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Assessment of a Rural Water Supply System: A Basis for Sustainable Water Resource Management

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ABSTRACT

This study assessed the water supply systems in the Municipality of Alcala, Cagayan, Philippines, to support sustainable water resource management, focusing on socio-demographic conditions, infrastructure status (groundwater sources, pipeline distribution, storage, and treatment), water quality compliance with Philippine National Standards for Drinking Water (PNSDW), and governance aspects such as availability, quality, affordability, and responsiveness. Using a mixed-methods approach that combines surveys, laboratory analysis, statistical tools, interviews, and field observations selected barangays, the findings revealed significant disparities in access, infrastructure, and management. Groundwater is still the main source, but many systems lack permits, monitoring equipment and adequate safeguards against contamination, especially during floods. Many barangays have no formal systems, and there are those that have partial coverage, limited treatment and inconsistent maintenance. Water quality is monitored, but treatment is still inadequate. Communities are concerned about reliability, affordability, and governance. Water resources are available, but sustainability is challenged by infrastructure gaps, weak regulation, climate risks and limited technical capacity pointing to the need for better governance, infrastructure development, better water quality management and climate resilient, community-based approaches.

Keywords: *Water Supply Systems, Sustainable Water Resource Management, Water Quality Assessment, Climate-Resilient Infrastructure, Water Governance*

INTRODUCTION

Water is a basic necessity of life, the sustainability of ecosystems and socio-economic development and is critical for life. It is the foundation of public health, food production, energy production and industrial operations and is therefore crucial to sustainable development. While the Earth is abundant in water, clean and accessible freshwater is unevenly distributed across the globe. Recent studies have shown that this is no longer only a problem of water quantity, but also of water quality, access and governance due to rapid global change (Jones et al., 2024; Shemer et al., 2023).

Water is the most significant natural resource of the planet and plays an important role in agriculture, manufacturing, sanitation and total economic production. Its effective management is crucial not just for food security and poverty alleviation but also to avoid water-related health problems. But growing populations, environmental degradation and the increasing impacts of climate change are putting serious pressure on the world's freshwater resources, especially in poor countries..

ISSN: 3116-3475
International Journal
of Education, Research, and Innovation Perspectives
Volume 2 Issue 11 (November 2026)

"Good management of water supply systems is fundamental to health, economic stability and social equity" (World Health Organization, 2020). Water scarcity is expected to affect roughly 2 billion people by 2030 (Naeem et al., 2023) and 45% of the world's population may live in water-stressed areas by 2050 (Zghibi, 2023). These estimates make sustainable water planning and resource management a worldwide problem.

The difficulties highlight the need for intervention from the global sustainability agenda specifically Sustainable Development Goal 6 (Clean Water and Sanitation) which underscores the necessity of universal and equal access to clean and cheap drinking water. Promising methods to increase water supply and create resilience include innovative approaches such as wastewater reuse, desalination and rainwater collecting (Ssekyanzi et al., 2024). However, achieving sustainable water security ultimately requires aligning policy, technology, and community engagement to drive collective action.

Scarcity and poor water quality have become a significant concern worldwide. Recent data show that about 56% of monitored water bodies around the world are meeting good water quality standards, with pollution from agriculture and untreated wastewater posing significant risks (UN SDG Report, 2024). Inclusion of water quality in shortage estimations shows that the population vulnerable to water stress is drastically overestimated when quality components are omitted (Jones et al., 2024). This highlights the need for a more comprehensive approach of water security that includes both quantity and quality dimensions.

While global access to improved drinking water sources has continued to increase in recent years, rural communities remain disproportionately underserved, particularly in developing countries (World Health Organization, 2023; UNICEF & WHO, 2023). This disparity globally is also seen in many developing countries, such as the Philippines, where there are gaps in safely managed drinking water services between urban and rural areas due to infrastructure limitations, governance issues and resource constraints (World Bank, 2023; National Water Resources Board, 2023).

The Philippines is endowed with a wealth of surface and groundwater resources owing to its tropical environment and wide hydrological network. Surface water is the main source of water for the agriculture, industry and home consumption of the country while ground water is a life line for the rural areas. Natural water is abundant yet there are major issues facing water availability including uneven distribution, contamination, lack of modern infrastructure and limited access in rural areas (Ausan et al., 2023).

The Philippines is endowed with abundant water resources due to its tropical environment, several river systems and significant groundwater reserves. Surface water is the main source of water supply for agriculture, industry and domestic usage, while groundwater is also a vital source of drinking water, especially for rural and remote communities. The country continues to face significant issues in water management, including unequal distribution of water resources, deterioration of water quality due to pollution, aging and insufficient infrastructure, and limited access to safe and dependable water services in underserved areas (Ausan et al., 2023). These concerns highlight the need for improved water resource planning and sustainable management strategies to provide equitable and long-term access to water in the country.

For instance, water systems for rural villages are generally underfunded and poorly maintained. Chronic problems, including poor infrastructure, low technical capacity and operational and maintenance inefficiencies, continue to impair rural water systems and have serious implications for service reliability and access to water (Magwilang et al., 2023; Kedir, 2023). In many developing contexts, such systems are compromised by financial restrictions and poor institutional support. The system often breaks down, and its utility diminishes over time. This low performance and frequent failure are typically driven by a lack of institutional support.

ISSN: 3116-3475
International Journal
of Education, Research, and Innovation Perspectives
Volume 2 Issue 11 (November 2026)

The growing need for water, the rising concerns over climate change, and the stress of aging infrastructure are compelling communities to establish proactive, inclusive, and sustainable approaches to water management. Recent studies have shown that climate change has a substantial impact on water availability and performance of infrastructure, which leads to higher system failures, operating stress and increased maintenance demands (Żywiec et al., 2024; Lyle et al., 2026). But decades of underinvestment and outdated water systems have created major infrastructure gaps, requiring substantial efforts to replace and modernize water infrastructure to deliver reliable service (Pew Charitable Trusts, 2024; American Water Works Association, 2024). Additionally, urbanization and evolving climate trends intensify the stress on municipal water systems, necessitating adaptive planning and climate-resilient strategies for water governance frameworks (Vinagre et al., 2023; Nydrioti et al., 2024).

Water resource management is a challenging but necessary task in a typical rural and third-class municipality of Alcala, Cagayan in the northeastern portion of the Philippines. It has a land area of 168.64 square kilometers and a population of 41,468 as per the 2024 Census. Alcala is an agricultural municipality comprising of 25 barangays. The majority of people depend on local water sources for domestic, agricultural and livelihood needs.

Alcala has a history of hydrometeorological disasters, especially flooding and drought, which have direct impact on the availability, dependability and safety of its water supply system. Climate-related disasters continue to harm water infrastructure and public health particularly in rural areas with little resources and technical knowledge (Asian Development Bank, 2024; World Bank, 2023).

Alcala is a third class municipality that can have restrictions in terms of financial resources, infrastructure development and technical support that can affect the operation, maintenance and sustainability of its water delivery systems. The city has its own municipal water system. Some barangays have their own water system also. However, the barangay water systems are under the supervision of local authority for basic operations and upkeep.

Alcala has considerable potential for water resources, but it suffers from uneven access, infrastructure limits, system reliability, and costly management practices.

These challenges highlight the need for greater governance, planning and sustainable water management practices to ensure reliable, safe and equitable water supply to all populations.

Research Objectives

This study aimed to evaluate the current water supply conditions in Alcala, Cagayan. Specifically, it sought to:

1. Determine the socio-demographic profile of all barangays in Alcala, Cagayan, focusing on:
    a. Number of Household
    b. Average person per household
    c. Average income per household
    d. Worst-case flood experience
    e. Water supply access and management
2. Examine the status of water supply systems in all barangays of Alcala, Cagayan in terms of:
    a. Groundwater Source
    b. Pipeline Distribution
    c. Water Storage Facility
    d. Water Treatment Facility
3. Determine the extent of compliance of the groundwater source and consumer tap in each barangay with the national water quality standards in terms of major water quality components, including microbiological, physical, and chemical parameters:
    a. Total Coliform/Thermotolerant/E.coli/HPC

ISSN: 3116-3475
International Journal
of Education, Research, and Innovation Perspectives
Volume 2 Issue 11 (November 2026)

b. pH
c. Turbidity
d. Nitrate
e. Arsenic
f. Cadmium
g. Lead
h. Total Dissolved Solids
i. Color
j. Chlorine Residual
k. Iron
l. Manganese

4. Determine the level of community experience and governance of respondents regarding the municipal/barangay water supply systems, specifically in terms of:
   a. Water availability
   b. Water quality
   c. Water tariff set by the municipal/barangay
   d. Responsiveness of municipal/barangay officials to water supply issues
5. Identify other challenges encountered in the operation and management of water supply systems.
6. Formulate a sustainable water resource management framework for Alcala, Cagayan based on the assessment of the existing water supply systems of the barangays.

Literature Review

Underpinning Theory

The philosophy of sustainable development highlights the need to balance present water needs with future water availability. It promotes environmental stewardship, economic viability and social inclusion, which are the key principles of the existing sustainable water governance frameworks (UN, 2024; UN-Water, 2023). Fagundes et al. (2023) apply this theory to evaluate the affordability and accessibility of water services in developing metropolitan contexts. They contend that pricing policies should consider equity to prevent the exclusion of vulnerable populations.

Besides, a further study by Adeoti et al. (2025) shows that the adoption of smart water management technologies results in sustainability through reducing non-revenue water and better service delivery thereby fulfilling the long-term objectives of Sustainable Development Goal 6 (Clean Water and Sanitation for All).

Water in Asian Context

Water issues in Asia remain very critical as the area still struggles with the challenge to provide fair access to quality drinking water and sanitation services. In Asia, hundreds of millions of people still lack access to safely managed drinking water and over a billion people lack access to adequate sanitation facilities, mainly in South and Southeast Asia (UNICEF & WHO, 2023; Asian Development Bank, 2024). Water resources of the region are already stretched, the pressure is enhanced by rapid population increase, urbanization and industrial expansion. Climate change is making these difficulties more acute by modifying precipitation patterns, increasing the incidence of droughts and floods, and decreasing water supply in many regions of Asia (Intergovernmental Panel on Climate Change, 2022; World Bank, 2023).

A large part of Asia's population will be living in areas of increased water stress by 2050, with serious consequences for food security, livelihoods and regional stability, according to current climate forecasts. Reduced availability of freshwater is expected to have severe impacts on agricultural output, raise

the danger of water-related conflicts, and cause migration in vulnerable areas (Asian Development Bank, 2024; UN-Water, 2023). Despite these limitations, Asia has made great progress in improving coverage of improved drinking water infrastructure during the last decades. But the differences are stark, especially in rural and low-income areas, where access to safely managed services lags behind that in urban areas.

While India is endowed with abundant water resources, these assets are under increasing stress due to rapid population growth, accelerating urbanization, and climate change variability. India's overall renewable water resources are still large as per the recent estimates but their spatial and temporal distribution is highly uneven and many regions are under severe water stress now (NITI Aayog, 2023; World Bank, 2023). Water resources are obtained from several sources, including as surface water, groundwater, precipitation, and natural storage systems like lakes and reservoirs. Together, these sources provide irrigation, residential supply, and hydropower generation (Central Water Commission, 2023). Major reservoirs and dams continue to play a crucial role in water storage and allocation, especially for agriculture, which remains the greatest consumer of water in the country (International Commission on Large Dams, 2023).

Philippine literature still highlights the importance of strengthening the capacity of local government units (LGUs) and water districts in planning, regulation, and resource management. Recent studies (World Bank, 2023; Asian Development Bank, 2024) indicate that decentralized water governance in the Philippines needs enhanced technical capacity, data-driven planning, and improved institutional coordination to tackle the increasing water demand and climate-related risks. Water resource evaluations at the local level are still relevant to inform policy and investment decisions, especially in regions of growing urbanization and environmental vulnerability where water stress is becoming more apparent (National Water Resources Board, 2023).

National efforts to increase access to safe and potable water in underserved and rural communities are still evident in government programs such as the Sagana at Ligtas na Tubig sa Lahat (SALINTUBIG) program and its successor frameworks. However, recent assessments point out persistent challenges such as limited monitoring systems, sustainability concerns, and the need for more robust post-project support and community engagement mechanisms (Department of the Interior and Local Government, 2023; National Economic and Development Authority, 2024). Furthermore, contemporary research emphasizes that climate resilience, better governance accountability, and increased operational capacity of local service providers are needed to attain the sustainability of water supply projects in the Philippines (UNICEF Philippines, 2022; World Health Organization, 2023).

Climate change presents new problems to the sustainability of water supply. More frequent droughts, floods and changing rainfall patterns threaten water supply and infrastructure. David et al. (2020) stressed the importance for local water districts in the Philippines to embrace climate-resilient planning to reduce disturbance and ensure future water supply.

Many communities in the Philippines continue to struggle with water distribution, service reliability, and resource depletion. Magwilang et al. (2023) noted that infrastructural constraints and poor demand management were significant impediments to appropriate supply and distribution in a research on Bontoc's municipal water works.

Sustainable Water Management

Their research focused on the growing demand for integrated assessment methods that address both the technical and social elements of water supply management. The majority of the existing assessment models pay too much attention to infrastructure and efficiency and mostly disregard the social participation and resilience of the system. Chapagain et al. (2024), on the other hand, emphasized community involvement and flexibility to future hazards, recognizing the significance of stakeholder participation in sustaining long-term sustainability.

ISSN: 3116-3475
International Journal
of Education, Research, and Innovation Perspectives
Volume 2 Issue 11 (November 2026)

Marques, et al. (2022) examined how water policies can help achieve sustainable water resources management in the face of climate change, and critically reviewed how policy design, implementation and institutional arrangements affect long-term water sustainability. Published in the Journal of Hydrology, their work bridges the gap between technical water management techniques and the wider socio-political context in which water decisions are decided.

A major feature of the Sharma et al. (2023) model is its capacity to accept uncertainty and unpredictability through scenario analysis, making it particularly helpful in places exposed to climate change and hydrological stress. Also, the inclusion of social and institutional components is a sign of the rising realization in the literature that water system sustainability cannot be guaranteed solely by technical performance.

Climate change makes problems with water supply worse because it changes rainfall patterns, making sources less reliable and more likely to cause droughts. Cacal et al. (2024) employed WEAP modeling in Puerto Princesa to model streamflow variability and offered adaptive IWRM-based measures to secure future water security.

Water Supply System

A sustainable water system includes well-maintained infrastructure. Recent global assessments show that aging pipelines, inadequate storage facilities and chronic underinvestment in operation and maintenance continue to be major sources of inefficiency and service failure of water supply systems, especially in developing countries (World Bank, 2023; Asian Development Bank, 2024). This is compounded by limited local level technical capacity and poor institutional support resulting to declining system reliability and growing water losses.

The literature has recently been updated by David et al. (2020) with studies that demonstrate that climatic variability continues to strongly impact local water service providers in the Philippines. Current systems are still exposed to seasonal shortages and adverse weather conditions without appropriate adaption mechanisms. Recent research stresses the importance of strengthening the capacity of local government units (LGUs) and adopting climate-resilient planning techniques, such as hydrological modeling and scenario-based forecasting, to promote the sustainability of the system (Nydrioti et al., 2024; World Bank, 2023).

Over extraction of groundwater and pollution of water bodies are serious environmental issues. Recent global research indicates that aquifer depletion, land subsidence and water quality deterioration are driven by unsustainable groundwater use, notably in quickly urbanizing portions of Asia (FAO, 2022; Asian Development Bank, 2024). In the Philippines, pressures from growing urbanization and watershed degradation continue to bear down on freshwater resources, underscoring the need for updated assessments and integrated water resource management plans (National Water Resources Board, 2023).

Water Quality in Sustainability

Water quality is a key determinant of sustainability of water delivery systems. Water contamination is a serious problem for public health and also damages the confidence of users in water service providers. Recent studies have highlighted the importance of continuous monitoring, risk assessment and enforcement of regulations as critical parts of sustainable water management systems for effective water quality governance (World Health Organization, 2023; UNICEF & WHO, 2023).

The Philippine National Standards for Drinking Water (2017) defined safe drinking water as water that is free from dangerous bacteria, chemicals and other impurities that may cause adverse health effects. When these criteria are not reached, water quality problems develop especially in terms of microbiological, physical, chemical and radiological parameters used in assessing water safety (DOH, 2017).

ISSN: 3116-3475
International Journal
of Education, Research, and Innovation Perspectives
Volume 2 Issue 11 (November 2026)

Safe drinking water is still a major public health concern particularly for low income and rural locations. Recent global research shows that polluted water is a major factor in waterborne infections, with microbiological and chemical pollution leading to millions of cases per year (World Health Organization, 2023). This highlights the need for enhanced surveillance methods and greater control of water safety to reduce health concerns and ensure reliable service provision.

More recently, in South Asia, Mahmud et al. (2021) discovered that Water Safety Plans led to significant reductions in microbial contamination in both piped and non-piped systems. They observed that incorporating Water Safety Plans within national regulatory frameworks enhances institutional accountability and compliance.

Ausan et al. (2023) conducted a sustainability assessment of a community water system in Magalang, Pampanga. The study revealed that while infrastructure was in place, water quality often failed to meet Philippine standards due to microbial contamination. The researchers recommended regular monitoring and public engagement to enhance system sustainability.

Monitoring and assessment are vital to maintaining high water quality standards. Gil-Samaniego et al. (2020) emphasized the importance of using methodological frameworks in industries to assess the sustainability and safety of water use, which includes continuous water quality testing and risk management protocols.

In the Philippines, the Department of Health (DOH) and Local Water Utilities Administration (LWUA) have promoted Water Safety Plan adoption under the Philippine National Standards for Drinking Water (PNSDW), aligning national efforts with WHO guidelines. Local studies such as that of Agustin et al. (2018) support the finding that WSP implementation enhances risk awareness and preventive maintenance in barangay-managed water systems.

Water Resources Management in the Philippines

Local studies in the Philippines, such as those by Cruz & Mercado (2019), stress the importance of involving local government units and barangays in water management initiatives. Community-based water monitoring has shown promising results in improving accountability and ensuring that water systems are maintained and responsive to users' needs. These findings align with the decentralized governance framework of the Local Government Code of the Philippines (RA 7160), which mandates local governments to take an active role in basic service delivery, including water.

Effective water governance is critical in ensuring sustainable water supply. Recent Philippine studies highlight that water governance involves complex interactions among national agencies, local government units, and water districts, where institutional fragmentation and overlapping mandates continue to affect efficiency and service delivery (Rola et al., 2024; Evangelista & Billones, 2024). In the Philippine context, the National Water Resources Board (NWRB) and Local Water Utilities Administration (LWUA) regulate water supply development, while local government units (LGUs) play a crucial role in implementation. However, recent policy analyses emphasize that unclear institutional roles and fragmented governance structures remain major barriers to effective water resource management (Senate Economic Planning Office, 2024; World Bank, 2023).

Understanding water consumption patterns and user behavior is essential for effective demand-side management in the Philippines. Recent studies show that household water demand is strongly influenced by socio-economic conditions, infrastructure reliability, and supply availability, particularly in urban and peri-urban communities (National Water Resources Board, 2023; Philippine Statistics Authority, 2024). These factors highlight the importance of integrating behavioral and socio-economic considerations into water conservation and planning strategies.

The decentralization of water services gives local government units (LGUs) and barangays greater authority to plan, implement, and manage water supply systems. Recent literature indicates that decentralized water governance can improve responsiveness, efficiency, and accountability when

ISSN: 3116-3475
International Journal
of Education, Research, and Innovation Perspectives
Volume 2 Issue 11 (November 2026)

adequately supported by technical capacity, financing, and community participation (Asian Development Bank, 2024; World Bank, 2023). However, the effectiveness of decentralization in the Philippines remains constrained by institutional fragmentation and uneven capacity across LGUs.

In the Philippine context, the Local Government Code (Republic Act No. 7160) continues to empower LGUs in the delivery of basic services, including water supply management. Recent assessments show that while decentralization has improved local autonomy, challenges such as inadequate funding, overlapping institutional mandates, and limited technical support continue to hinder effective water governance and service delivery (National Economic and Development Authority, 2024; Department of the Interior and Local Government, 2023). Strengthening inter-agency coordination and local capacity-building is therefore essential for improving the sustainability of water systems in decentralized settings.

In barangay-managed and community-based water systems, recent findings suggest that active community participation improves accountability and system functionality. However, many systems still experience operational challenges due to limited technical expertise, insufficient maintenance, and weak long-term planning (UNICEF Philippines, 2022; Asian Development Bank, 2024). These studies highlight the need for continuous training, financial support, and institutional strengthening to sustain rural and local water systems.

Climate change impacts, such as prolonged droughts and intense rainfall, affect water supply reliability and infrastructure resilience. In the Philippines, studies by David et al. (2020) showed that local water service providers must incorporate climate adaptation strategies into planning to ensure long-term sustainability.

The reviewed literature emphasizes that sustainable water supply remains a significant challenge, particularly in Asia, where rapid population growth, urbanization, climate change, and increasing water demand continue to place pressure on water resources. While access to improved water services has expanded, many rural and low-income communities still experience inadequate water supply, poor service reliability, and vulnerability to climate-related hazards such as droughts and floods. These conditions highlight the need for climate-resilient and sustainable water management strategies that ensure equitable access to safe and reliable water.

The literature further reveals that sustainable water systems depend not only on adequate infrastructure but also on effective governance, water quality management, community participation, and institutional capacity. Studies consistently emphasize the importance of regular water quality monitoring, climate adaptation measures, stakeholder engagement, and strengthened local government capabilities in achieving long-term sustainability. In the Philippine context, decentralized water governance offers opportunities for improved service delivery, but challenges related to technical expertise, funding, maintenance, and institutional coordination remain. These findings support the need for localized assessments to guide evidence-based interventions and enhance the sustainability of water supply systems.

Research Paradigm

The researcher theorizes that the sustainability of water resource management is the ultimate outcome of the study, representing the integration of technical, social, and governance dimensions. This sustainability is shaped by the socio-demographic profile of households and the status of the water supply system, which together influence compliance with national water quality standards. Compliance then affects both community experience and governance as well as the challenges faced in operation and management. Governance and challenges interact dynamically, reinforcing or undermining each other, and their combined effects converge with compliance to determine whether water resource management can remain equitable, efficient, and resilient over time.

ISSN: 3116-3475
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of Education, Research, and Innovation Perspectives
Volume 2 Issue 11 (November 2026)

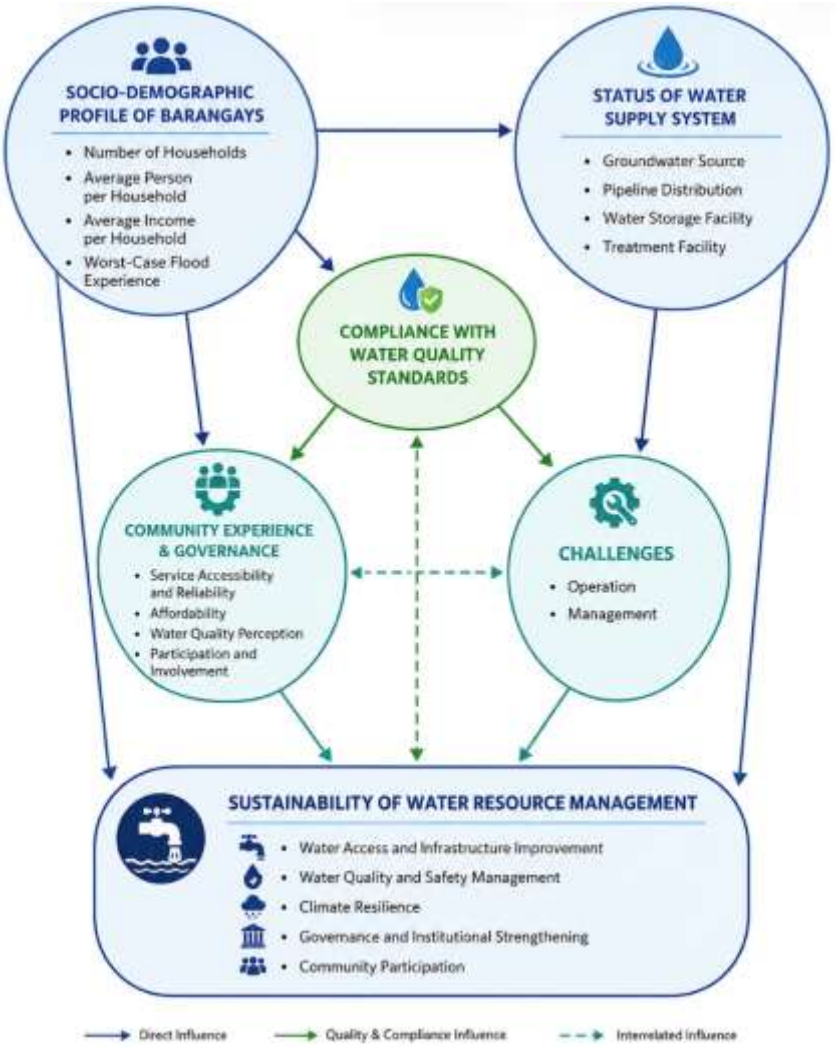


Figure 1: *Conceptual Framework*

The output of the paradigm is the development of a Sustainable Water Resource Management Framework for Alcala, Cagayan. This framework serves as a basis for improving water access, ensuring water quality, strengthening governance, and promoting the long-term sustainability of the rural water supply system.

METHODS

Research Design

This study employed a mixed-methods descriptive case study design, focusing on the Municipality of Alcala, Cagayan as the single case under investigation. As a predominantly rural municipality that relies heavily on groundwater-based water supply systems and is frequently exposed to flooding, Alcala represents a typical rural community facing challenges in achieving sustainable water resource management. A case study approach was appropriate because it allowed an in-depth examination of the municipality's water supply conditions, management practices, governance mechanisms, and community

ISSN: 3116-3475
International Journal
of Education, Research, and Innovation Perspectives
Volume 2 Issue 11 (November 2026)

experiences within their real-world context. Since these conditions may differ from those of other municipalities, a case study provided a comprehensive understanding of the unique factors influencing water sustainability in Alcala.

The study integrated both quantitative and qualitative methods to provide a holistic assessment of the municipality's water supply systems. The quantitative component included structured household surveys, documentary analysis, and laboratory testing of water samples to determine the status of water supply systems, the level of community experience and governance, and the extent of compliance of groundwater sources and consumer taps with national drinking water quality standards. The qualitative component involved interviews with municipal and barangay officials, field observations, and thematic analysis of responses to open-ended survey questions regarding challenges encountered in water supply management and service delivery. The integration of quantitative and qualitative findings enabled a more comprehensive understanding of the technical, social, and governance dimensions of sustainable water resource management in Alcala, Cagayan.

Locale of the Study

The study was conducted in Alcala, a third-class municipality in the Province of Cagayan, Philippines, located in the northeastern part of Luzon within the Cagayan Valley Region. Geographically, Alcala lies along the Cagayan River, the longest river in the country, which strongly influences its physical environment, agricultural activities, water resources, and exposure to flooding. The municipality is characterized by low-lying floodplains, agricultural areas, and gently rolling terrain, making it suitable for rice and corn production but also vulnerable to flood events, especially during heavy rainfall and river overflow.

The study focused on five selected barangays that are dependent on groundwater as their primary source of water supply and have existing community water supply systems. The selection of these barangays was based on two criteria: (1) they are among the most populous barangays in the municipality, and (2) they rely on organized groundwater-based water supply systems for domestic use. These characteristics make them suitable representatives for assessing community experiences and governance practices related to water supply management. Their dependence on groundwater is particularly important because flooding may affect water safety through possible contamination, while prolonged dry periods may influence water availability and reliability.

The selected barangays were dispersed across different areas of the municipality to represent varying physical and environmental conditions, particularly in relation to flood exposure, proximity to the Cagayan River or its tributaries, elevation, settlement pattern, and agricultural land use. This distribution allowed the study to capture differences in water supply conditions among barangays located in flood-prone lowland areas and those situated in relatively less flood-exposed locations. By selecting highly populated barangays with established water supply systems and varying environmental settings, the study provided a more comprehensive basis for assessing groundwater dependence, water quality, community experiences, and governance of barangay water supply systems in Alcala.

Respondents of the Study

The respondents of the study consisted of two groups: barangay officials or water supply system personnel, and household respondents from the five selected barangays of Alcala, Cagayan. The barangay officials or water supply system staff answered Parts 1 and 2 of the questionnaire, which covered the Barangay Socio-Demographic Profile Survey and the Status of the Water Supply System. These respondents provided information on the profile, operation, management, and existing condition of the barangay water supply systems.

ISSN: 3116-3475
International Journal
of Education, Research, and Innovation Perspectives
Volume 2 Issue 11 (November 2026)

Meanwhile, the household respondents answered Part 3 of the questionnaire, which focused on the Community Experience and Governance of Respondents Regarding the Municipal/Barangay Water System. The five barangays were selected based on two criteria: they were among the top five barangays with the highest population according to the 2024 Census, and they had an existing water supply system serving the community.

The number of household respondents was determined using Slovin's formula at a 5% margin of error and was distributed among the five selected barangays using stratified random sampling. Due to the varying availability of household respondents, data gathering was conducted during scheduled barangay assemblies to maximize participation and ensure adequate representation from each barangay. The distribution of household respondents is presented in Table 1.

Table 1. *Respondents in Community Experience and Governance in Alcala, Cagayan*

Barangay	Population	Respondents	Percentage (%)
Afusing Daga	3158	84	23
Baybayog	2246	60	17
Calantac	2643	70	19
Centro Sur	2953	79	22
Tupang	2601	69	19
Total	13601	362	100

Research Instrument

The questionnaire used in the study was a structured researcher-made instrument designed to gather both quantitative and qualitative data on the barangay water supply systems. It was composed of three major parts: the barangay socio-demographic profile, the status of the water supply system, and the community experience and governance of respondents regarding the municipal/barangay water system.

Part I gathered information from barangay informants on the barangay profile, including number of households, population, average household size, estimated income, environmental risks, and water supply access and management. Part II focused on the technical status of the water supply system, including groundwater source, pipeline distribution, water storage facility, and water treatment facility. Part III was answered by household respondents and assessed their experiences in terms of water availability, water quality, water tariff, and responsiveness of barangay officials using a five-point scale, with an open-ended question on challenges encountered in the operation and management of the water supply system.

The qualitative component of the questionnaire includes the open-ended items on the description of water supply access and management in Part 1, as well as the challenges encountered in the operation and management of water supply systems in Part 3.

To complement the assessment, water samples from groundwater sources and household taps were collected from strategic locations in Alcala, covering barangays situated on both sides of the Cagayan River, and were subjected to laboratory testing to determine their quality. The laboratory test results served as the primary and objective basis for assessing water quality, while the survey responses provided information on residents' perceptions and experiences regarding water quality. The survey findings were then used to support and validate whether community perceptions were consistent with the actual laboratory results.

To enhance the quality and appropriateness of the research instrument, the questionnaire underwent expert validation by professionals from the Tumauini Water District and the Metropolitan Tuguegarao Water District. It was also reviewed by research experts to determine the relevance, clarity, and alignment

ISSN: 3116-3475
International Journal
of Education, Research, and Innovation Perspectives
Volume 2 Issue 11 (November 2026)

of the questionnaire items with the objectives of the study. Recommendations from the validators were incorporated to refine the instrument and ensure that it adequately captured the information required for the investigation.

Data Gathering Procedure

Prior to data collection, the researcher secured permission from the Municipality of Alcala, Cagayan. Upon approval, the researcher coordinated with key barangay personnel to access the respondents through scheduled barangay assemblies.

The researcher personally administered the structured questionnaire to the designated participants in each barangay. Before distribution, the researcher explained the objectives of the study, assured the confidentiality of responses, emphasized voluntary participation, and discussed the potential benefits of the study. The researcher also explained the different parts of the questionnaire to ensure that the participants clearly understood the items. Any questions or clarifications raised by the respondents while answering the questionnaire were promptly addressed by the researcher.

For the testing of groundwater sources and consumer/household tap water, the water sampling procedure strictly followed the guidelines prescribed in the 2017 Philippine National Standards for Drinking Water (PNSDW). Proper sampling, handling, preservation, and transport protocols were observed under the monitoring of a Licensed Sanitary Engineer to ensure the integrity and representativeness of the collected samples. All samples were tested and analyzed by Platinum Research Laboratory, Inc., a third-party accredited laboratory located in Quezon City.

The testing included microbiological examination for Total Coliform, Thermotolerant Coliform/Escherichia coli, and Heterotrophic Plate Count (HPC). The physical-chemical analysis covered pH, turbidity, nitrate, arsenic, cadmium, lead, total dissolved solids, color, residual chlorine, iron, and manganese. For chlorine residual test, the researcher conducted analyzed immediately because chlorine dissipates rapidly.

The results of these analyses were used to determine the compliance of the barangay water supply with the PNSDW and to assess the overall safety and quality of drinking water provided to consumers.

Data Analyses

The quantitative data were analyzed using frequency and percentage distribution for the profile of respondents and barangays, while mean and weighted mean were used to determine the level of community experience and governance. The computed means were interpreted using a descriptive scale provided in Table 2.

Table 2. *Scale for Household Response on Level of Community Experience and Governance*

Numerical Range	Interpretation	Description
1.00-1.80	Very Good	Very favorable condition
1.81-2.60	Good	Favorable condition
2.61-3.40	Fair	Acceptable but needs improvement
3.41-4.20	Poor	Unfavorable condition
4.21-5.00	Very Poor	Very unfavorable condition

For the water quality assessment, the laboratory results were analyzed through comparative analysis by comparing each parameter with the allowable limits set by the 2017 Philippine National Standards for Drinking Water (PNSDW) as shown in Table 3.

ISSN: 3116-3475
International Journal
of Education, Research, and Innovation Perspectives
Volume 2 Issue 11 (November 2026)

Table 3. *PNSDW Parameter Standards*

Parameter	Unit	PNSDW Standard Limit
Thermotolerant coliform / E. coli	MPN/100ml	<1.1
Heterotrophic Plate Count (HPC)	CFU/ml	500
pH	pH units	6.5 – 8.5
Turbidity	NTU	≤ 5
Nitrate (as NO_3)	mg/l	≤ 50
Arsenic	mg/l	≤ 50
Cadmium	mg/l	≤ 0.003
Lead	mg/L	≤ 0.01
Total Dissolved Solids (TDS)	mg/L	600
Color	CU	≤ 10
Chlorine Residual	mg/l	0.3-1.5
Iron	mg/l	1.0
Manganese	mg/l	0.40

The number of parameters that complied with the standards was then used to determine the extent of compliance as shown in Table 4.

Table 4. *Interpretation of Extent of Compliance with the 2017 PNSDW*

Percentage of Parameters Complied	Extent of Compliance	Interpretation
81% - 100%	Very Great Extent	The water sample complied with almost all or all required parameters.
61% - 80%	Great Extent	The water sample complied with most of the required parameters.
41% - 60%	Moderate Extent	The water sample complied with about half of the required parameters.
21% - 40%	Limited Extent	The water sample complied with only a few required parameters.
0% - 20%	Not Compliant	The water sample failed to comply with most or all required parameters.

The percentage of compliance in Table 4 was computed by dividing the number of parameters that met the allowable limits by the total number of parameters tested, multiplied by 100.

The qualitative data from open-ended responses, interviews, and field observations were analyzed using thematic analysis. Responses were grouped into recurring themes such as water availability, water quality concerns, maintenance issues, governance practices, and challenges in water system operation. The

ISSN: 3116-3475
International Journal
of Education, Research, and Innovation Perspectives
Volume 2 Issue 11 (November 2026)

quantitative and qualitative results were then integrated through triangulation, allowing the survey findings, laboratory results, and qualitative responses to support and validate one another.

Ethical Considerations

Participation in this study was completely voluntary, and no form of coercion was used in recruiting respondents. Prior to data collection, informed consent was obtained through a written consent form attached to the questionnaire, explaining the purpose of the study, research procedures, duration of participation, possible risks and benefits, confidentiality measures, and the respondents' right to refuse or withdraw from participation at any time without penalty. Answering the questionnaire took approximately 15-30 minutes. The possible risks were minimal and involved only slight inconvenience in answering the questions, while the potential benefits included contributing information that may help improve the sustainability, accessibility, and quality of water supply systems in the selected barangays of Alcala.

The researcher declared no conflict of interest in the conduct of the study. All information gathered were treated with strict confidentiality, and respondents' identities remained anonymous through the use of codes instead of names. The collected data were securely stored and used solely for academic and research purposes. Only the researcher and authorized adviser have access to the data, and results were presented in summarized form to protect the identity of the respondents. Furthermore, the research proposal was submitted to the Research Ethics Board (REB) for ethical review and approval prior to the conduct of the study.

RESULTS AND DISCUSSION

Socio-demographic Profile of Barangays in Alcala, Cagayan

The socio-demographic profile of the barangays in Alcala, Cagayan provides an essential baseline for understanding the characteristics of the population and households within the study area.

Household Information

Table 5. *Household Information of Barangays in Alcala, Cagayan.*

Statistical Measure	Number of Households	Population	Average number of persons per household	Average household monthly income (Php)
Maximum	902	3548	5	10000
Minimum	106	423	3	3000
Average	454	1816	4	5,522

Table 5 presents the household information of the selected barangays in Alcala, Cagayan in terms of number of households, population, average household size, and average monthly income. The data show that the largest barangay had 902 households with a population of 3,548, while the smallest barangay had 106 households with a population of 423. On the average, the selected barangays had 454 households and a population of 1,816. This shows variation in the size of the barangays included in the study, which may also influence the level of demand for water supply services (Leon et al., 2026).

In terms of household size, the average number of persons per household ranged from 3 to 5, with an overall average of 4 persons per household. This suggests that the selected barangays have moderate household sizes, which may contribute to regular domestic water demand for drinking, cooking, washing, sanitation, and other household activities (Bautista et al., 2025). Barangays with larger populations and

ISSN: 3116-3475
International Journal
of Education, Research, and Innovation Perspectives
Volume 2 Issue 11 (November 2026)

more households are expected to require greater water supply capacity, wider distribution coverage, and more consistent system maintenance (Sukardi et al., 2024).

The average monthly household income ranged from Php 3,000 to Php 10,000, with an overall average of Php 5,522.00. This indicates that the selected barangays are generally rural communities with relatively low income levels. Such economic condition may affect the affordability of water tariffs, the willingness and capacity of households to pay water fees, and the ability of the community to support maintenance, repair, and improvement of the water supply system (Alam, 2022).

The household profile suggests that sustainable water resource management in the selected barangays should consider both population demand and economic capacity. While the communities require reliable and safe water supply, their limited household income may constrain cost recovery and long-term system sustainability (Abeje et al., 2025). Thus, water management strategies should be affordable, community-based, and supported by appropriate technical and institutional assistance.

Flood Risk Scenario

Table 6. *Flood Risk scenario of Barangays in Alcala, Cagayan.*

No.	Barangay	Yes	No	Partially	Worst Flood Experience
1	Abbeg			✓	Rising water level of the Cagayan River, with a recorded highest flood level of 12 meters.
2	Afusing Bato	✓			Rising water level of the Cagayan River, with a recorded highest flood level of 10 meters.
3	Afusing Daga	✓			Rising water level of the Cagayan River, with a recorded highest flood level of 8 meters.
4	Agani		✓		
5	Baculod			✓	Rising water level of the Cagayan River, with a recorded highest flood level of 4 meters.
6	Baybayog	✓			Rising water level of the Cagayan River, with a recorded highest flood level of 4 meters.
7	Cabuluan		✓		
8	Calantac			✓	Rising water level of the Cagayan River, with a recorded highest flood level of 2 meters.
9	Carallangan	✓			Rising water level of the Cagayan River, with a recorded highest flood level of 10 meters.
10	Centro Norte		✓		
11	Centro Sur			✓	Rising water level of the Cagayan River, with a recorded highest flood level of 13 meters.
12	Dalaoig	✓			Rising water level of the Cagayan River, with a recorded highest flood level of 14 meters.
13	Damurog	✓			Rising water level of the Cagayan River, with a recorded highest flood level of 6 meters.
14	Jurisdiccion	✓			Rising water level of the Cagayan River, with a recorded highest flood level of 4 meters.
15	Malalatan	✓			Rising water level of the Cagayan River, with a recorded highest flood level of 6 meters.
16	Maraburab	✓			Rising water level of the Cagayan River, with a recorded highest flood level of 2 meters.

ISSN: 3116-3475
International Journal
of Education, Research, and Innovation Perspectives
Volume 2 Issue 11 (November 2026)

17	Masin	✓			Rising water level of the Cagayan River, with a recorded highest flood level of 7 meters.
18	Pagbangkeruan	✓			Rising water level of the Cagayan River, with a recorded highest flood level of 6 meters.
19	Pared	✓			Rising water level of the Cagayan River, with a recorded highest flood level of 6 meters.
20	Piggatan	✓			Rising water level of the Cagayan River, with a recorded highest flood level of 2 meters.
21	Pinopoc	✓			Rising water level of the Cagayan River, with a recorded highest flood level of 2 meters.
22	Pussian			✓	Rising water level of the Pared River/Cagayan River, with a recorded highest flood level of 12 meters.
23	San Esteban		✓		
24	Tamban	✓			Rising water level of the Cagayan River, with a recorded highest flood level of 15 meters.
25	Tupang			✓	Rising water level of the Cagayan River, with a recorded highest flood level of 8 meters, affecting 15 households.
Total	**25 Barangays**	**15**	**4**	**6**	

Table 6 shows the categorization of barangays in Alcala, Cagayan in terms of flood susceptibility while Figure 2 provides the distribution of these classes. Results reveal that flooding is a frequent and recurring danger in most of the barangays of the municipality. Such widespread flood exposure has immediate repercussions for communities and infrastructure, as well as for the resilience and safety of current water delivery systems (Padre et al., 2023).

Among the 25 barangays, 15 are classified as highly flood-prone, 6 are moderately vulnerable, and only 4 face low risk. The distribution in Figure 2 highlights that the vast majority of the municipality is exposed to flooding. This lack of safe zones indicates that most communities are susceptible to varying levels of flood risk (Gacul et al., 2024). This widespread exposure implies that critical infrastructure, especially in low-lying areas, is highly vulnerable to service disruption, physical damage, and contamination during floods, threatening the continuity of the clean water supply (Grant et al., 2024).

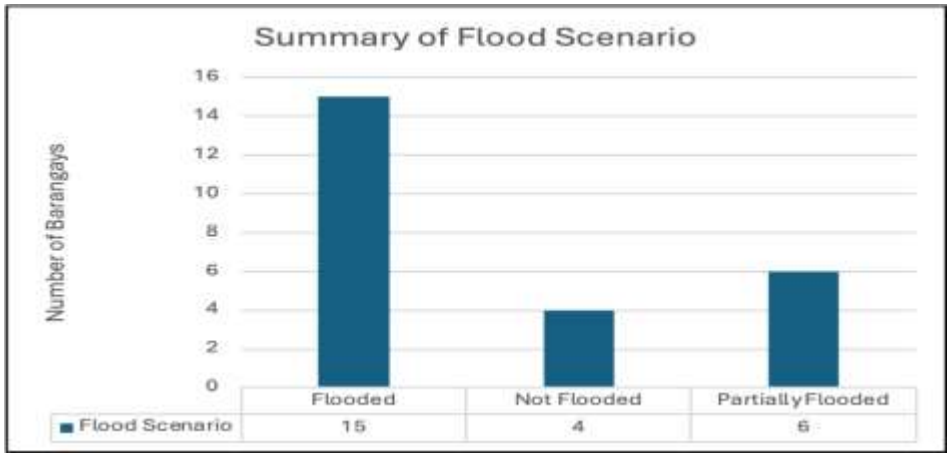


Figure 2. *Summary of Flood Scenario*

ISSN: 3116-3475
International Journal
of Education, Research, and Innovation Perspectives
Volume 2 Issue 11 (November 2026)

The map also highlights the worst flood episodes documented stressing the severity of floods in the area. Several barangays were recorded with extreme depths of flooding including Tamban (15 meters), Centro Sur (14 meters) and Abbeg and Pussian (12 meters). Other barangays with high flood levels are Afusing Bato and Carallangan (10 meters) and Afusing Daga and Tupang (8 meters). These data show that certain regions are prone to catastrophic flooding with the potential for extensive damage to infrastructure, displacement of people and disruption of economic activity. For water supply systems, such extreme depths might cause pump stations to be submerged, pipelines to be damaged and storage facilities to be compromised, resulting in long-lasting disruptions of service (Barbetta et al., 2022). Furthermore, floodwaters can bring sediments and contaminants into water supplies, posing substantial risks to water quality and human health, particularly in communities depending on untreated or partially treated sources (Alfee & Bloor, 2024). Additionally, flooding can carry sediments and toxins into water supplies, posing significant hazards to water quality and human health, especially in places that rely on untreated or partially treated water sources (Alfee & Bloor, 2024).

An important conclusion is that majority of the reasons of the reported flood are linked to the rising water level of the Cagayan River, proving the river is a crucial element in the flood dynamics of the municipality. For example, Pussian is influenced by the Pared River and the Cagayan River, pointing to the compounded hazards in places near river confluences. This highlights the need of assessing watershed level processes and conditions in the upstream areas in flood risk management. In these locations, the dependence on river-based or shallow groundwater sources for water delivery systems makes them more vulnerable to contamination and altering water quality during flood events, necessitating more source protection and treatment approaches (Dzodzomenyo et al., 2022).

Moreover, the partially flood-prone barangays (e.g. Abbeg, Baculod, Calantac, Centro Sur, Pussian, and Tupang) suggest that flooding is not uniform over the barangays but may be concentrated in low-lying or river-adjacent locales. This indicates that flood occurrences are controlled by the local geography, drainage patterns and land usage. This could lead to uneven reliability of water service within the same neighborhood, with some areas being disrupted or contaminated while others are working. This underscores the significance of strategic location and elevation of water infrastructure, and zoning of distribution networks to mitigate localized impacts.

On the other hand, the barangays of Agani, Cabuluan, Centro Norte and San Esteban are non-flood-prone and are possibly located in higher elevations or locations with better natural drainage systems. These geographical features lower the risk of flooding and lead to more stable environmental conditions. Hence, these barangays can be potential areas for the establishment of water supply facilities such as groundwater sources, pumping stations or centralized water facilities. However, while the direct flood hazard exposure is lower in these places, indirect effects of flood events can still be felt, particularly if they are connected to municipal water systems serving flood-prone areas. Thus, these barangays could be potential advantages for water resource development. However, the resilience of the municipality's water supply network as a whole depends on integrated planning and system-wide flood risk management.

With respect to planning, the results highlight the necessity for prioritized and location-specific interventions. High flood-prone barangays, particularly those with documented flood depth above 10 meters, should be emphasized on structural mitigation measures such as flood control structures, riverbank stabilization, and enhanced drainage systems (Okaiyeto et al., 2023). At the same time, water supply infrastructure in these locations should be constructed or retrofitted to be flood-resilient, including elevated pump stations, protected pipes, and secure storage facilities (Liu et al., 2024). Meanwhile, targeted interventions like as localized drainage improvements, land-use restrictions to minimize settlement in high-risk zones, and improvements in water distribution design may be beneficial to some partially flood-prone barangays.

ISSN: 3116-3475
International Journal
of Education, Research, and Innovation Perspectives
Volume 2 Issue 11 (November 2026)

Moreover, the frequency of floods necessitates more attention to non-structural solutions such as early warning systems, community preparedness, evacuation protocols and awareness campaigns. Integrating flood risk information into land use planning and infrastructure design is important to reduce future vulnerabilities. It also necessitates the development of emergency water supply, backup sources and water quality monitoring techniques in case of catastrophic occurrences for water supply systems (Das, 2025). The results also underscore the necessity of inter-barangay and watershed-level coordination, as flooding is largely a result of river systems that cross some barangay lines (Nacaya et al., 2023).

Flooding is still one of the key environmental and socio-economic concerns in the Municipality of Alcala. Table 6 and Figure 2 show that the municipality's barangays are subjected to different levels of flood susceptibility showing the widespread breadth of the problem. The results provide a sound basis for evidence-based planning and decision-making, highlighting the need for comprehensive, inclusive and sustainable flood risk control methods. Structural and non-structural mitigation measures alone are not sufficient to address flood dangers. Resilience principles also need to be included into key public services. Flood resilience should be incorporated into planning, design, operation an d management of water supply systems so that safe, reliable and appropriate water services can be delivered during and after flood occurrences. Such an approach can improve community resilience, reduce service disruption, safeguard public health and promote the long-term sustainability of local development projects (Das, 2025).

Water Supply Access and Management

Table 7. *Water Supply Access and Management of Barangays in Alcala, Cagayan.*

No.	Barangay	Remarks
1	Abbeg	No water supply system available; households rely on individual water sources.
2	Afusing Bato	The water supply system is Level III, and consumers handle any problems or issues that occur.
3	Afusing Daga	The water system is managed by LGU of Alcala.
4	Agani	No water supply system available; households rely on individual water sources.
5	Baculod	No water supply system available; households rely on individual water sources.
6	Baybayog	The water system is managed by LGU of Alcala.
7	Cabuluan	No water supply system available; households rely on individual water sources.
8	Calantac	The water system is managed by the barangay, with only 35% coverage.
9	Carallangan	The current water system is Level I and needs to be upgraded to Level III, as water supply becomes insufficient during the summer season.
10	Centro Norte	The water system is managed by LGU of Alcala.
11	Centro Sur	The water system is managed by LGU of Alcala.
12	Dalaoig	No water supply system available; households rely on individual water sources.
13	Damurog	The current Level I water system needs to be upgraded to Level III, as water supply becomes insufficient during the summer.
14	Jurisdiccion	The water system is managed by LGU of Alcala.
15	Malalatan	No water supply system available; households rely on individual water sources.
16	Maraburab	The water system is managed by the barangay, with only 14% coverage.
17	Masin	The water system is Level II (communal), not Level III (household connections).
18	Pagbangkeruan	The water system is managed by LGU of Alcala.
19	Pared	The water system is managed by Barangay.
20	Piggatan	The water system has only 14% coverage and is turned over to an association for maintenance after construction.

ISSN: 3116-3475
International Journal
of Education, Research, and Innovation Perspectives
Volume 2 Issue 11 (November 2026)

21	Pinopoc	The water system is managed by Barangay.
22	Pussian	No water supply system available; households rely on individual water sources.
23	San Esteban	No water supply system available; households rely on individual water sources.
24	Tamban	The water system is managed by Barangay.
25	Tupang	The water system is managed by LGU of Alcala.

Table 7 and Figure 3 depict the current status of access and management of water supply of the 25 barangays of Alcala, Cagayan. The results show a very heterogeneous and irregular distribution of water supply systems in the municipality, which is indicative of discrepancies in terms of access, level of service and organizational arrangements.

It is important to note that 8 out of 25 barangays do not have a formal water delivery system and households depend on individual sources such as wells, springs, or other unregulated mechanisms. This is also the largest group as shown in Fig. 3. This condition points to a significant shortfall in basic service delivery, leaving households with unpredictable access to water and potential water quality problems, particularly during dry seasons or contamination incidents. The reliance on single sources points to the absence of centralized infrastructure and underlines the pressing need for intervention in these under-served communities (Gizaw et al., 2022).

In terms of system administration, a significant portion of the municipality relies directly on the Local Government Unit (LGU) of Alcala, which centrally manages the water supply for seven barangays. This shows a somewhat centralized management structure in some sectors, which may help in better coordination, technical support and maintenance. The other barangays are either governed at the barangay level (3 barangays) or by associations with possible limited technical and financial capabilities. This variance in management structure implies disparities in service quality, operational efficiency and sustainability of the water systems (Obosi, 2023).

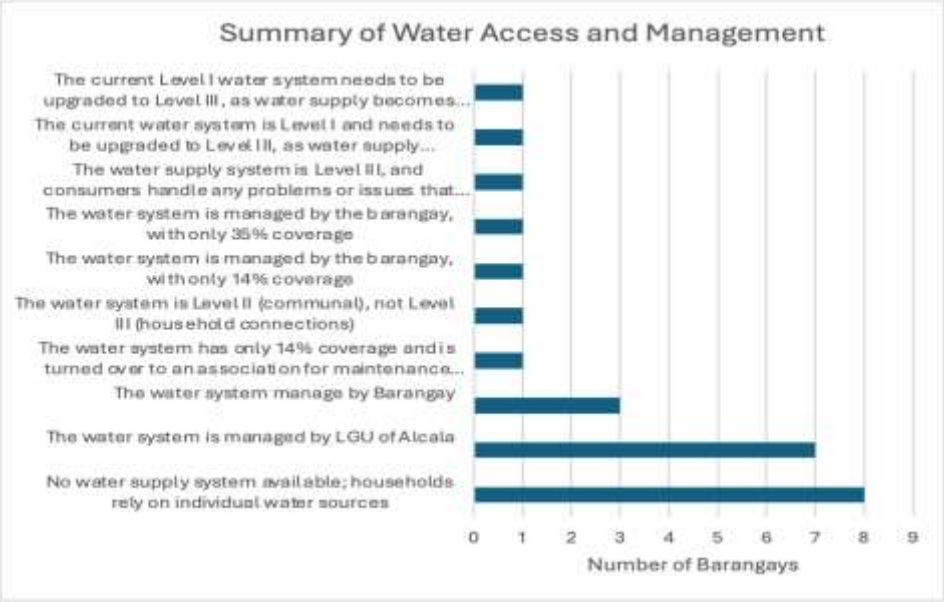


Figure 3. *Summary of Water Access and Management*.

Table 7 indicates that while several barangays possess functional water systems, their current capacities are insufficient to meet local demand. Multiple areas currently rely on Level I systems that urgently need

ISSN: 3116-3475
International Journal
of Education, Research, and Innovation Perspectives
Volume 2 Issue 11 (November 2026)

upgrading to Level III, a vulnerability that is heavily exacerbated by water shortages during the summer months. This means that there is infrastructure, but it is not enough for the current demand or for reliable service round the year (Sarkar, 2023). One barangay still uses a Level II (community) system that restricts household access and convenience, compared to Level III systems.

Another key worry found is the inadequate service coverage with some barangays reporting only 14% to 35% coverage . This suggests that in locations having water infrastructure, the majority of the homes do not have access to it and still use other water sources that may be unsafe. The poor coverage may be due to the absence of appropriate infrastructure, financial resources, or challenges in scaling and maintenance of the system (Rajapakse et al., 2023).

The presence of at least a Level III system in at least one barangay, where consumers are responsible for resolving minor operational difficulties, indicates a higher level of service with household connections. However, reliance on consumers for troubleshooting may suggest weaknesses in formal maintenance support, or in institutional management (Preña et al., 2026).

Figure 3 strongly supports these findings, indicating that most barangays lack a water supply system or depend on decentralized management, with only a few having highly sophisticated or well-managed systems. This distribution is a reflection of the inequity of water service supply across the municipality.

Generally, these findings reveal that water access in Alcala remains in a transitional phase, as many barangays still operate without reliable, safe, or sustainable water systems. These combined elements of limited infrastructure, low service coverage and different management capacities indicate that residents may be subject to inconsistent water supply, especially during periods of high demand, such as summer, as well as increased susceptibility to health risks due to possible contamination (Moreno, 2024).

Moreover, integrating flood risk scenarios reveals even greater system vulnerabilities. Flooding heavily compromises water safety in barangays relying on shallow individual wells, while simultaneously threatening infrastructure continuity in areas with limited service capacity (Barbetta et al., 2022). Ultimately, this emphasizes the essential need for climate-resilient and flood-adaptive water delivery systems.

The results shown in Table 5 and Figure 3 underscore the importance of an integrated and comprehensive water supply planning in Alcala. Priority efforts should include expanding access to Level III systems, upgrading existing Level I and II systems, improving service coverage, and enhancing institutional administration, especially at the barrio and community levels. In addition, collaborations with the LGU, barangays, and communities should be strengthened to ensure sustainable operation and maintenance.

Status of Water Supply Systems

The state of water supply system gives an overview of availability, accessibility and management of water resources in the studied region, which are vital to ensure safe and reliable water for the community. It also identifies the gaps and obstacles in service delivery. The state of the water supply system is reported in terms of the groundwater source, pipe distribution, water storage facility and water treatment facility, since these components jointly determine the efficiency, sustainability and quality of water supply across the barangays in this study.

ISSN: 3116-3475
International Journal
of Education, Research, and Innovation Perspectives
Volume 2 Issue 11 (November 2026)

Ground Water Source

Table 8. *Ground Water Source Status in Alcala, Cagayan*

Variables	No. of Barangays	Percentage
Groundwater Source		
With groundwater system (Deep/Shallow Well)	18	72%
No groundwater system	7	28%
Type of Source		
Deep Well	17	94%
Shallow Well	1	6%
Permit Status		
With permit (NWRB/Barangay/LGU)	10	56%
Without permit / Unknown	8	44%
Flood Exposure		
Submerged during flood	9	50%
Not submerged	9	50%
Groundwater Volume Measurement Device Availability		
Yes	5	28%
No	13	72%
Groundwater Source Location Near Septic Tank		
Yes (5 m and 10 m respective distances)	2	11%
No	16	89%
Water Sufficiency		
Sufficient year-round	12	67%
Not sufficient (mostly summer shortages)	6	33%
Maintenance Practice		
With regular maintenance	12	67%
No maintenance / Irregular	6	33%

A detailed picture of status of the sources of groundwater is shown in Table 8. Groundwater is the mainstay of water supply in the studied barangays. In the Philippines, access to water is generally well-established, with 72% of barangays using groundwater systems. The 28% of barangays without groundwater systems however suggest a severe gap in service provision. Thus, the water infrastructure in some areas is unstable, and some households rely on alternative or informal sources that may be hazardous, unreliable, or inadequate, with implications for equity in water distribution and public health outcomes (Allaire et al., 2024).

The high percentage of deep wells (94%) is another sign of a transition to safer and higher volume sources of water. Deep wells are often less prone to pollution than shallow wells and are more resilient to seasonal changes, which helps to ensure a more reliable water supply (Eliraz et al., 2025). However, this high dependence also poses problems regarding long-term sustainability given that continued extraction without sufficient monitoring could result in reduced output, declining groundwater levels and potential aquifer depletion, particularly during periods of high demand (Waqas, 2024).

Groundwater is frequently used; however, only 56% of systems are regulated and 44% operate without permits or with ambiguous status according to the permit status. This means that there is no institutional control on groundwater extraction that may result in unregulated use, wasteful distribution and

ISSN: 3116-3475
International Journal
of Education, Research, and Innovation Perspectives
Volume 2 Issue 11 (November 2026)

even overuse of resources. This absence of regulation undermines the sustainability of water delivery systems and hinders authorities' ability to set demands for the safe and effective use of water (Howard, 2023).

The fact that 50% of sources are flooded during floods indicates the vulnerability of groundwater systems to environmental challenges. This has serious implications for water safety since flooding can introduce rubbish, contaminants and diseases into groundwater sources (O'Shea-Boland et al., 2026). This means that despite the physical availability of water, its quality can be compromised, hence elevating the probability of waterborne diseases and leading to interruptions in the drinking water supply . This underscores the need for climate-resilient infrastructure and safeguards.

Only five barangays (28%) maintain instruments for measuring groundwater output; conversely, the majority of thirteen barangays (72%) do not. This means that most of the barangays are not able to monitor the groundwater extraction making it difficult to manage the water resources efficiently and sustainably. Without measurement instruments, there is a high likelihood of over-extraction, depletion of uncharted groundwater sources, and poor planning for future water demand (Rochford et al., 2022). The lack of installed or operating meters, which is vital for avoiding over-extraction and ensuring sustainable aquifer management, cannot be adequately measured and this actually impacts groundwater governance (NWRB, 2025).

Of these 18 barangays, only two (11%) indicated that the groundwater sources are located close to septic tanks, at a distance of five and ten meters, respectively, while the others (89%) reported no such proximity. Groundwater sources within 5–10 meters of septic tanks are a concern for potential contamination, even though most adhere to safe distance limits. This intimate interaction can serve as a pathway for diseases and toxins into the groundwater, particularly in places with permeable soils or poor maintenance of septic systems (Otunola & Zhou, 2024). PD 856, The Code of Sanitation of the Philippines, requires that septic tanks be located horizontally not less than 25 meters from any source of potable water supply such as springs, wells and other ground water abstractions.

While 67% of barangays report sufficient water supply throughout the year, the remaining 33% face seasonal shortages. These summer deficits point to clear boundaries in groundwater availability caused by climate patterns. Consequently, water supplies fail to meet peak demand when seasonal recharge drops, leading to erratic delivery, reduced pressure, or scheduled water rationing. Ultimately, these reliability issues disrupt both household routines and local economic output.

Operational practices also play a significant impact in the maintenance of the water supply (Horbatuck et al. 2025). Sixty-seven percent of the barangays consistently maintain their systems to ensure better system performance and life, while the other 33 percent with irregular or no maintenance are in danger of system deterioration, leaks and inefficiencies. Poor maintenance can cause service disruptions and higher costs, jeopardizing the reliability and sustainability of water supply systems (Hegazy, 2024).

The ground water source in Alcala is a common source of water but its effectiveness is limited by unequal access, weak regulatory enforcement, vulnerability to flooding, inadequate monitoring due to lack of measurement devices, localized risks of groundwater contamination due to improper siting of septic systems, seasonal insufficiency, and inconsistent maintenance practices. Such linked issues affect the availability, security, reliability and sustainability of water distribution systems (Moreno, 2024). To tackle these challenges, a comprehensive approach is necessary, encompassing the expansion of infrastructure coverage, the enhancement of governance and permitting systems, the improvement of climate resilience, and the establishment of regular maintenance to guarantee a safe and equitable water supply for all barangays (Ariffin et al., 2023).

ISSN: 3116-3475
International Journal
of Education, Research, and Innovation Perspectives
Volume 2 Issue 11 (November 2026)

Pipe Distribution

Table 9. *Pipe Distribution Status in Alcala, Cagayan*

Variables	No. of Barangays	Percentage
Piped Water Distribution (out of 18 barangays with ground water source)		
Full coverage	6	33%
Partial coverage	10	56%
No system	2	11%
Type of System Installed (out of 16 barangays with pipe distribution)		
Level II (communal faucet)	1	6%
Level III (household connection)	15	94
Pipe Material Used (out of 16 barangays with pipe distribution)		
PVC	11	69%
Galvanized Iron (GI)	4	25%
HDPE	5	31%
Age of Piping System (out of 16 barangays with pipe distribution)		
0-5 years	6	38%
6-10 years	5	31%
Above 10 years	5	31%
System Management (out of 16 barangays with pipe distribution)		
Barangay	7	44%
LGU	7	44%
Private owner	1	6%
Association	1	6%
Pipe Repair Practice (out of 16 barangays with pipe distribution)		
Yes	13	81%
No	3	19%
Pipe Flushing Practice (out of 16 barangays with pipe distribution)		
Yes	13	81%
No	3	19%
Frequency of Pipe Flushing (out of 13 barangays with pipe flushing)		
Monthly	8	61%

ISSN: 3116-3475
International Journal
of Education, Research, and Innovation Perspectives
Volume 2 Issue 11 (November 2026)

Variables	No. of Barangays	Percentage
Quarterly	2	15%
Annually	1	8%
Upon complaint	1	8%
If pressure allows	1	8%

Table 9 presents a complete picture of the pipe distribution network in Alcala, Cagayan, highlighting both service coverage and system operations. Of the barangays surveyed with groundwater sources, only six have complete piped water coverage, while ten have only partial coverage. This reveals that existing piped systems do not guarantee universal access, potentially restricting steady water flow to many residences. Crucially, two barangays completely lack piped infrastructure entirely, a conspicuous service gap that requires immediate intervention from local authorities.

Regarding the type of system, most of the Level III systems (15 out of 16 barangays with pipe distribution) indicate that most areas have very modern water supply infrastructure with direct household connections. One barangay has only one communal faucet or Level II system This is a good indicator of infrastructure improvement as Level III systems normally provide more convenience, improved sanitation and higher water availability. Nevertheless, the continued existence of partial coverage despite the widespread usage of Level III systems could point to limitations in network expansion, pressure distribution, or economic capacity for comprehensive home linkages (Jain et al., 2024).

The preferred materials for the pipe distribution system are PVC pipes (11 barangays) followed by HDPE (5 barangays) and galvanized iron (GI) pipes (4 barangays). PVC and HDPE are generally good materials as they are corrosion resistant, durable and ideal for potable water systems (Wei, 2021). However, future use of GI pipes may provide a concern of corrosion, leakage and potential water quality deterioration over time (Taneez et al., 2023). This indicates the necessity to modernize the system in steps and standardize materials for long-term efficiency and safety (Taneez et al., 2023).

The age distribution of the piping systems is evenly distributed; six barangays have recently installed systems (0-5 years), five have systems aged 6-10 years, and another five operate systems that are over 10 years old. In effect, while some areas have had recent infrastructure enhancements, a large portion of the systems are old and may already be under wear and strain (Shah et al., 2022). The older the system, particularly beyond 10 years, the higher the likelihood of leaks, pressure loss and pollution, therefore regular maintenance and rehabilitation programs are vital (Mohammed & Swalaha, 2025).

The management of the water systems appears to be decentralized with equal participation of barangays (7) and LGU (7). There are fewer privately owned or operated by an association. This difference in management structures might affect the uniformity of service delivery, maintenance procedures, and resource allocation (Sukma & Leelasantitham, 2022). At the barangay level, systems may be restricted in technical skills and money, while LGU systems may have stronger institutional support. Hence, there is a need to enhance coordination and capacity building among various management institutions (Quitorio et al., 2024).

Operational practices show that most of the barangays with pipe distribution carry out pipe repair (13 out of 16) and pipe flushing (13 out of 16) which are important for system functionality and water quality. However, the lack of these practices in three (3) barangays indicates flaws in maintenance, which could lead to system inefficiencies and health problems. In the case of those that undertake pipe flushing, most of them (8 barangays) do it monthly which is a beneficial practice in maintaining water quality (Vedrin, 2023). Some flush regularly, yearly or when pressure allows or when there is a complaint. This suggests

ISSN: 3116-3475
International Journal
of Education, Research, and Innovation Perspectives
Volume 2 Issue 11 (November 2026)

that there is heterogeneity in standards of maintenance and likely reactive rather than preventative actions (Ra et al., 2023).

According to Table 7, Alcala has seen significant progress in piped water systems, especially in the use of Level III systems across the town. However, there remain major challenges of achieving full coverage, uniform system quality, and consistent operational practices (Toska et al., 2024). Hence, strategic steps should be put in place to expand coverage to unserved barangays, improve aging and deficient infrastructure, and harmonize management and maintenance procedures to enhance sustainable and equitable delivery of water services (Hossain et al., 2023).

Water Storage Facility

Table 10. *Water Storage Facility Status in Alcala, Cagayan*

Variables	**No. of Barangays**	**Percentage**
Availability of Water Storage Facility (out of 18 barangays with ground water source)		
Yes	16	89%
No	2	11%
Type of Storage Facility (out of 16 barangays with water storage facility)		
Elevated concrete tank	8	50%
Elevated steel tank	7	44%
Ground level steel tank	1	6%
Cleaning of Storage Facility (out of 16 barangays with water storage facility)		
Yes	14	87.5%
No	2	12.5%
Frequency of Cleaning the Storage Facility (out of 14 barangays cleaning water storage facility)		
Monthly	10	71.5%
Quarterly	3	21.5%
Annually	1	7.0%

Table 10 indicates the condition of water storage facilities in Alcala, Cagayan specifically on the availability, type and maintenance practices of water storage facilities of barangays that depend on groundwater sources. Statistics show that 16 of the 18 barangays have established water storage facilities, which means that there is a significant degree of infrastructural support for water supply systems. Most of the barangays recognize the importance of storage in providing the continuous availability of water, controlling supply and pressure in distribution systems (Dirie et al., 2026). However, the absence of storage facilities in the two barangays shows a significant gap as these places could be more subject to supply disruptions at times of high demand or pump failure (Nair & Palaniappan, 2024).

The most frequent type of storage facility is elevated concrete tanks (8 barangays) followed by elevated steel tanks (7 barangays). There is only 1 barangay with a ground level steel tank. The presence of elevated storage systems is a positive indication as these structures tend to perform better in supplying adequate water pressure and allowing gravity-based distribution which is energy-efficient and reliable

ISSN: 3116-3475
International Journal
of Education, Research, and Innovation Perspectives
Volume 2 Issue 11 (November 2026)

(Gomez-Alvarez, 2023). High concrete tanks are known for their strength and long service life, whereas high steel tanks offer flexibility and quicker installation (Yadav & Mane, 2023). Limited use of ground level storage may be an indication of a preference for systems that are better adapted to stable pressure and distribution efficiencies.

Maintenance practices indicated that 14 of the 16 barangays with storage facilities clean them regularly, which is critical for water quality and contamination prevention. This is usually an excellent knowledge of cleanliness and public health. However, the two barangays that do not clean are a concern as unmaintained storage facilities can be a source of microbial development, silt accumulation and waterborne infections (Slavik et al., 2020). This gap points to the need for closer monitoring and execution of maintenance activities.

Among the barangays that maintain their systems, ten conduct maintenance activities on a monthly basis. This regular schedule demonstrates a commitment to excellent operational standards and a proactive approach to water quality control. The regular monthly cleaning prevents the buildup of contaminants and guarantees the safety of the drinking water for users (Slavik et al., 2020). On the other hand, three barangays undertake cleaning weekly and one barangay annually, indicating variability of maintenance frequency. Cleaning less often might cause the water quality to decline over time, especially for systems that are used a lot or are exposed to environmental contaminants (Aryal et al., 2022). This disparity shows the necessity for set standards on cleaning schedules for uniformity in water safety procedures in all barangays.

Table 10 indicates that Alcala has a rather solid base in water storage infrastructure with large availability and good use of elevated systems. However, the inequalities in the presence of facilities and maintenance methods suggest the room for development (Velázquez et al., 2022). Strengthening the policies on mandatory cleaning, technical assistance to the barangays without facilities, and promotion of consistent maintenance schedules will be very essential in enhancing the reliability, safety, and sustainability of the municipality's water supply system (Molina et al., 2021).

Water Treatment Facility

Table 11. *Water Treatment Facility Status in Alcala, Cagayan*

Variables	**No. of Barangays**	**Percentage (%)**
Water Treatment/Disinfection System (out of 18 barangays with ground water source)		
Full treatment (filtration, chlorination, etc.)	5	28%
Chlorination only	1	5%
No treatment	12	67%
Regular Water Quality Testing Conducted (out of 18 barangays with ground water source)		
Yes	17	94%
No	1	6%
Frequency of Water Quality Testing (out of 17 barangays conducted water quality testing)		
Monthly	1	6%
Quarterly	2	12%
Annually	14	82%
Responsible for Water Quality Monitoring (out of 17 barangays conducted water quality testing)		

ISSN: 3116-3475
International Journal
of Education, Research, and Innovation Perspectives
Volume 2 Issue 11 (November 2026)

Variables	No. of Barangays	Percentage (%)
Barangay Health Unit	3	18%
Municipal Health Office	14	82%

Table 11 details the status of water treatment and quality monitoring protocols in Alcala, Cagayan, focusing specifically on the 18 barangays reliant on groundwater sources. The findings reveal that only five of these communities (28%) utilize full water treatment systems, such as combined filtration and chlorination, while one barangay (5%) relies solely on chlorination. Critically, the vast majority of these communities, twelve barangays, or 67%, do not employ any water treatment mechanisms, presenting a significant gap in localized water safetyThis is a severe public health threat, since groundwater, although normally considered safe, can be susceptible to pollution from biological, chemical or environmental sources. The low adoption of comprehensive treatment systems indicates potential limitations in technical capability, financing or knowledge and underscores the urgent need for investments in safe water treatment infrastructure (Kagan et al., 2025).

Data show that frequent water quality testing is prevalent with 17 of the 18 barangays (94%) conducting regular testing, yet implementation of treatment is weak. This is a positive sign and shows a strong commitment to monitoring safety of water. However, a more detailed investigation at testing frequency reveals that majority of the barangays (14 or 82%) test only once a year, with a few (2 barangays or 12%) doing it quarterly and only 1 (6%) doing it monthly. While testing on an annual basis is beneficial for baseline evaluation, it might not be enough to detect pollution episodes or seasonal variations in water quality in a timely manner (Kumar et al., 2024). More regular testing is usually recommended, to enable rapid detection of hazards and immediate corrective procedures, if necessary (Rozemeijer et al., 2025).

Out of the 17 barangays undertaking water quality monitoring, the Municipal Health Office (MHO) is the main responsible authority for monitoring in 14 barangays (82%). The BHUs are involved in only three (3) barangays (18%). Although this centralized approach may guarantee technical reliability and standardization of the testing methods, it may also constrain the responsiveness of monitoring efforts at the local level. Increasing the capacity of BHUs to carry out or facilitate routine testing will improve community level monitoring and allow more rapid measures if concerns occur.

The results indicate a gap between surveillance and treatment techniques. While water quality monitoring is frequent, the absence of adequate treatment systems in most barangays causes a gap in delivering safe and drinkable water (Galezzo et al., 2024). Monitoring alone cannot reduce chances of contamination without appropriate therapeutic interventions. Thus, the municipality should prioritize the installation of water treatment facilities, encourage more frequent and consistent testing schedules, and strengthen coordination between the Municipal Health Office and Barangay Health Units (Molina et al., 2021). These initiatives will help the more holistic and proactive approach to water safety and public health protection in Alcala, Cagayan.

Compliance of Ground Water Source and Consumer Tap

Nine (9) water samples were collected for the investigation of water quality in Alcala, Cagayan. Four (4) samples were taken directly from groundwater sources and five (5) samples were taken from consumer taps connected to the water distribution systems. Sampling sites were built around the municipality encompassing barangays on either side of Cagayan River to give a representative assessment of water quality conditions. Note, however, that some barangays share a common source of groundwater and are connected to each other by the same water supply system. As a result, water from a single source can be used by numerous barangays within the municipality.

ISSN: 3116-3475
International Journal
of Education, Research, and Innovation Perspectives
Volume 2 Issue 11 (November 2026)

Table 12. *Water Quality Testing.*

	Ground Water Source				Consumer Tap				
Parameters	**Centro Norte**	**Pagbangkeruan**	**Calantac**	**Afusing Daga**	**Tupang**	**Centro Sur**	**Baybayog**	**Calantac**	**Afusing Daga**
A. Microbiological Test									
Total Coliform	C	C	C	NC	NC	NC	C	NC	NC
Thermotolerant coliform / E. coli	C	C	C	NC	NC	NC	C	NC	C
Heterotrophic Plate Count (HPC)	C	C	C	NC	NC	NC	NC	NC	NC
B. Physical-Chemical Test									
pH	C	C	C	C	C	C	C	C	C
Turbidity	NC	NC	C	C	NC	NC	NC	C	C
Nitrate (as NO_3)	C	C	C	NC	C	C	C	C	C
Arsenic	C	C	C	C	C	C	C	C	C
Cadmium	C	C	C	C	C	C	C	C	C
Lead	C	C	C	C	C	C	C	C	C
Total Dissolved Solids (TDS)	C	C	C	NC	C	C	C	C	NC
Color	C	C	C	C	C	C	NC	C	C
Chlorine Residual	NC	NC	NC	NC	NC	NC	NC	NC	NC
Iron	C	C	C	C	C	C	C	C	C
Manganese	NC	NC	C	NC	NC	NC	NC	C	C
Total Compliance Count	11	11	13	7	8	8	9	10	10
Extent of Compliance	**Great Extent**	**Great Extent**	**Very Great Extent**	**Moderate Extent**	**Moderate Extent**	**Moderate Extent**	**Great Extent**	**Great Extent**	**Great Extent**

Note: C - Compliant; NC - Non-Compliant;

Table 12 presents the compliance status of water samples across several sampling stations in Alcala, Cagayan, evaluated against both microbiological and physical-chemical parameters. The findings suggest that water quality compliance varies significantly by location, with total compliance counts ranging from 7 to 13. Notably, Calantac achieved the highest compliance count of 13 among all

ISSN: 3116-3475
International Journal
of Education, Research, and Innovation Perspectives
Volume 2 Issue 11 (November 2026)

groundwater sampling points. This is interpreted as a 'Very Great Extent' of compliance, signifying that nearly all evaluated parameters satisfied acceptable water quality requirements and establishing Calantac as having superior overall water quality compared to alternative stations.

Centro Norte and Pagbangkeruan, also ground water sources, both had a compliance count of 11 while consumer tap in Baybayog, Calantac and Afusing Daga got compliance counts of 9 to 10 all interpreted as Great Extent. The results show that the water sources or sampling stations largely conformed with many of the parameters assessed. Some non-compliance was nevertheless identified, especially in terms of microbiological indicators, turbidity, chlorine residual and manganese. This suggests that overall compliance is good, but ongoing monitoring and corrective steps are still necessary (Andre et al., 2025).

Conversely, Afusing Daga as ground water source, and consumer tap in Tupang, and Centro Sur registered reduced compliance numbers from 7 to 8, categorized as Moderate Extent This implies that these sampling points have higher water quality issues than the others. Non-compliant microbiological results, insufficient chlorine residual, turbidity problems, or manganese levels may cause decreased compliance (Lima et al., 2025). The results show the necessity for a closer inspection, better treatment and maintenance of the water delivery system in these areas.

For microbiological test, some sampling points were designated NC, especially for total coliform, thermotolerant coliform/E. coli and heterotrophic plate count. This is essential because microbial contamination may be indicative of potential exposure to fecal pollution, poor sanitation, pipeline leaking or inadequate disinfection (Ferro et al., 2023). Therefore, these factors deserve rapid attention because they are directly tied to public health and water safety.

In the physico-chemical test, most parameters such as pH, arsenic, cadmium, lead and iron were generally compliant at the sampling stations. This suggests that the water samples were generally within the permitted range for these parameters. However, the residual of chlorine was non-compliant in all the sampling points suggesting that the disinfection may be insufficient or the chlorine levels were not maintained up to point of use (Joshi et al., 2023). Non-compliance was also observed in several places for turbidity and manganese which may influence clarity, acceptability and overall quality of the water.

Table 12 demonstrates the compliance level of the selected barangays' water delivery system to the water quality criteria. Several sampling points showed a Great Extent or Very Great Extent of compliance, however the presence of microbiological non-compliance and consistent non-compliance in chlorine residual suggests the need for improved disinfection, regular water quality testing, pipeline inspection and stronger monitoring of water sources and consumer taps (Ha et al., 2023). These results emphasize the need for ongoing water quality control to provide safe, clean and reliable water to the population.

The selected barangays' findings are generally representative of the variety of situations in the whole municipality. The barangays were chosen for study because of their relatively high populations and their dependence on organized water supply systems, therefore they provide a good sample of places where the sustainability of water supply has important implications for a large number of residents. The convergence of the results from the municipality-wide assessment and the Sample-Barangays lends support to the suitability of the sampling strategy and the confidence that the detailed analyses are pertinent to the broader context of Alcala.

Following the status of water resources and water quality the next parts discuss the community experience and governance aspects of water supply sustainability. These characteristics are important because the effectiveness of a water supply system is not only dependent on the quantity and quality of water but also the way in which residents perceive the service and how local institutions manage, operate and sustain the system. The results are given using quantitative measurements, employing weighted mean

ISSN: 3116-3475
International Journal
of Education, Research, and Innovation Perspectives
Volume 2 Issue 11 (November 2026)

scores from survey replies, and qualitative insights from thematic analysis of open-ended responses and interviews.

Community Experience and Governance

The community/household experience on the water supply system in the five populous barangays of Alcala, Cagayan with water supply system is presented in Table 13. The results show that water availability had the overall mean of 2.86 evaluated as Fair. This shows that, overall, water is available in modest amounts in households, but the classification also states that the water supply might not always be sufficient, continuous or trustworthy. Concerns of low pressure, irregular flow, seasonal shortages, or interruptions during high demand (Thomas et al., 2024) may be present. Barangay Centro Sur got the highest mean of 3.16 and Tupang got the lowest mean of 2.28 which may indicate that the families in Tupang may be struggling in getting enough water supply compared to the other barangays.

The overall mean was 3.31 for water quality again assessed as Fair. This indicates that the water used by dwellings is usually good but may need to be enhanced to suit family expectations and safety regulations. Concerns might be concerning clarity, taste, flavor, cleanliness or perceived safety for drinking and domestic consumption (Galezzo et al., 2024). Greatest mean was in Tupang with 3.62 and lowest mean was in Centro Sur with 2.74. This indicates that perceptions of water quality vary between barangays. The variances in water supply, distribution system, storage method, treatment process, and maintenance of infrastructure can explain this diversity (Yazawa et al., 2026).

For water tariff rate, the aggregate mean was 2.27 and it was graded as Very Good. This indicates that the water rate is generally considered affordable and reasonable by the families. The finding shows that cost may not be the main challenge in the water delivery system especially when compared to the issues of availability and quality (Vicky et al., 2025). However, affordability needs to be balanced with the requirement to sustain and improve the system. Very low rates may limit funds for repairs, water purification, system expansion, and routine maintenance (Fagundes et al., 2024).

Table 13. *Community Household Experience on Water Supply System*

Experiences	Afuáng Daga		Baybayog		Calantac		Centro Sur		Tupang		Average	Interpretation
	Mean	Interpretation	Mean	Interpretation	Mean	Interpretation	Mean	Interpretation	Mean	Interpretation		
Water Availability	2.93	Fair	3.08	Fair	2.87	Fair	3.16	Fair	2.28	Fair	2.86	Fair
Water Quality	3.34	Fair	3.29	Fair	3.57	Fair	2.74	Fair	3.62	Fair	3.31	Fair
Water Tariff (rate)	1.79	Very Good	2.12	Very Good	1.85	Very Good	2.93	Very Good	2.67	Very Good	2.27	Very Good
Responsiveness of Barangay/ Municipal Officials	2.42	Good	3.49	Good	1.56	Good	2.74	Good	2.45	Good	2.53	Good

The mean of 2.53 on the responsiveness of barangay/municipal authorities was judged as good. This means that local leaders tend to respond positively to water supply problems. However, the result also indicates that there is still room for improvement, particularly on the faster action on complaints, regular monitoring, timely repair of damaged facilities, transparent communication with households, and stronger coordination between barangay and municipal offices (Magwilang et al., 2023).

The result reveals that the water delivery system of the selected barangays is generally functional but not totally suitable in all aspects. Tariff rates and official responsiveness are also rated well, although water availability and water quality are still the issues most in need of improvement. The results underscore the importance of adopting more sustainable water supply management practices that encompass routine water

ISSN: 3116-3475
International Journal
of Education, Research, and Innovation Perspectives
Volume 2 Issue 11 (November 2026)

source assessments, enhanced distribution systems, frequent water quality monitoring, preventive maintenance, and robust community feedback systems (Moreno, 2024). We need to tackle these issues so that people may access a reliable, safe and inexpensive water supply system."

Challenges Encountered in the Operation and Management of Water Supply Systems

Figure 4 presents the challenges encountered in the operation and management of water supply systems, which have been systematically categorized into thematic areas for clearer analysis and interpretation.

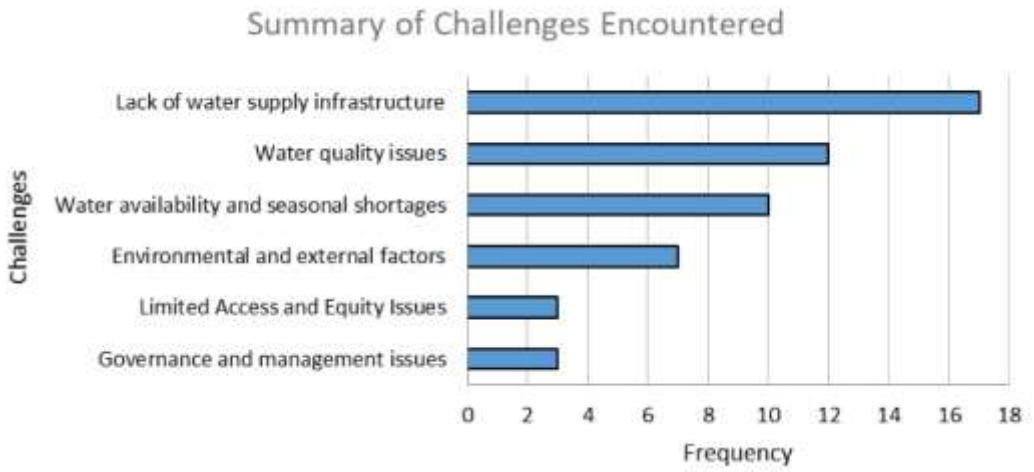


Figure 4. *Summary of Challenges Encountered in the Water Supply Systems*

Lack of Water Supply Infrastructure

Table 14. *Challenges related to Water Supply Infrastructure*.

Challenges	Frequency
No established/formal water supply system in the barangay	7
Households rely on individually sourced water	7
Source originally intended for a single barangay	1
System is not classified as Level III	1
No designated personnel or unit responsible for water system management	1

Figure 4 shows that the most frequently reported concern, with a frequency of 17, is the absence of an established water supply system. This situation compels households to depend on individually sourced water, such as wells, springs, and other informal sources, which may affect the reliability, safety, and sustainability of water access in the community. In several areas, even where water systems exist, essential components such as pipe distribution networks and storage facilities are either absent or inadequate.

ISSN: 3116-3475
International Journal
of Education, Research, and Innovation Perspectives
Volume 2 Issue 11 (November 2026)

Furthermore, some systems are not classified as Level III water systems, thereby limiting access to piped, treated, and household-level water connections.

The absence of a formal and functional water supply infrastructure reflects a significant service delivery gap that directly affects accessibility, reliability, and equity (Abungu et al., 2026). Households that depend on individual water sources are often exposed to inconsistent supply and potential contamination, particularly during adverse weather conditions or periods of high demand (Cropper et al., 2025). This situation disproportionately affects low-income and geographically isolated communities, which may lack the resources to develop or maintain their own water sources. Consequently, disparities in access to safe and potable water become more pronounced across barangays (Magwilang et al., 2023).

Moreover, the lack of Level III systems indicates limited capacity for centralized water treatment and distribution, which is critical for ensuring compliance with water quality standards and for supporting increasing population demands. Without a structured system, there is also minimal regulation and monitoring, further increasing the risk of unsafe water consumption and associated health concerns (Grigg, 2024).

From a planning perspective, these findings suggest that current water infrastructure development has not kept pace with population growth and settlement expansion (Saravanan, 2024). The absence of distribution networks and storage facilities also limits the ability to manage supply efficiently, particularly during peak demand or emergency situations (Mohammed et al., 2023).

Water Quality Issues

Table 15. *Challenges related to Water Quality.*

Challenges	**Frequency**
Water quality issues during storage	5
Recurring water quality issues	4
Water quality problems persist	2
Water quality issues are evident	1

Recurring and intermittent water quality issues were reported with a frequency of 12, indicating that concerns regarding water safety and quality remain persistent and widespread within the service area. This finding suggests the need for continuous monitoring, regular maintenance, and appropriate treatment measures to ensure that water supplied to households consistently meets established quality standards. These issues are most frequently observed during service interruptions, system flushing, and routine maintenance activities, where disturbances in the distribution system tend to mobilize sediments and introduce contaminants. Notably, in several barangays, water quality problems persist even during normal operations, suggesting deeper systemic deficiencies rather than isolated operational disturbances.

The findings reveal that water quality concerns are strongly associated with both infrastructure limitations and operational inefficiencies (Horbatuck & Beruvides, 2024). Intermittent supply systems are highly vulnerable to contamination due to pressure fluctuations that can induce backflow and allow the intrusion of pollutants through leaks and compromised pipelines (Moreno, 2024). Aging distribution networks, inadequate pipe materials, and the absence of continuous pressurization further exacerbate this condition (Mohammed & Swalaha, 2025). In addition, the lack of adequate treatment facilities, such as filtration and disinfection systems, and the limited implementation of real-time water quality monitoring mechanisms contribute to the persistence of these issues (Waseem et al., 2024). Operational practices,

ISSN: 3116-3475
International Journal
of Education, Research, and Innovation Perspectives
Volume 2 Issue 11 (November 2026)

including irregular flushing schedules and insufficient maintenance protocols, also play a significant role in deteriorating water quality (Moreno, 2024).

From a public health perspective, compromised water quality presents serious risks, including the transmission of waterborne diseases and potential long-term health effects (Vedrin, 2023). Beyond these health concerns, persistent water quality issues undermine public trust and confidence in the supply system, often compelling households to seek alternative sources that may be unregulated and unsafe (Nelson et al., 2024). This condition reflects critical deficiencies in service reliability, system management, and governance. Addressing these challenges requires the adoption of a comprehensive and integrated water management approach that prioritizes infrastructure rehabilitation, effective treatment and continuous monitoring, strengthened operational and maintenance practices, and enhanced capacity-building and community engagement to ensure the consistent delivery of safe, potable water and to restore public confidence (Ebrahim, 2025).

Water Availability and Seasonal Shortages

Table 16. Challenges related to Water Availability

Challenges	Frequency
Water supply becomes insufficient during the summer season	3
Low water pressure during summer months	2
Intermittent water supply	2
Reduced water availability due to over-extraction	1
Water source shutdowns affect supply	1
Storage facility is inadequate to meet demand	1

A frequency of 10 respondents reported experiencing intermittent water supply, with complete service unavailability occurring during the summer months. This finding indicates a critical and recurring shortage in water provision, highlighting the vulnerability of the existing water supply system to seasonal variations and the need for measures to improve water source reliability, storage capacity, and distribution efficiency. These supply disruptions are primarily attributed to source depletion, limited system capacity, and increasing demand driven by the growing number of household connections. In addition, low water pressure and irregular supply patterns are commonly observed, further reflecting deficiencies in the distribution system.

The findings indicate that water availability in these barangays is highly sensitive to seasonal variability, particularly during prolonged dry periods when primary water sources significantly decline or become insufficient (Paran et al., 2026). The evident mismatch between supply and demand highlights the inability of existing systems to accommodate population growth and increased consumption requirements (Magwilang et al., 2023). Moreover, low pressure and intermittent supply suggest inadequacies in system design, including undersized pipelines, insufficient storage facilities, and inefficient distribution layouts (Alzahrani & Tawfik, 2024). These technical limitations are often compounded by operational challenges such as poor demand regulation, lack of pressure management, and limited system monitoring (Grigg, 2024).

ISSN: 3116-3475
International Journal
of Education, Research, and Innovation Perspectives
Volume 2 Issue 11 (November 2026)

The implications of these conditions extend beyond inconvenience, as they disrupt essential household activities, compromise sanitation and hygiene practices, and increase the risk of public health issues (Juwana et al., 2024). Intermittent supply systems also heighten the potential for contamination due to pressure fluctuations and pipeline intrusion (Preciado et al., 2021). Furthermore, prolonged water scarcity can negatively affect local economic activities and overall community well-being (Moreno, 2024).

These findings underscore the need for a strategic and sustainable approach to water resource management. Priority interventions should include the development and protection of reliable water sources, expansion and upgrading of system capacity, and optimization of distribution networks to ensure equitable and continuous supply (Das & Mishra, 2025). The implementation of demand management strategies, such as water conservation programs and leakage control, is also essential (Tyagi et al., 2025). Strengthening system monitoring, improving pressure management, and enhancing institutional capacity for operation and maintenance will further support the delivery of a resilient and dependable water supply system (Bernabé-Crespo & Loáiciga, 2024).

Environmental and External Factors

Table 17. *Challenges related to Environmental and External Factors.*

Challenges	Frequency
Water supply becomes unavailable during power interruptions	3
Water supply becomes unavailable during flooding	2
Maintenance shutdowns interrupt water service	1
Limited access due to upland area	1

Environmental and external factors, including flooding, power interruptions, and elevation differences, were reported with a frequency of 7, indicating that these conditions significantly affect water supply operations and service delivery. These factors further compound existing system limitations by disrupting water distribution, reducing system efficiency, and increasing the vulnerability of water services, particularly during adverse weather conditions and emergency situations. Flood events often result in complete service disruption due to damage to infrastructure and contamination of water sources, while power outages critically impair pumping operations, leading to low pressure or total loss of supply. In addition, households located in higher elevation areas consistently experience reduced access to water, reflecting inequities in distribution.

These external stressors amplify underlying vulnerabilities in the water supply system. Flooding not only disrupts service, but also introduces sediments and pollutants that compromise water quality and require additional treatment (Alfee & Bloor, 2024). Heavy reliance on electrically powered pumping systems exposes the supply network to frequent interruptions, particularly in areas with unstable power infrastructure (Ayyash et al., 2025). Meanwhile, elevation-related challenges point to deficiencies in system design, such as the absence of adequate pressure zoning, booster stations, or elevated storage facilities to ensure consistent delivery across varying terrain (Zhang et al., 2025).

The combined impact of these factors underscores the need for more resilient and adaptive water supply systems. Addressing these challenges requires the integration of climate-resilient infrastructure, such as flood-protected facilities and reinforced pipelines, as well as the adoption of alternative or backup energy sources, including generators or solar-powered pumping systems (Das, 2025). Furthermore, improving system design through hydraulic optimization, pressure management, and the installation of appropriate distribution mechanisms is essential to achieve equitable water access, consistent with the

ISSN: 3116-3475
International Journal
of Education, Research, and Innovation Perspectives
Volume 2 Issue 11 (November 2026)

findings of the study on "Technological Solutions for Water Sustainability: Challenges and Prospects," (2023). Strengthening preparedness and response strategies for environmental disruptions will also enhance system reliability and sustainability in the face of increasing climate variability (Kumar et al., 2023).

Limited Access and Equity Issues

Table 18. *Challenges related to Access and Equity.*

Challenges	Frequency
Access is limited to consumers who can afford to pay	2
Some households continue to depend on individual water sources due to limited service coverage	1

Figure 4 reveals that existing water systems are constrained by limited access and equity issues, as reported with a frequency of 3. Cited concern that access to the water supply system is limited to consumers who can afford to pay suggests that financial capacity remains a barrier to equitable access to safe and reliable water services. Although water tariffs are necessary to support the operation and maintenance of water systems, some households may find the cost burdensome, particularly those with low and irregular incomes (Moncaleano et al., 2024). As a result, economically disadvantaged families may experience reduced access to improved water sources, raising concerns about inclusiveness and social equity in water service delivery.

Another challenge identified was that some households continue to depend on individual water sources due to limited service coverage. This indicates that not all residents are connected to the existing water supply systems, forcing some households to rely on private wells or other alternative sources. Limited service coverage may be attributed to inadequate infrastructure, distance from distribution lines, or financial constraints associated with system expansion (Mekonnen, 2022). This finding is consistent with the municipality-wide assessment, which showed that several barangays in Alcala still lack organized water supply systems or have limited access to existing services.

Governance and Management Issues

Table 19. *Challenges related to Governance and Management.*

Challenges	Frequency
Non-payment of water tariffs by some consumers	2
Operator faces challenges due to non-payment of water fees	1

Three respondents highlighted specific governance-related challenges, including the non-payment of water tariffs, a lack of designated personnel for system operation and maintenance, and an over-reliance on privately managed water systems. In several instances, management inefficiencies further contribute to recurring operational issues, affecting both service reliability and system performance.

The findings highlight the important role of effective governance in ensuring the sustainability of water supply systems. Non-payment of tariffs undermines the financial viability of operations, limiting the capacity to fund routine maintenance, system upgrades, and emergency repairs (Adanma & Ogunbiyi, 2024). The absence of clearly assigned and accountable personnel results in weak oversight, irregular maintenance practices, and delayed response to system failures (Bloetscher et al., 2023). Furthermore, reliance on privately managed systems may lead to inconsistencies in service provision, challenges in

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of Education, Research, and Innovation Perspectives
Volume 2 Issue 11 (November 2026)

regulation, and potential inequities in access, particularly in the absence of standardized policies and monitoring mechanisms (Dektar et al., 2021).

Beyond these concerns, weak institutional arrangements often result in the lack of formalized operating procedures, limited transparency in financial management, and insufficient community engagement. The absence of structured governance bodies, such as water user associations or local management committees, reduces accountability and limits the participation of stakeholders in decision-making processes (Rajarethinam & Devadas, 2021). This can further lead to poor compliance with policies, ineffective resource allocation, and reduced system sustainability over time.

The findings emphasize the need to strengthen institutional and governance frameworks. This includes the establishment of clear organizational structures, designation of trained personnel responsible for system operations, and enforcement of transparent and equitable tariff systems to ensure financial sustainability (Santos et al., 2025). Capacity-building programs for local operators, improved regulatory oversight for privately managed systems, and the promotion of community participation are also essential. Implementing accountability mechanisms, such as regular monitoring, reporting, and performance evaluation, will further enhance governance effectiveness and contribute to a more reliable, efficient, and sustainable water supply system (Nimanya, 2022).

Sustainable Water Resource Management Framework for Alcala, Cagayan

Figure 5 presents a structured approach for achieving sustainable water management in Alcala, Cagayan. It is anchored on the vision of ensuring a safe, reliable, affordable, equitable, and climate-resilient water supply for all communities. The framework responds to the study findings showing concerns on water availability, water quality, flood exposure, uneven service coverage, and the need for stronger governance and community participation. It recognizes that sustainable water management is not limited to the presence of water sources alone, but also involves the proper operation, protection, monitoring, financing, and governance of the entire water supply system (Olatunde et al., 2024).

The first component, Water Access and Infrastructure Improvement, focuses on expanding water service coverage to all barangays and upgrading existing Level I and Level II systems into Level III household connections. This is important because some barangays still have limited or no formal water supply system. Improving pipelines, storage facilities, pumps, and distribution networks will help ensure a more continuous and reliable water supply (Ibrahim et al., 2025). This component also addresses the need to reduce disparities among barangays by prioritizing areas with low coverage, seasonal shortages, or dependence on individual water sources. Through infrastructure improvement, households can gain better access to safe water within their homes, reducing inconvenience and improving health and sanitation conditions (Ari et al., 2024).

The second component, Water Quality and Safety Management, emphasizes regular water testing, proper chlorination, protection of groundwater sources, and compliance with the Philippine National Standards for Drinking Water. This component directly addresses the non-compliance observed in some water quality parameters, particularly microbiological indicators and chlorine residual. Immediate action on non-compliant results is necessary to protect public health (Abeje et al., 2025). Since unsafe water may expose residents to waterborne diseases, water quality monitoring should be institutionalized as a regular activity rather than a one-time assessment (Otorkpa et al., 2024). The framework also highlights the importance of protecting wells and water sources from possible contamination, especially those located near septic tanks or flood-prone areas.

The third component, Climate and Flood Resilience, recognizes that Alcala is vulnerable to flooding and other climate-related hazards. Water facilities must therefore be elevated, protected, and designed to withstand flood events. Backup water sources, emergency water supply plans, and climate-risk-based planning should be integrated to reduce service interruptions and contamination during disasters

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Volume 2 Issue 11 (November 2026)

(Geremew et al., 2023). This component is particularly important because flooding can damage pipelines, submerge water sources, contaminate groundwater, and interrupt water distribution. By integrating flood risk information into water system planning, the municipality can strengthen the resilience of water facilities and ensure that communities continue to have access to safe water even during emergencies (Amadio et al., 2024).

The fourth component, Governance and Institutional Strengthening, highlights the need to clarify the roles and responsibilities of the LGU, barangays, water associations, and system operators. Stronger monitoring, reporting, data management, permit compliance, and technical capacity-building are needed to improve accountability and ensure proper operation and maintenance of water systems (Hossain & Haque, 2023). This component addresses the observed differences in management arrangements among barangays. Clear governance mechanisms can help avoid duplication of functions, delayed responses, and weak maintenance practices (Marcos, 2024). Capacity-building for local water system managers and barangay officials is also necessary to improve technical skills in system operation, water safety monitoring, record keeping, and emergency response (Quitorio et al., 2024).

The fifth component, Community Participation and Financial Sustainability, stresses the importance of involving residents in planning, monitoring, reporting complaints, conserving water, and supporting maintenance activities. Affordable and fair water rates should be maintained, but these should also generate enough funds for repairs, treatment, and long-term system improvement. Community participation strengthens ownership and accountability because residents are the direct users of the water system (Marshall et al., 2023). When households are informed and involved, they are more likely to conserve water, report leaks, support maintenance activities, and comply with water safety practices (Abong & Wamalwa, 2025). Financial sustainability is equally important because a water system cannot remain functional without funds for operation, repair, disinfection, and future expansion.

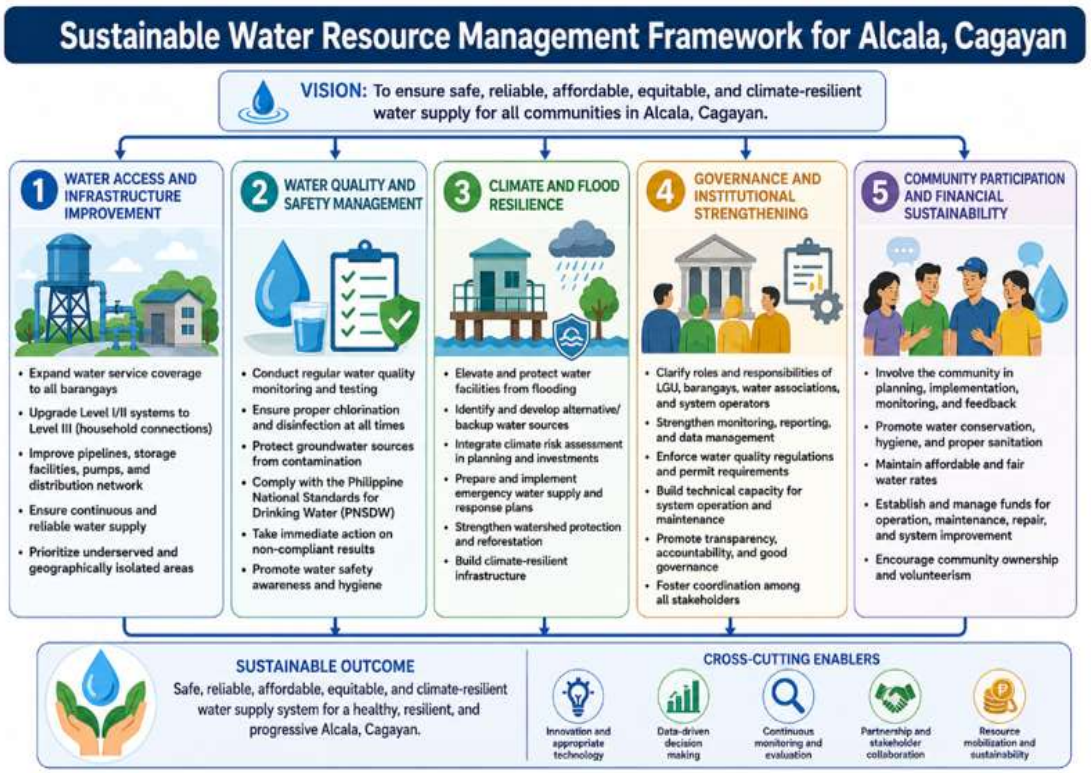


Figure 5. Sustainable Water Resource Management Framework for Alcala, Cagayan

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of Education, Research, and Innovation Perspectives
Volume 2 Issue 11 (November 2026)

The framework also includes cross-cutting enablers, such as innovation and appropriate technology, data-driven decision-making, continuous monitoring and evaluation, partnership, and resource mobilization. These enablers support all five components by ensuring that decisions are based on evidence, resources are properly allocated, and improvements are continuously assessed. For instance, installing water meters, maintaining records of water quality results, mapping flood-prone water facilities, and establishing regular reporting systems can help the LGU and barangays make more informed decisions (Olatunde et al., 2024).

The framework in Figure 5 shows that sustainable water management cannot be achieved through infrastructure alone. It requires the integration of technical improvement, water safety, climate resilience, good governance, community involvement, and financial support (Lin & Chen, 2023). If implemented, the framework can guide Alcala toward a more reliable, safe, inclusive, and sustainable water supply system. More importantly, it provides a practical basis for local planning by linking the actual problems identified in the study with specific strategies that can improve water access, protect public health, strengthen resilience, and promote long-term sustainability.

CONCLUSION

The study found that the rural water supply system in Alcala, Cagayan is operational, but remains only moderately sustainable due to challenges in water accessibility, service reliability, water quality, infrastructure adequacy, and management practices. Although groundwater serves as the primary water source and most barangays have storage facilities, unequal access, limited distribution coverage, seasonal water shortages, inadequate treatment and monitoring, and weak regulatory compliance continue to affect service delivery and long-term sustainability.

Flooding, seasonal water insufficiency, inadequate monitoring, and varying maintenance practices affect long-term sustainability. Thus, sustainable water resource management requires an integrated approach involving infrastructure improvement, water quality monitoring, climate and flood resilience, institutional strengthening, community participation, and financial sustainability to achieve a safe, reliable, affordable, equitable, and climate-resilient rural water supply system.

Recommendations

To promote the long-term sustainability of water resources in the study area, it is strongly recommended that the actions and strategies identified in the Sustainable Water Resource Management Framework be implemented by the concerned stakeholders. Guided by the findings of the study, the following recommendations are proposed to support and strengthen the implementation of the framework:

1. Barangays with no formal water supply system should be prioritized for the establishment of safe and reliable water facilities. Existing Level I and Level II systems should be upgraded to Level III household connections, especially in areas experiencing insufficient supply during summer and limited service coverage.
2. The LGU and barangays should conduct periodic testing of groundwater sources and consumer taps based on the Philippine National Standards for Drinking Water. Immediate corrective actions should be implemented for parameters that showed non-compliance, particularly microbiological indicators and chlorine residual.
3. Since chlorine residual was a major concern, proper chlorination procedures should be established and regularly monitored. Water system operators should be trained on correct dosage, treatment procedures, and maintenance of disinfection facilities.

4. Wells and other groundwater sources should be properly sealed, elevated, fenced, and located away from possible sources of contamination such as septic tanks, drainage canals, animal waste, and flood-prone areas.
5. Since Alcala is exposed to flooding, water facilities should be designed or improved to withstand flood events. This may include elevated pump facilities, protected pipelines, secure storage tanks, and emergency water supply plans during disasters.
6. Clear roles and responsibilities should be established among the LGU, barangay officials, water associations, and system operators. Regular reporting, monitoring, record keeping, and maintenance schedules should be institutionalized.
7. Engage households to report leaks, water disruptions, quality issues and repair needs. Water conservation, sanitation and safe water handling should also be part of community awareness initiatives.
8. Water rates need to be cheap, but also enough to pay for operations, maintenance, repairs, water testing and future system enhancements. A specific maintenance fund may be established for each water system.
9. Barangay water system operators and authorities need to be trained in water system operation, maintenance, water safety planning, chlorination, basic troubleshooting and emergency preparedness.
10. The framework can serve as guidance to the LGU and barangays in establishing plans, programs and policies for safe, dependable, cheap, equitable and climate-resilient rural water supply system.
11. Develop and implement a comprehensive Water Safety Plan (WSP) to ensure the safety, reliability and sustainability of the water delivery system. The WSP should employ a risk-based and preventive management approach covering the full water supply chain, from source protection, treatment, storage and distribution up to the consumer tap.
12. Future studies could expand upon these findings by conducting in-depth assessments of groundwater availability, seasonal shifts in water quality, household willingness to pay, and the long-term viability of community-managed water systems. Furthermore, future investigators should test and improve the proposed Sustainable Water Resource Management Framework in other rural and flood-vulnerable municipalities to evaluate its overall applicability and effectiveness under different socioeconomic, environmental, and institutional conditions.

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