for additional sources is the best way to adapt to variations in water production at the sources due to climate variability. This is a challenge to the existing system on top of the demand for upcoming developments. The intermittent supply of the existing water supply network was not considered in the initial system design. It produces a new scenario in the water supply network which was not considered in the initial design of the system. Pressure variation and the new system arrangement as a result of intermittent supply led to a higher loss and immediate pipe burst.

The water supply network systems were not designed with consideration of system management in most cases. Most systems lack an intermediate water measurement device to cross-check the water at the sources and distribution networks. The systems have a water meter at sources and endpoints (households for billing) which make water loss management hard. There is high water loss which needs equivalent intervention to the upcoming development. There are efforts to minimize water loss in the water supply system. Water loss management is a challenge that requires the use of technology with sensors and computer-based system regulation, integrated into a water supply network system (Jury & Vaux 2005). This is most challenging in developing nations that require skilled personnel with extensive knowledge of computer simulation, loss management, and advanced information technology. This is usually done to ensure efficient system operation and management in the water supply.

Based on data collected from a town water municipality, Figure 1 shows the water supply system in a large city. The system was evaluated under the following topics to show future policies and directions. These are design capacity, water production at sources, consumption, billing, loss or unaccounted water, and unused capacity. The water supply system design capacity was estimated based on the usual procedures. The system has been designed following an appropriate design procedure. Despite the fact that some of the values appeared to be ideal, a large amount of water was not available. There is a significant change in the water produced at the sources. It was observed that water was not pumped or extracted from a borehole/river as per the design. Pumping and abstraction hours were limited to a maximum of 12 h, with certain days intermittently. Here, it indicates that there is a rapid environmental change that significantly affects water abstraction from sources. The water capacity at the sources was both surface and groundwater. There is a clear alteration in water availability.

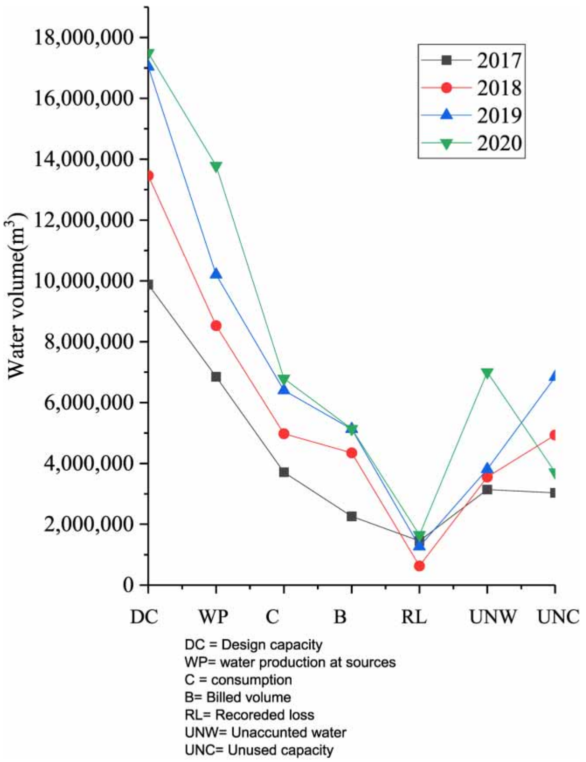

Figure 1 | Water utility data on water management (practical data collected at Hawassa town water supply and sanitation enterprise) in Ethiopia.

The data recording at a utility's production section differs greatly from the data recording at its distribution section. Of course, there is a certain acceptable loss under normal conditions. However, the overall system needs an Information Communication Technology (ICT) supported database system that improves data organization. Consumption includes loss and is billed as per the data gathered. Even in the recorded data, water loss ranges from 20 to 40%, which is a very high percentage. The billed amount is relatively low compared to the production, design capacity, and all. Unaccounted water is water recorded in the production section but not on the bill. The water was not measured at intermediate points; it is only measured at the end of the consumer's meter, indicating a failure in the planning system. There is an urgent need to install a water management system to improve service and reduce water loss. Some water may be stolen and there is a faulty metering system at the consumers' houses. Due to the variation in the environment, the unused capacity in the water system accounts for more than 35% of the volume. It is possible to conclude that 30–40% of the capacity under a normal design was not readily available for consumption due to current environmental changes.

Generally, the water supply system needs an integrated planning system with thorough understanding of the problems observed in practice. The system design at the planning stage must include a system management and loss reduction system. The qualification requirements were challenging. It required engineering, management, ICT, and updated software for design and management. The university and training center need to revise their curriculum to equip trainees to solve the prevailing challenges. The water distribution networks simulation model was intensively used for the system design. It is equally important for system management to evaluate the variation in the water distribution system due to unforeseen reasons at the planning stage. System improvement has made significant contributions to recent developments.

4. SOME PRACTICAL CHALLENGES IN WATER SUPPLY AND SANITATION DEVELOPMENT

4.1. The water supply and sanitation services in rural areas

Rural water supply and sanitation as water, sanitation and hygiene (WASH) are good approaches using water as a major development catalyst. Integrated developments include community water supply, school WASH, water facilities for health centers, and community-led total sanitation (CLTS). It significantly changes the perceptions and attitudes of the community and children in rural areas to foster water supply and sanitation improvement. The WASH approach has the advantage of bringing all relevant issues of the community to a specific place even beyond water supply and sanitation. This is an encouraging practice that must be exercised to come up with a solution for common problems of the community. Training on behavior and attitudes related to hygiene can also be practiced in this group. The major drawback of the arrangement is that all the major development issues come under one place. This makes the management of tasks for each sector difficult. Most WASH coordinating members were politically engaged with an additional task which impacted their availability during decision-making.

Sanitation and hygiene development have soft and hard components. Since it is relatively easy to apply and requires fewer resources, the soft component was in practice at most instances. Awareness creation and training on the selected community members, such as the students at the schools, model families, WASH committee members as role models, and selected community members, are convincing approaches to establish WASH practicing communities. It improves the community's attitude and perception toward a hygienic property. In most places, the community started to build a communal latrine to make open densification-free (ODF) within villages. This needs strong support from local governments to be the trend in a community. Budget allocation and prioritization of the sanitation facility were challenging in most projects. The construction of the facilities' toilets and waste management system was challenging both in terms of technology and budget requests. Model pit latrines were constructed at school and community levels. The construction of model latrines encourages some community members to build their own latrines at home. Household facilities are not up to standard and are constructed from locally available materials. Handwashing facilities were part of the component of the system including provision of soap. Although some improvements have been made in rural areas, sanitation and hygienic standards are well behind.

The water supply component has been progressing relatively well; at least more than half of the population is served in Ethiopia. Although full cost recovery is challenging, most countries recover operation costs. The operation cost recovery policy also is also challenged due to water source selection, as part of climate resilience development. Operation of a rural water supply in Ethiopia, for example, has been challenging. The operation cost recovery policy fits with a water supply system that requires less cost during the implementation phase than other systems. Shallow wells and springs are not convincing sources of climate-resilient development. As a source of water, deep wells and perennial rivers are most commonly used in community water supply systems. This incurs a high energy requirement which makes the water tariff even higher than in a big city. Grid electricity was not available everywhere. Besides, the electric supply on the places where it was available was not reliable. It required a standby energy source for the water supply system. All these circumstances make the rural water cost recovery policy questionable.

Some practical challenges relating to energy provision for water supply projects include the facts that a typical water supply projects can be far from the grid system and can require generators and fuel costs. Water tariff computation was done based on a total cost recovery and partial cost recovery in urban and rural water supply projects, respectively, in Ethiopia. The tariff setting in rural areas is based on partial cost recovery which is challenging due to the additional cost required for climate-resilient development. Even operation cost recovery is a complicated task under current development consideration needs. The tariff setup as per the policy on rural water needs to be revised. Recent developments in off-grid solar panel installations for water supply operations look attractive under the rural operation cost recovery policy. It is known that solar panel energy operation costs are relatively low. The affordability for improved water supply and sanitation needs to consider all aspects including the policy.

4.2. Water supply and sanitation development in urban areas

Water supply and sanitation in urban contexts are in progress. Climate change and operation problems have challenged the water supply system in large cities. The increase in population and rapid city development induced large water demands. The design and management of the water supply system were not well linked to climate-resilient development. The theoretical design of a water supply system needs to be revised to consider current climate change dynamics. This will significantly challenge the water supply system's operation.

The installed water network system faced water shortages which were not taken into account at the initial design. Water system sources, either rivers or boreholes, are unable to supply the full design capacity of the system. This situation enforces the utility to supply water under an intermittent program which was not initially considered in the design of water supply networks. This causes pressure variation in the network system and higher water loss. Besides, in some places, a pipe burst will occur due to high pressure in the system which further contributes to more water loss. In most water supply systems, more than 40% of water is lost without revenue which is a challenge in most water supply systems.

The increase in water demands due to population growth, rapid industrial development, socioeconomic changes, and the need for improved sanitation services all contribute to increasing the water demand abruptly. Water loss and climate change impacts and poor system management are causing water systems to fail to deliver the service required. The biggest challenges were that in most cases, the water production was measured somehow, water distribution has no measurement, and finally the billed amount. The system does not have any leakage detection and regulating mechanism at the intermediate location between sources and water meters. If water supply is not properly billed is impossible to know where the water goes. In addition, the billing system is sometimes very poor, and even the invoice is not collected on time in some cases.

The challenge in urban areas in developing countries is that the water supply implementation does not fully consider the water share for the sanitation component. This component is currently absorbing more water due to rapid economic development in urban areas of developing nations. The water demand for the sanitation component was relatively higher than predicted, which is seen as a major threat to most cities' water supply systems. Besides, rapid construction development demands more water. Water recycling is an important solution to practice. The water supply and sanitation sector need to address the forthcoming demands through integrated, holistic, and innovative system development approaches for sustainable and resilient development. The system design only focuses on the supply of water, lacking the management aspect of the water supply system. Water supply system administration requires a combined understanding of design aspects, system management, water supply network, and billing system with information technology support. It is a challenge to find skilled personnel with practical knowledge in all areas that are important to run the utilities effectively. In order to make the complex water supply system manageable, engineers and managers need to be trained in the latest skills. If loss and system management can improve, it is one of the options available which can be considered equivalent to the response to climate change adaptation. This can significantly improve water availability.

5. DISCUSSION AND RECOMMENDATION

Water supply and sanitation development must consider the current climate effect and skill requirements for sustainable water system development. Water supply and sanitation development need to strive for a holistic approach that considers engineering, management, and developing soft skills both in management and engineering. Climate change resilience development requires greater advancements in knowledge and technology. The adaptation on hand at the current state for water sources and variation on the water supply systems from the predesigned values due to climate change calls for extra investment in water sources as a reserve potential. Groundwater potential variation with climate change needs to be studied intensively at a local and global scale. Rapid depletion of shallow groundwater wells and excessive water level variation in deep groundwater wells are common on most sites. Most shallow wells and springs have become unreliable sources.

Scientific knowledge of groundwater occurrences and variations with climate and human interference needs more advanced technology and intensive research. Current climate change affects water sources for water supply and sanitation as a consequence of the water supply system design and management can no longer be effective using the old theoretical knowledge. It is imperative that universities provide training or new courses in engineering, management, and soft computational skills, as well as technologically assisted system regulation. There is a lack of integration of such disparate knowledge which can improve water supply and sanitation challenges and also all development sectors too.

The 2030 UN agenda in water supply and sanitation was significantly influenced by climate change effects and a resilient development approach today. The goal was challenged due to high inflation on the market and additional investment costs for climate-resilient development approach. The recent environmental events were far beyond predictions, showing that environmental changes need significant consideration. In water supply and sanitation development, rapid ground water depletion and high variation in surface water sources were the major events.

Research and experimentation are required to understand environmental changes accurately. More funds are needed to foster development and regulate demand and supply. A compressive training program should be provided for implementing organizations. The courses need to include recent soft skills that can significantly improve the operation and management of water supply and sanitation development. Climate change information that can be used by individuals for local implementation should be easily available. Detailed ground water investigation at a local level needs to be carried out to improve information for future development.

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AUTHORS CONTRIBUTIONS

A.T.B. conceptualized, prepared the methodology, prepared model setup, did data curation, wrote the draft, prepared the manuscript, and edited work. G.A.Y.A. visualized the study, investigated the study, validated, wrote, reviewed, and edited the article.

DATA AVAILABILITY STATEMENT

Data cannot be made publicly available; readers should contact the corresponding author for details.

CONFLICT OF INTEREST

The authors declare there is no conflict.

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